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Sangeun Jin · Jeong Ho Kim ·
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Proceedings of the 22nd Congress of the International Ergonomics Association, Volume 3

Better Life Ergonomics for Future Humans (IEA 2024)

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Preface

This proceedings book is a publication of selected excellent papers presented at the World Congress on Ergonomics, the International Ergonomics Association 2024 (IEA 2024), held in Jeju Island, Republic of Korea, in August 2024. Representatives from over 50 countries, totaling approximately 1,600 ergonomics professionals, attended the event to present their outstanding research findings in the field of ergonomics and share their insights. About 1100 abstracts and full papers were presented, and all were subjected to a stringent peer review process that ensured both anonymity and double-blinding. Only submissions meeting the established standards were selected for inclusion in the conference proceedings.

The proceedings aim to encompass a broad spectrum of theories and applications within human factors and ergonomics (HFE). This multidisciplinary field is dedicated to understanding the interactions between humans and various systems, products, environments, and technologies. The volume covers a diverse range of scientific areas, including engineering, design, human biology, psychology, and so forth. It explores the application of human factors and ergonomics across various domains such as healthcare, medicine, transportation, aviation, automotive, construction, mining, manufacturing, agricultural engineering, education, and sustainable development.

The themes of the IEA 2024 conference and the structure of the papers included in each volume of the proceedings are as follows:

IEA 2024 Conference Theme: "**Better Life Ergonomics for Future Humans**"

Volume I: Affective Design (I), Aging (I), Agriculture (I), AI (I), Anthropometry (I), ATWAD (I), Aviation (I), Bio-signal (I), Building and Construction (I).

Volume II: Building and Construction (I), Design (I), DHM (I), Gender (I), Healthcare (I), HMI (I), Macro-ergonomics (I), Manufacturing (I).

Volume III: Manufacturing (I), Musculoskeletal (I), Product (I), Resilience (I), Robotics (I), Safety and Health (I), Slips (I), Sustainable Development (I), Training Education (I).

Volume IV: Training Education (I), Transport (I), UI/UX (I), Visual (I), VR/AR Metaverse (I), Others (I).

Volume V: Others (I), Affective Design (II), Aging (II), Agriculture (II), AI (II), Anthropometry (II), ATWAD (II), Bio-signal (II), Design (II), DHM (II), Healthcare (II), HMI (II), Macro-ergonomics (II), Manufacturing (II), Musculoskeletal (II), Product (II), Resilience (II), Safety and Health (II).

Volume VI: Safety and Health (II), Slips (II), Sustainable Development (II), Training Education (II), Transport (II), UI/UX (II), Visual (II), VR/AR Metaverse (II), Others (II), Affective Design (III), AI (III), Anthropometry (III), ATWAD (III), Bio-signal (III), Building and Construction (III), Design (III), DHM (III), Healthcare (III), Macro-ergonomics (III), Manufacturing (III), Musculoskeletal (III), Product (III), Robotics (III) Safety and Health (III), Space (III), Sustainable Development (III), Training Education (III), Transport (III), UI/UX (III), Visual (III), Others (III).

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Contents

Manufacturing (I)

Ergonomic Risk Factors that Generate an Increase in the Manufacturing Cycle Time

Lamberto Vázquez Veloz(✉), Diego Alberto Vázquez Soqui, and Lamberto Vázquez Soqui

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Abstract. Manual assembly workstations are part of production processes that maintain a sequential operational dynamic, where the sequencing is structured based on the standard time assigned to each productive activity and the transportation time from one workstation to another. The standard time is defined based on the productive capacity of an average operator, plus the combination of tolerances and performance ratings that describe the operator's behavior in performing their task, maintaining this time throughout the workday. This situation conceals a differential between the operation's cycle time and the defined standard time, framing a chronological growth throughout the workday in the cycle time when the workstation does not involve ergonomic guidelines, mainly due to the activity's characteristics, such as high repetitiveness, monotony, high concentration, low locomotion, and short cycle times. This research is based on a multivariate classification of manual assembly workstations, showing an increase in cycle time of up to 70%. This increase is due to the effect of fatigue on the worker and entails an implicit decrease in production volume, reducing the company's profitability and affecting the operator's quality of life.

Keywords: Manual assembly workstations · cycle time · multivariate statistics

1 Introduction

The northwest border area of Mexico has been characterized by supporting its development in the transformation industry, particularly focusing on the program called the Manufacturing, Maquiladora and Export Services Industry (IMMEX), in this sense, the number of establishments considered within this program has had a national average growth of .2% per month according to the National Institute of Statistics, Geography and Informatics of Mexico (INEGI, 2023). For the case of the area of influence of the present research project, considered as the border states of the northwest of the country, the total number of productive entities within the program is 1,630, as of November 2023 (INEGI, 2023).

The characteristic operations system in the industry under study is made up of intermittent systems with inline flows, which, depending on the production sequencing, can follow line, "U" (Zhang et al., 2020) or hybrid distributions. These distributions are

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selected based on achieving the optimal point of the com-bination of volume and product variety; repetitiveness and monotony of the operations; customer requirements and product life cycle.

In the design and measurement of work in linear flows, the process maintains an interdependent relationship between the configuration of the work area and the workforce, specifically in the man-machine-work environment triad (Di-ego-Mas, 2020). A particular situation of this is the manual assembly workstations, which have characteristics such as high repetitiveness, monotony, high degree of concentration, low locomotion, and short cycle times.

The fact that the man-machine-work environment triad supports the company's ability to produce the articles with the quality, quantity, flexibility, and at the costs demanded by the market, is precisely what underlies the need to find a synergy between the anatomical and physiological capabilities of the operators and the functional structure of the workstation or work area, an aspect that is of utmost importance for companies in general and particularly for the object of study.

This synergy maintains a set of important variables, focusing on the postures in which the worker interacts with the workstation, the force required to carry out the work action, and the repetition of the activities included in the work dynamics (Possan Junior et al., 2023). All of this together completes the process of transforming raw material into a finished product. When the postures in which the worker performs his work, from an anatomical and physiological point of view, are not adequate, the force applied is biomechanically high, and the repetitiveness of movements is high, the worker develops a gradual growth in his fatigue (Karwowski and Marras 2003), which affects the cycle time of the operation. All of this leads to the presence of symptoms that harm his health, reduce productive performance, and affect cost increases, which can impact the organization's competitive capacity reduction. To be precise, the increase in cycle time and impact on the health of the worker, who develops his activities in manual assembly workstations, is proposed as a research problem.

2 Methodology

A research study is structured based on the positivist paradigm of science, using the quantitative research path (Hernández-Sampieri & Mendoza, 2018), by developing a multivariate hierarchical procedure with the technique called hierarchical tree, which allows relating the impact of posture, force, and task repetitiveness, with the increase in cycle time. The dependent and independent variables of the hierarchical model cannot be manipulated, and the study is carried out over a period of time, so the study is non-experimental and cross-sectional.

The development of the research process was defined in two phases in a systematic and chronological order:

2.1 Phase 1: Methodological Analysis of Theories

The epidemiological evidence necessary for the development of the ergonomic assessment procedure is based on a methodological analysis of the theories, which allows recognition of the biomechanical efforts of the operators, the levels of repetitiveness in the tasks, the uncomfortable work postures, and the appearance of Musculoskeletal Disorders, in addition to this, it is necessary to analyze the ergonomic assessment methods and the discrepancies, sufficiencies and inefficiencies of each method in the evaluation of the workstations, object of study of our research. Another indispensable point for the development of the procedure is the norms, rules, and guidelines of ergonomics, which allow structuring the improvement recommendations when applying the procedure. With this theoretical foundation, a platform of scientific support is structured for the development of the ergonomic assessment procedure.

The assessments established by the procedure are based on the complication that the posture generates for the operator, calculated by establishing the difference between the neutral posture of the human body and the posture in which the worker performs his activity. For the force component, the maximum permissible biomechanical lift is calculated based on weight, sex, and movement in the body planes. The last component is repetitiveness, included in the procedure based on what is outlined in the ISO 11228–3:2007 standard.

Characteristics of manual assembly workstations: The main characteristics of manual assembly workstations in production processes with inline flows are: monotony in postures, repetitiveness, short cycle time, speed, mechanical and contact stress, vibration, detail, and static effort.

2.2 Phase 2. Development of the Analytical Hierarchy

A total of 2,500 systematic evaluation samples were applied with the procedure, in manual assembly workstations. Where a multivariate classification was developed, based on the construction of a multivariate hierarchical tree, which com-pared the impact of the different operator positions in performing their task, the force used in the action, and the repetitiveness of movements, with the increase in the cycle time of the workstation throughout the workday, establishing this variable as the percentage difference in three-time intervals during their work-day. The intervals were classified in agreement with the hours of less negative incidence for production, reducing the probability of distraction due to rest, meals, and material supply. The intervals are from 8 am to 10 am, from 11 am to 1 pm, and from 2 pm to 4 pm. By determining the position of each body part of the operator involved in the task completion, the force used, and its repetitiveness, and comparing it with the diminution of their productive capacity, it is possible to hierarchize the influence of these three characteristics according to the percentage increase in cycle time. In this sense, the result of the analytical hierarchy developed in the SPSS statistical software version 23 (Aguado & Provecho, 2019) is presented, which classifies the influence of the three characteristics necessary for the development of the task, with the increase in the operational cycle time, into 4 categories. Figure 3 presents the analytical hierarchical tree obtained.

3 Results

Up to this point, the ergonomic assessment procedure has been applied in 560 manual assembly workstations in the manufacturing, maquiladora, and export services industry, located in the border area of the states of Baja California, Sonora, and Chihuahua. Each application establishes the evaluation of the current situation of the workstation, a series of improvement proposals, and the cycle time of the redesigned workstation.

Table 1 shows a portion of the 560 applications carried out by the ergonomic assessment procedure.

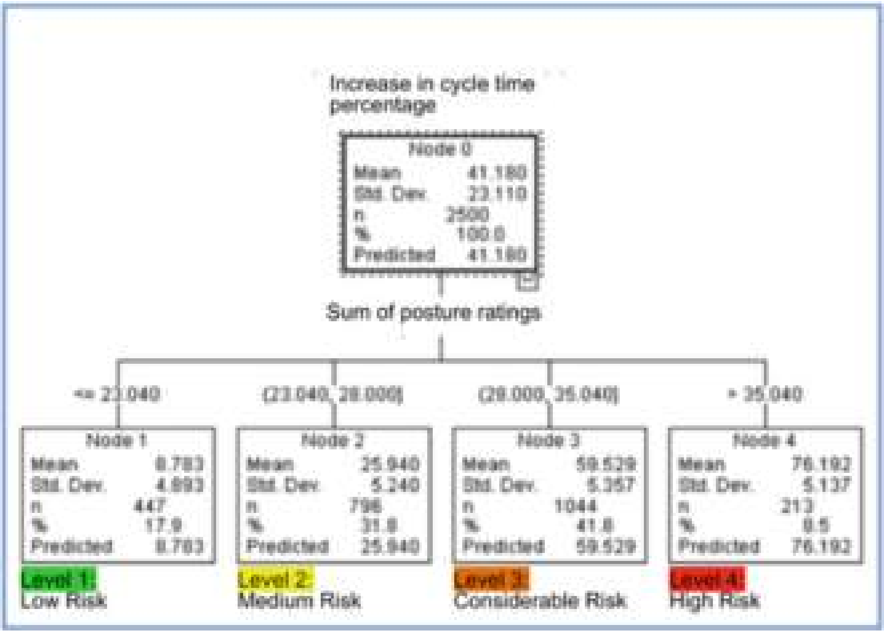

Fig. 1. Multivariate analytical hierarchy tree.

Table 1 shows the rating issued by the assessment procedure, the risk maintained by the worker performing his work at the workstation, and the operating cycle time, which is calculated based on the provisions of the ISO 11228 3:2007 standard.

Table 2 shows 5 of the 560 results of the application of the ergonomic assessment procedure, where the comparative between the risk levels, cycle times, and the difference in the reduction of the cycle time before and after the application can be highlighted.

Table 3 presents the compendium of the 560 applications, showing the number of applications where a decrease in risk levels was achieved and the average percentage of decrease in cycle time that was achieved through the application of the procedure.

Table 1. Partial comparative of results in the application of the procedure.

	Before the application of the procedure				After the application of the procedure		
Workstation	Risk Level	Rating obtained	Cycle time (min)	Improvements proposed by the procedure	Cost of improvements	Risk Level	Cycle time (min)
CI-4	3	28.08	1.5	Use ergonomic chairs (model JG-051) Provide an adjustable footrest Arm support	MXN 3,260	2	1.1
CE-1	4	39.36	0.9	The seat should be made of porous fabrics, have a slight incline on the edge, height adjustment options, 5 support points and the seat should be swiveling	MXN 2,630	3	0.9

Table 2. Partial global comparative in the application of the procedure

Before application		Application of the procedure		After application		
Workstation	Cycle time (min)	Rating obtained	Risk level	Risk level achieved	Cycle time (min)	Decrease in cycle time (min)
1	2.57	28.88	3	1	1.47	1.1
2	3.1	44.24	4	2	1.85	1.25
3	1.2	28.64	3	1	1.05	0.15
4	1.45	36.48	4	2	0.78	0.67
5	1.58	28.08	3	2	1.1	0.48

Table 3. Total compendium of procedure applications and their results.

Current risk level	Risk level achieved with the application of the recommendations suggested by the procedure	Number of applications where this level of risk reduction in the workstation was obtained	Average % reduction in cycle time
4	1	156	69.41%
3	1	132	54.75%
2	1	24	25.16%

4 Conclusions

The manufacturing, maquiladora, and export services industry is one of the most dynamic sectors in northwestern Mexico, which implies a considerable income of foreign exchange to the country, direct and indirect employment, and technology transfer. In it, the sequential production processes in line are developed, and most of its workstations involve manual assembly.

The study carried out shows that the increase in cycle time is a function of the position adopted by the worker in the workstation where they perform their activities, the force, and repetitiveness applied to accomplish the task. This is presented by correlating these three characteristics with the increase in cycle time, based on a multivariate analytical hierarchical model in a tree structure.

The designed procedure has been applied so far in 560 workstations. The application has evidenced a decrease in occupational risks in the workstations and a decrease in cycle times ranging from 8.7 to 76.1%.

The proposed ergonomic assessment procedure conditions the company to the development and implementation of processes for the continuous improvement of the conditions in which the operators perform their tasks and the company's business results.

It is important to establish that the ergonomic assessment procedure can be substantially improved by applying pattern recognition models, which allow distinguishing the complex postures in which the operator performs his function and correlating them with the cycle time that occurs.

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Exoskeletons to Enhance Workforce Sustainability in SMEs – A Field Study in 11 Austrian Companies

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Abstract. Physical strain persists in manufacturing, particularly in small and medium-sized enterprises, as a cause of musculoskeletal disorders. While exoskeletons offer potential solutions, their effectiveness in SMEs remains understudied. Existing research on the effectiveness of exoskeletons focuses on laboratory settings and larger companies, overlooking practical challenges and benefits for SMEs. This study aims to bridge this gap by assessing the suitability and effectiveness of exoskeletons in 11 different Austrian SMEs. It seeks to guide their selection and implementation in SMEs based on field testing in 16 workplaces with 28 employees applying 5 different exoskeletons. To conclude on their applicability and effectiveness in SMEs, the test procedure included questioners and electromyography measurements. The results reveal different suitability based on trade-offs between rigidity and flexibility, physical demands and movement sequences as well as workers' attitudes. As a result, we propose a framework for applying exoskeletons along the categories of (1) dynamics of work tasks and (2) loading on the worker, including 5 categories of feasible work tasks. This framework should help identify suitable systems and effective implementation strategies in SMEs for maximizing their benefits while mitigating risks. While further research is needed, the study provides valuable information on their implementation in SMEs, emphasizing the need for a nuanced approach considering objective and subjective performance metrics and potential benefits for SMEs.

Keywords: Human-centered work · physical assistance · exoskeleton in SME

1 Introduction

The manufacturing industry has been a driver of economic well-being but has changed significantly due to Industry 4.0, automation, new production methods, and continuous process optimization [1]. However, in situations where a complete substitution of human labor with machines is neither feasible nor suitable, individuals will remain subject to physical loads. Depending on the specific workplace and tasks, workers may frequently encounter significant physical stress, increasing the risk for long-term health implications. Physical strain caused by tasks such as material handling, repetitive small

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movements, or unfavorable postures still contributes to the persistence of work-related musculoskeletal disorders (MSDs) [2]. These stress factors depend on the size of the company and occur more frequently in small and medium-sized enterprises (SMEs) [3].

There are various methods for the prevention of MSD, such as ergonomic workplace design or the implementation of measures for maintaining workability by reducing physical stress in the workplace [4]. Exoskeletons (EXO), as a potential solution, could reduce the physical effort and fatigue of workers in demanding activities, contribute to increased vigilance and productivity, increase occupational safety and quality of work, and potentially prevent the occurrence of work-related MSD [5, 6]. They provide individualized support to users with different physical needs regarding strength, mobility, or endurance, particularly when other technical and organizational measures are not feasible or effective [7].

Previous research on EXO implementation mainly relates to laboratory environments and highly standardized tasks such as line production [8]. Although several studies have shown the positive effect of exoskeletons in labs, there is still a lack of studies applying them in a real-life context, particularly in SMEs [9]. This leads to low usage in SMEs despite different frameworks for implementation and evaluation [e.g. 10,11], caused by the gap between user requirements and system specifications, as well as lacking standardization, benchmarking opportunities, and decision support for SMEs [12].

When evaluating the effects of EXOs, different aspects are assessed mainly by qualitative questionnaires, and to some extent by physical measurements [8]. In terms of objective parameters, muscle activity measurements via electromyography (EMG) are usually performed, while only a few studies measure heart rate, oxygen consumption, postures and movements, time, or performance (speed, quality, cost) [8]. In subjective evaluation, acceptance, ease of use, perceived workload, and wearing comfort are mostly investigated with questionnaires or surveys [8].

2 Case Setting and Methodology

To close SME-related knowledge gaps, we conducted a field study with 11 Austrian companies, applying five different exoskeletons (see Fig. 1) to provide insights into their suitability for SME working conditions. We used three back support (Ottobock Paexo Back (EXO1), Ottobock Paexo BackX (EXO 2) and Auxivo LiftSuit (EXO3)) and two shoulder support systems (Ottobock Paexo Shoulder (EXO4) and Comau Mate-XT (EXO5)). Their selection was subject to the conditions of the workplace and tasks, evaluated by the key indicator method (KIM) risk level (green (1), yellow (2), orange (3), and red (4)) [13], and an analysis of movement patterns at the workplaces.

We examined a variety of different loading situations with all five EXOs. The test duration depended on the willingness of the worker to extend testing. It ranged from 5 days to up to 25 days. Apart from the duration, the same test procedure was applied in every company. It included (1) the selection of a suitable EXO (workplace, task, and worker), (2) initial training and pretest questionnaire, (3) observation of the worker applying the EXO for the first day, (4) independent test period (different) with follow-up visits on a regular (mostly daily) basis for collecting feedback, daily posttest questionnaires or conducting EMG measurements and (5) a final interview.

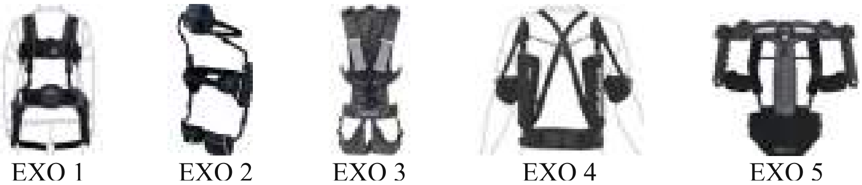

Fig. 1. Exoskeletons used in different field tests (Pictures © Ottobock, Comau, Auxivo)

The evaluations included subjective and objective metrics. Subjectively we assessed usability (SUS [14]), perceived workload and reduction (NASA TLX [15]), and the perception of strengths, weaknesses, opportunities, and risks of the EXO. The objective evaluation was based on short-term EMG tests on muscle activity changes in real working sequences and conditions (e.g. fixed cycles or periods). However, based on the availability of EMG equipment and experts, as well as voluntary testing, this was only applied in six workplaces. We tested muscle groups in the lower back (erector spinae and erector spinae) and shoulder muscles (deltoideus clavicularis, deltoideus acromialis, trapezius descendens) for the respective EXO. A total of 16 workplaces were identified in 11 companies where 28 participants conducted tests (Table 1).

Table 1. Overview of conducted field studies in SMEs

Case	Company	Workplace & task	Time [days]	Workers [#]	EMG [Y/N]	EXO [1–5]	Risk level [1–4]
C01	Wholesaler	T1 Order picking	15	2	Y	3	na
C02	Railway	T2 Order picking	5	3	N	1	na
C1	Car workshop	WP1 Tire change	5	1	Y	1	4
C2	Food manufacturer	WP2 Order picking	5	1	N	5	3
C3	Automotive supplier	WP3 Order picking	5	1	N	2	2
		WP4 Order picking	5	2	N	5	2
C4	Scrap dealer	WP5 Autogenous cutting	6	1	N	5	4
		WP6 Order picking	8	2	Y	2	4
C5	Gate manufacturer	WP7 Bulky assembly	5	1	N	2	3

(*continued*)

Table 1. (*continued*)

Case	Company	Workplace & task	Time [days]	Workers [#]	EMG [Y/N]	EXO [1–5]	Risk level [1–4]
		WP8 Powder coating	8	1	Y	5	4
C6	Furniture manufacturer	WP9 Order picking	5	1	N	3	2
		WP10 Dispatching	5	2	N	2	4
C7	Silo & truck body manufacturer	WP11 Silo welding	5	2	N	5	4
		WP12 Metalwork	5	2	N	2 & 3	2
C8	Industrial painter	WP 13 Painting	25	3	Y	4 & 5	4
C9	Fruit wholesaler	WP14 Pick & Place	20	3	Y	2 & 3	4

3 Case Setting for Exoskeletons Testing in SME Work Tasks

The first two field studies (C01 and C02) served as pre-studies to identify and eliminate issues for field testing and measurements. Two back-supporting EXOs were tested by 5 workers, and EMG was applied to evaluate the impact on order-picking stress.

In the main study, we tested the different EXO in different SMEs focusing on their applicability, benefits, and disadvantages for variable work tasks as available in SMEs. In Case 1 we evaluated the effects of a back EXO in a car workshop (Fig. 2 left). The workers were provided the EXO for 5 days to use twice for 4 h in their daily work. After initial familiarization, we conducted EMG measurements for the most stressful tasks of stacking car tires from a specific starting point onto a pallet as well as for mounting them on the car. The KIM evaluation and perceived stress was high indicating a risk of overloading.

In cases 2, 3, and 9 we evaluated EXOs in order-picking at a food supplements producer, and the logistics department of a supplier for car-testing equipment (Fig. 2 middle), and a vegetable wholesaler (Fig. 2 right). Workers tested a shoulder and back EXO for 5 to 25 days at medium- to high-stress tasks. EMG testing was conducted at the wholesaler for storing boxes of vegetables in a representative routine activity. The trial included the transfer of melons (20 kg per box) from a wooden to a plastic pallet. A total of 32 boxes were restacked. Two back EXOs were used and measured for one cycle of restacking 32 boxes (see Fig. 2 right).

Fig. 2. Exoskeleton application for order picking, tire sacking, and lifting activities

Case study 4 comprised cutting, sorting, weighting, and storing tasks for metal scrap. For autogenous cutting (Fig. 3 right) a shoulder support EXO was applied, which was used for 6 days. For sorting and storing we tested a back-support EXO for 8 days at the workstations, as heavy loads have to be lifted and carried over short distances. For EMG testing, a standard cycle of storing materials contained 17 kg of cables, 18,5 kg of fittings, 20 kg of packages, and 18 kg of batteries. The order of the objects to be stored remained the same in both runs and the carrying distance was under 5 m (Fig. 3 left). For sorting, a two-minute cycle of sorting fittings and wires stored in a box was recorded. As there were no specific instructions, lifting movements were carried out in the usual way (see Fig. 3 middle).

Fig. 3. Application of exoskeletons for metal scrap storage and sorting

In C5 and C6 we investigated the applicability of EXO in heavy and bulky part assembly at a sliding gate producer and a furniture manufacturer. In both jobs, workers handle bulky parts and heavy weights, resulting in high stress for the back. For gate production, we tested a back EXO in gate (up to 20 m) assembly processes because, despite the presence of stationary aids such as overhead cranes, unfavorable postures are repeatedly carried out due to the special work processes (Fig. 4 left). In the furniture company, we applied two different back EXOs in order-picking to assist in load handling in awkward postures (Fig. 4 middle) and trolley (un)loading, involving carrying heavy loads over short distances (see Fig. 4 right).

Fig. 4. Exoskeleton application for bulky part handling and assembly

In case studies 5, 7, and 8 the applicability of EXOs for tasks with extended arm elevation (e.g., powder coating, welding, and painting) was evaluated by the gate manufacturer, an industrial painter, and a producer of silo body parts. At first, heavy metal parts are produced, powder coated, and assembled resulting in high perceived stress and medium- to high-risk levels (Fig. 5 left). The second involved tasks of a painter on large construction sites including ceiling grinding. For this, a grinder (10 kg) must be operated overhead imposing high stress on the shoulder region (Fig. 5 middle). The last dealt with welding activities for big parts, requiring a steady hand to produce high-quality welds (Fig. 5 right). Here we tested the EXO to enhance stability and precision, and its applicability in constrained environments such as inside a silo.

For EMG measurement, we tested coating activities where the workers were instructed to perform the movement as usual (from top to bottom); even if a different movement would be beneficial for the EXO. The gate to be processed had dimensions of 12 m in width and two meters in height requiring the whole movement range of the EXO to be used. The test duration was three minutes. For painting two different shoulder EXOs were tested for three minutes, regardless of the painted area. The hand was not changed and the grinding device was not put down during the test.

Fig. 5. Exoskeleton application for powder coating, grinding, and welding activities

4 Results of Exoskeleton Testing

In all companies surveyed, a wide variety of workplaces were identified in which EXOs could be successfully implemented based on subjective evaluation results (see Table 2). Usability was evaluated at the end of the first day, as well as at the end of testing. In Table 2 the final values for perceived system usability (1–100) are reported. To subjectively evaluate their effects on the perceived workload, NASA TLX values at the end of the EXO trial phase were compared to those without it on the first day. Integration in the workplace was assessed using the school grading system, ranging from excellent (1) to not sufficient (5).

Table 2. Overview of the subjective evaluation of exoskeletons (mean values)

Workplace & task	Time [days]	Workers [#]	SUS final score [1–100]	TLX with EXO at the end [0–20]	Perceived workload difference [%]	Workplace integration [1–5]
WP1: Tire change	5	1	na	na	na	na
WP2: Order picking	5	1	67,5	10,1	+17	3
WP3: Order picking	5	1	72,5	11,8	–3	1
WP4: Order picking	5	2	45	14,3	+65	3
WP5: Metal cutting	6	1	90	9,9	–7	2
WP6: Order picking	8	2	85	7,2	–7	2
WP7: Bulky parts	5	1	90	12,4	–25	2
WP8: Powder coating	8	1	65	8,0	+4	4
WP9: Order picking	5	1	80	13,2	–5	1
WP10: Dispatch	5	2	81	10,1	–20	2
WP11: Silo welding	5	2	65	9,2	–7	3
WP12: Metalwork	5	2	73	5,6	–11	2
WP 13: Painting	25	3	100	10,1	–55	1
WP14: Pick & Place	20	3	90	9,7	–3	2

Four workplace implementations achieved a final SUS score of 90 or higher, indicating a good to excellent match. Only two tests achieved SUS values below 65, indicating that the participants rejected the system.

There were large differences in the results for perceived workload changes based on the EXO. For example, shoulder-supporting EXOs were able to reduce the perceived workload by 55% at one workplace, while at another it increased by 65%. For workplaces that are characterized by dynamic arm movements (WP2, WP4, and WP8), low SUS scores and an increased perceived workload were documented for the used systems, indicating missing suitability.

Although the workplaces studied were very different, they comprised similar work processes and movement patterns. Since in most cases, the range of activities is varied and changing, problems can arise in the application and use of EXOs. This is because these passive assistance systems usually support one activity very well but restrict another activity. For example, at the painting company, the EXO could only be used in ceiling work. It was not suitable for other activities such as plastering or painting walls. In general, we classified five different movement patterns (G1-G5) from the SME cases, where three benefits from shoulder support and two from back support based on the subjective and objective evaluation (see Table 3).

Movement groups G1 and G2 are characterized by extended overhead activities with heavy equipment while stabilizing the arms over a longer period without major movements. Such tasks can include holding tools or performing precision work. Here the successful implementation of the shoulder EXO was documented by subjective and objective evaluation for WP4, WP8, and WP12. For G1, EMG measurements show a reduction in the load in the measured muscle region due to the EXO.

Table 3. Classification of exoskeleton implementations use cases in SMEs

Group G1 Shoulder Support	Group G2 Shoulder Support	Group G3 Shoulder Support	Group G4 Back Support	Group G5 Back Support
Work overhead with heavy tools	Stabilization for static tasks	Constant dynamic arm movement	Range of motion >5m	Range of motion <5m
				
WP 13	WP 5,11	WP 1,2,4,8	WP 3,7,10,12	WP 6,9,14

In both cases, a significant unloading of the middle trapezius was observed, which contributed to the stabilization of the arms in a raised position. However, an increase in muscle activity of other muscles was also observed (see Fig. 6 top). The more compact Comau Mate-XT reduced the muscle activity in all measured regions, compared to the more flexible Ottobock Paexo Shoulder, which only reduced the activity in one muscle. This might be caused by the stronger support force and the more rigid design of the first (see Fig. 6 top).

For category G3, where constant dynamic arm movements are performed, no objective reduction was found in the EMG analysis for powder coating activities (see Fig. 6). This can be attributed to the arm movement of the employee, who constantly moved the arm from top to bottom, working against the supporting force of the EXO.

Movement patterns in G4 and G5 consider material handling activities with different ranges of motion. Work with a range of motion over 5 m was categorized in G4. Here usually lower weights were handled compared to G5, where the range of movement is under 5 m, but heavier goods are moved and lifted. For G4 and G5 the use of the EXO led to a reduction in muscle activity during all test activities (see Fig. 6 bottom). Especially for the sorting activities noticeable relief in the lumbar spine area was found since the employee had to remain in a stooped position which placed a high strain on the lower back. For such tasks, the more flexible EXOs provided better reduction than the rigid ones. It is possible that the rigid ones restricted the freedom of movement, which led to an unusual handling of the load and therefore the full potential of the EXO could not be utilized.

At the end of each field study, participants were asked to name and assess general strengths, weaknesses, and associated opportunities and threats for the EXOs used. The main strengths included posture and movement correction (15/28 times mentioned), effective support (10), good implementation characteristics (8), and ease of use (7), while the main weaknesses were limitations for movements and other activities (16), lack of wear comfort (14), and missing support (2). Opportunities were seen in physical relief (18), reduction of absenteeism (16), assistance with reentry to work (7), and increasing performance (8). As potential threats, the workers mentioned the limitation of freedom of movement (12), change of movement patterns (8), and pressure points (7).

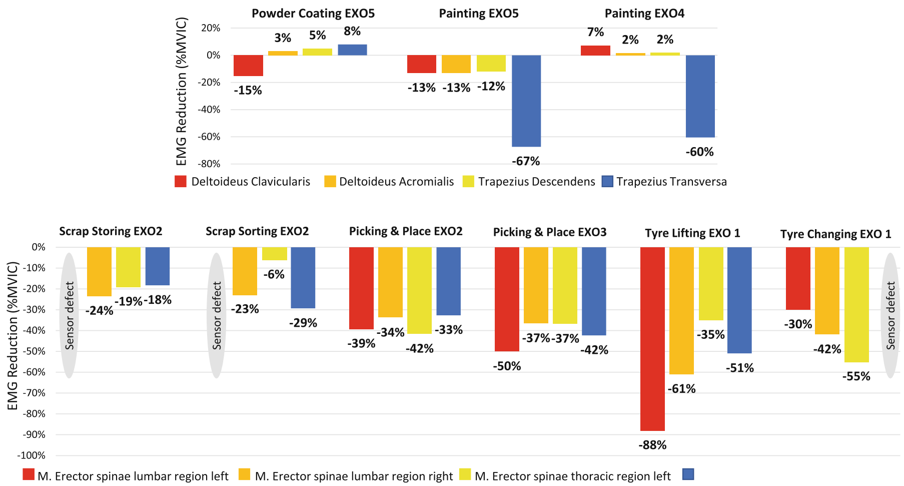

Fig. 6. Results of the EMG measurement for different muscles. Reduction or increase in muscle activity with and without exoskeleton for the shoulder (top) and back (bottom)

5 Conclusions and Discussion

The study revealed high variability in EXO performance based on the (1) design (soft to rigid) and (2) function (low to high support – measured by EMG), (3) task (static to dynamic), (4) loading (low to high), (5) movement pattern (low to high range of motion), as well as (6) perceived support (subjective assessment). This highlights the importance of matching EXO types to specific tasks. Five models were examined, revealing trade-offs between rigidity and flexibility. Flexibility offered higher comfort but potentially lower support, and each showed distinct strengths and weaknesses according to the specifics of the workplace. To identify strengths and weaknesses, workplaces were classified according to physical demands and movement sequences, determining the EXO´s suitability for each category. As a result, we propose a framework for the application of EXOs along the categories of (1) dynamics of work tasks and (2) loading on the worker, including three categories of feasible work tasks (green areas in Fig. 7). This framework should facilitate the identification suitable EXOs and effective implementation strategies in SMEs.

Shoulder EXOs were shown to be most suitable in categories G1 and G2. Comparable studies that performed the same activities under real working conditions could not be evaluated, but laboratory studies under similar conditions showed a reduction in strain on the shoulder and arm region [16]. However, we found no benefit in applying them in category C3 as participants reported no support in such activities. They also noted that exceeding the zero-assistance point caused a sudden change in the force exerted on the upper arm, which was perceived as extremely disruptive. However, more research is needed as another study [17] showed that the use of a passive assistance system of a similar type was successfully implemented in such movement patterns by subjective evaluation.

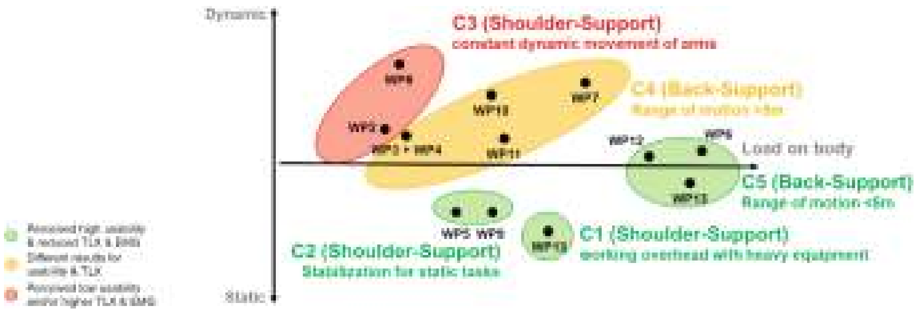

Fig. 7. Framework of the suitability of exoskeletons according to SME-specific task

Back support EXOs were applicable for G4 (limited) and G5. In these work environments, heavy objects were often transported, with a limited range of movement. In G4, where the radius of movement in the workplaces was larger than five meters and bulky or unhandy goods were frequently handled, the EXOs were considered disturbing during the activity. Furthermore, since physical strain was not as high as at the workplaces in G5, workers did not perceive them as very useful in G4 work environments. Interestingly, we couldn't identify studies that have been conducted in real work environments with such specific requirements for freedom of movement. Most laboratory studies focus exclusively on lifting movements without adequately reflecting the variety of prevailing conditions and requiring more evaluation studies (see e.g. [18]).

The versatility of activities and the different processes in SMEs pose challenges as EXOs can excel in one task while limiting others. Therefore, we categorized five load and movement groups, where successful implementation was documented. However, a limited number of participants and the variety of task and EXO combinations limit the study. Further studies are needed to confirm findings, especially regarding varied movement patterns. However, the study provides valuable insights into their implementation in SMEs, emphasizing the need for a nuanced approach considering both objective and subjective performance metrics.

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Musculoskeletal (I)

Work Conditions and Low Back Pain: An Ergonomic Assessment on a Large Retail Store

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Abstract.
Aims: To assess the risk factors associated with work-related low back pain among the operators of a large retail store.

Methods: The study employed an ergonomic approach, conducted over a period of one month on a large retail store in Tunisia. The first stage consisted of an assessment of socio-demographic and occupational risk factors using a pre-established questionnaire, which was supplemented by an assessment of psycho-social risk factors using the Karasek questionnaire. The second stage involved observation of the operators' actual activity, followed by an analysis of biomechanical constraints using the KIM tool.

Results: Of the workers exposed to manual handling, 86% handled loads of less than 25 kg, while 14% were constantly exposed to a load of at least 25 kg. In the current study, 88% of employees had low decision latitude, 44% had low psychological demands and 68% had low social support. The ergonomic analysis of the physical workload showed that 72% of the employees were in risk class 3, 12% in risk class 2 and 16% in risk class 1.

Conclusion: In this study, we confirmed the multifactorial origin of this condition, explained by the interaction between individual, organizational, biomechanical and psychosocial factors. Therefore, preventive actions adapted to these risks must be integrated into a multidisciplinary strategy.

Keywords: Back Pain · Ergonomic Assessment · Large Retail Store

1 Introduction

Low Back Pain (LBP) is the most common cause of activity limitation in people under the age of 45. It has been demonstrated that 25% of occupational accidents are attributable to low back pain [1]. According to the 2017 statistics published by the Tunisian National Social Security Fund, low-back accidents account for 9.8% of accidents at work in

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Tunisia [2]. Low back pain is the commonest musculoskeletal disorder affecting every socioeconomic group of the world's population [3]. It is associated with a considerable absence rate and loss of productivity, which entails a financial burden for employers, employees and health systems [4]. This ergonomic intervention was carried out in a Tunisian Sales and Marketing center and carried out following a recurring complaint back pain problems, job dissatisfaction of operators. The aim of the study was to analysis the risk factors of work-related low back pain among details operator trade.

2 Presentation of the Company

It is an international company, specialized in trade, distribution and the creation of distribution chains of all categories, created in Tunisia since 1995 and is located in 15 governorates of Tunisia with a total of 44 shops. This intervention took place in a large retail store in the Mahdia region of Tunisia, consisting of 6 workstations distributed as follows (Table 1):

Table 1. Distribution of employees by workstation

Workstation	Effective	%
Cash desk	11	27
Security	2	4.8
Cleaning	1	2.4
Administration	2	4.8
Reception	3	7.31
Shelves	22	53.65

Different Tasks identified as performed by operators include: stocking shelves, sorting products, de-palletising, placing products in display cases, storing stock, replenishing stock, unloading lorries, loading trolleys, unloading trolleys and unpacking. Back pain and job dissatisfaction was reported by 61% of all employees and over the past year, seven employees (departmental workers) in this company have been absent from work due to back pain. The duration of their absence ranged from seven to 30 days.

3 Methods

The first phase of the study consisted of an assessment of socio-demographic and occupational risk factors using a pre-established questionnaire, supplemented by an assessment of psychosocial risk factors using the Karasek questionnaire [5]. The second stage consisted of an observation of the actual activity of the operators, followed by an analysis of the biomechanical constraints. We used the KIM tool developed by the German Federal Institute for Occupational Safety and Health in cooperation with German labour inspectors [6] which assesses the risk of manual handling of loads at screening level. The risk score is calculated according to the following scheme:

Load score + posture score + working conditions score = TotalTotal × Duration Score = Risk Score

Data were analyzed using the free version of SPSS (Statistical Package for the Social Sciences) software. Frequencies and percentages were calculated for qualitative variables and means, medians and standard deviations for quantitative variables. For univariate analysis, Pearson's chi-square test was used to compare qualitative data. In the case of small numbers, Fisher's exact test was used. Multiple binary regressions were used to identify determinants of LBP. The p-significance level for statistical tests was set at 0.05.

4 Results

The study population is made up of 41 employees, with a male predominance (56%), and an average age of 38 ± 8 years. Over two-thirds of respondents had been with the company for over 5 years. More than two thirds of the population (87.5%) has had LBP during the last 12 months. The duration of the functional impairment of which was between one and seven days for 60.7% of subjects. Among the employees exposed to manual handling, 86% handled loads less than 25 kg and 14% were constantly exposed to a load ≥ 25 kg (Table 2).

In this study, 88% of the employees had little decision-making latitude, 44% had a low psychological demand and 68% of employees had low social support.

After logistic regression, LBP was significantly correlated to body mass index (P = 0.011, OR = 2.8; IC = [0.147–0.994]).

The ergonomic analysis of the physical load revealed that 72% of employees are in risk class 3, 12% in risk class 2 and 16% are in risk class 1 (Table 3).

5 Discussions

Low Back Pain (LBP) is a major occupational health problem and back injuries are one of the most costly musculoskeletal disorders. The prevalence of LBP is estimated to be around 60–90% [7] and is generally considered to be a biopsychosocial phenomenon [8]. It has been estimated that approximately 90% of workers return to work within 2 months of an episode of LBP [7]. However, there is evidence that the risk of long-term disability increases substantially as the likelihood of returning to work decreases with increasing duration of symptoms [9]. Preventing new episodes or recurrences of LBP, and also predicting which workers will develop chronic LBP, seems a logical approach to potentially reduce the impact of long-term disability. according the present study, the risk of developing low back pain is significantly associated with overweight or obesity, which is comparable to the literature [10]. Employees suffering from low back pain occupied the position of "ray worker" in 58% of cases and have had professional seniority greater than 5 years. These results may be explained by the cumulative effect of micro-trauma related to biomechanical constraints at work as described in the literature [11]. Carrying heavy loads is the main constraint at risk of low back pain [12]. Ergonomic analysis of the physical load at work found that 72% of employees had a risk score between 25 and 50. Therefore they are in risk class 3, concluding that the load is greatly increased and a re-conception is recommended. Nevertheless, the carrying of heavy loads and

Table 2. Correlation of low back pain risk to socio-professional characteristics

Socio-professional characteristics		Effective	(%)	p
Age	<40 years-old	26	64.5	0.79
	>40 years-old	15	35.5	
Gender	Male	20	48	0.08
	Female	21	52	
IMC	Normal	9	22.6	0.006
	Overweight/ Obesity	32	77.4	
Medical histories	No	35	84	0.57
	Yes	6	16	
Work station	Ray worker	24	58.6	0.5
	Others	17	41.9	
Number of hour of work	8h/j	31	74.9	0.29
	5h/j	10	25.8	
Seniority in position (years)	]1–5]	24	58.7	0.52
	]6–20]	17	61.2	
Professional experience (years)	]1–5]	8	19.3	0.05
	]6–20]	33	80.6	
Exposition to carrying heavy loads	Yes	32	77.4	0.86
	No	9	22.5	
Weight of load (Kg)	$\leq$ 25	37	90.5	0.28
	>25	4	9.5	
Push or pull a pallet truck (Kg)	$\geq$ 500	23	57.1	0.52
	<500	18	42.9	
Handling tools	Use of pallet truck	15	37.5	0.21
	No Pallet truck use	26	62.5	

Table 3. Ergonomic evaluation of the physical load at work

Risk score	%	Risk class	Description of the work situation
<10	16	1	Low load, physical overload unlikely
10 < 25	12	2	Increased load, helpful redesign for less fit subjects
25 < 50	72	3	Highly increased load, redesign recommended

the lack of mechanization were not retained as risk factors for low back pain ($p = 0.28$). These findings may be biased by the small sample of the studied population and by the over-estimation of spinal pain problems by employees. A number of authors have developed strategies and guidelines to prevent low back pain in the workplace. Mika Kawaguchi and colleagues demonstrated that lifting a weight of at least 25 kg by hand was a significant risk factor for low back pain [13]. The Afnor X 35-109 recommends for the carrying of repetitive loads a limitation of the unit mass to 25 kg for men aged between 18 and 45 years and to 12.5 kg for women of the same range [14]. Malchaire J. recommends that loads to be handled should be placed at a height of 70 to 80 cm, and that heavy loads ($>$10 kg) should be stored at hip height. In addition to biomechanical considerations, the influence of stress on the emergence and exacerbation of musculoskeletal disorders has been extensively documented in the scientific literature [15]. According to the results of a study of Slovenian professional drivers, there was a strong correlation between psychosocial risk factors and low back pain ($p < 0.001$) [16]. In the present study, 64.5% of workers with back problems had high psychological demands, with a statistically significant association ($p = 0.05$). In fact, psychosocial factors a.t work can exacerbate the influence of mechanical strain or is the cause of MSDs Themselves through increased muscle tension and impaired motor coordination [17].

In order to optimize the prevention of low back pain in our study population, we need to act simultaneously on different axes. For example, to reduce physical strain, we suggested reducing handling distances as much as possible, reducing the weight of crates and limiting the load on manual pallet trucks to 360 kg. We also suggested that electric pallet trucks should be made available to workers for pallets weighing more than 360 kg and that the number of workers should be increased depending on the season and sales requirements (promotions). Among the corrective actions related to work organization, we asked for traffic areas to be cleared, working space in the shop and warehouse to be increased, and the width of traffic aisles to be increased.

Training cycles for operators on the correct gestures and postures to adopt for safe manual handling of loads were planned.

It should be noted that the study was interventional and aimed at all workers. However, certain limitations exist, particularly the small sample size of the study population and the subjective nature of self-report based on the questionnaire used. Further, more in-depth longitudinal studies are needed to better investigate the problem of LBP in the workplace.

6 Conclusions

Low back pain is an occupational health problem that affects all professional sectors. In this study, we confirmed the multifactorial origin of this condition, explained by the interaction between individual, organizational, biomechanical and psychosocial factors. Therefore, preventive actions adapted to these risks must be integrated into a multidisciplinary strategy.

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Initial Biomechanics Approach of Non-powered Hand Tool Size Selection: An Analysis for Optimal Ergonomic Design

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Abstract. Modern businesses regularly invest in research, labour, and studies to increase productivity while keeping workers as the main industrial resource. With this in mind, managers of industrial ergonomics are continuously concentrating on refining the process of choosing the right tools for designing a tailored workstation. Through a literature revision of the geometrical movements and the forces and parameters involved during the kinetics, this work focuses on the interaction between the hand performing the movement and the equipment or environment to develop a method to explain the necessary steps for tool selection for industrial activities. This work also defines the way for improving the selection method for the primary conditions for correct hand tool selection. At the end of this research, the managers have a multi-analysed and organized guide to ensure the choice of the best tool, reducing the necessary force during the use of hand tools.

Keywords: Tools selection · Hand tools · Biomechanics · Occupational safety · Kinematics

1 Introduction

Modern businesses continually invest in research, labour, and studies to increase productivity while keeping an eye on human resources; as a result, managers of industrial ergonomics are constantly working to enhance how tools are selected at each workstation [1–3]. In industrialized countries, the process of watching musculoskeletal disorders number focuses on companies that for accomplishing the exact activity at each workstation, used hand tools. The industrial sector focuses on risk assessment methods that identify dangers that can produce a range of occupational illnesses and problems affecting a range of body components. To lessen the causes that cause employee illness, this work has been done utilizing a variety of tools, from paper and pencil worksheets to virtual reality simulations. The threats to health conditions can be avoided by including a constant monitoring of the position of the body part in your work days, and by using existing devices with artificial visualization the realized task is improved to ensure the workers' health [4, 5].

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During the study of the different standardized industrial documents, it is possible to identify the variables to be controlled, and the relationship between these variables and worker's behaviour, in this form, shall be acquired [6], Another important part is that it documents some variable parameters that could affect the final tool selection. To avoid work-related musculoskeletal disorders (WMSDs), some elements like mechanical, organizational, psychophysical, and individual factors shall be considered to contribute to the tool selection. According to the Italian government's Organization for Insurance Against Work-related Injuries, exists a rise in work-related musculoskeletal disorders each year. Risk factors for hand kinematics include high muscle power, repetitive manual motions, and wrist flexion and extension. Hand cumulative trauma diseases have been given top priority by the ergonomics managers at each factory. In order to improve production efficiency and reduce worker injuries and long-term health problems, a biomechanical analysis of a guide for selecting a non-powered tool for a certain hand activity is offered [7, 8].

The guide helps the managers avoid worker illness keeping in mind any body position can cause discomfort and fatigue after some time in this position even if the posture is natural body posture or relaxed tool fixing posture from its point of view the kinematic studio of the method supports the steps for a tool selection [9, 10]. To present this research process, the document is structured as follows: Sect. 2 determines the biomechanical characteristics of a tool selection method. Section 3 Results. Finally, Sect. 4 Conclusions.

2 Biomechanical Characteristic of a Tool Selection Method

The Compiled Data collection method shall be used for evaluating the data collected from the literature to make a correct selection criterion. The main ergonomic characteristics of tools are chosen as the criteria for selecting information, based on the statements of international occupational health institutions for applying in general selection of devices for a task aimed at avoiding future illness. During workers' daily tasks, hand tools, including hammers, chisels, pliers, and screwdrivers, pose a significant danger of harm. The many types of injuries are depicted in Fig. 1 and can be caused by a variety of things, including worker disease, which may also be classified as a separate form of injury.

International standards include measures to promote safety and health improvements throughout work activities at each station, and the tool selection process includes phases like "work activity analyses," "hand tool identification, and "ergonomic hand tool gripping".

2.1 Work Activity

At the beginning of the process, the work activity is assessed at each station to identify the necessary tools, keeping in mind that hand tools have a specific purpose. If the tool has the wrong application or activity, it could produce device damage or even labour accidents. One additional step in the first part includes the observation of hand movement during the activity, to determine the necessary kinetic position, the necessary movement to realize the manipulation of different tools like a screwdriver, the movement to handle a hammer, the movement to use a sander and finally the movement to use other tools.

Fig. 1. Injury causes and effects diagram.

2.2 Hand Tool Identification

In order to prevent future damage sources due to awkward postures and dangerous contact pressures, the chosen hand tools must suit the hand while taking into account the key tool characteristics and the evaluation criteria for each device. Besides the postures, the analysis of the actuating forces is needed to determine the correct tool, Fig. 2A shows the actuating forces during the realized activities using hammers, Fig. 2B shows the actuating forces during the realized activities using screwdrivers, Fig. 2C shows the actuating forces during the realized activities using precision tools and finally 2D shows the actuating forces during the realized activities using pliers or any kind of tweezers.

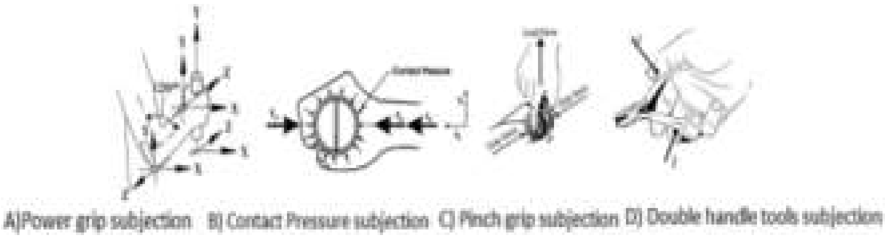

Fig. 2. Hand movements [11].

2.3 Ergonomic Hand Tool Gripping

Identifying the work method is the next task in the selection process. Tool applications, tool size and grip technique are considered in the light of the anthropometry of the worker's hands. In addition, other consequences of a wrong choice of tool could be integrated and it should cause some possible injuries to the work users. Information on the studies carried out to collect anthropometric data from industrial workers is shown in Table 1.

Table 1. Anthropometry size of hands [12]

Anthropometry size	Hand size	Palm length	Thumb length	Middle finger size	Ring finger size	Little finger size	Index finger size	Maximum grip diameter
Minimun	15,90	8,90	4,00	6,90	5,90	4,30	6,00	4,30
Maximun	20,50	11,60	5,80	9,00	8,00	6,30	7,90	5,90

3 Results

For effective tool selection with an emphasis on handling, four hand-measure measurements are necessary: "palm length," "maximum grip diameter," "middle finger length," and "index finger length". The workplace designers shall select the hand tools whose sizes guarantee that 90% of the workers' hands can be used during the activity. Processing anthropometrics data from Table 1 to ensure the use of hand tools for the majority of the work population is determined as a result:

Considering the smaller surface contact between the device and the body, the middle finger length and the middle of the palm length, these anthropometric data are presented in Fig. 3. These characteristics are used during "pinch grip subjection" and "contact pressure subjection" to realize the activity with the hand tool.

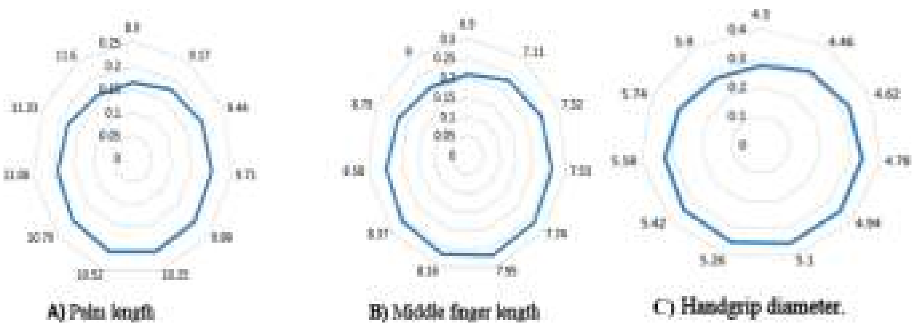

Fig. 3. Hand Anthropometry.

In activities performed using the thumb, middle, and index fingers, which have a small point of contact with the body, the maximum handgrip diameter is the most significant size. "Single-handle" and "power grip" are ways of handling that use these anthropometric data and are shown in Fig. 3 C and Fig. 4 A. Double hand tools subjection uses the thumb, middle, and index fingers are the smaller surface of contact with the device. These anthropometric data are presented in Fig. 4.

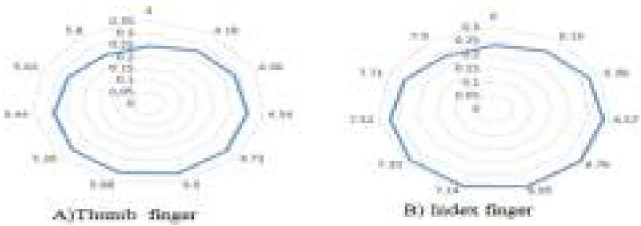

Fig. 4. Thumb and index finger Anthropometry.

4 Discussions

The initial biomechanics approach to non-powered hand tool size selection is an important part of achieving optimal ergonomic design for maximizing user comfort, efficiency, and lowering the risk of musculoskeletal disorders (MSDs). In concordance with studies where established the ergonomic design seeks to create physically appropriate tools for the user and promote safe and efficient work practices [10]. The right tool size to match the user's anthropometric measurements and biomechanical requirements is a fundamental consideration in ergonomic design. This approach recognizes that individuals vary in terms of their hand size, grip strength, and range of motion, and a one-size-fits-all approach may not be suitable.

By integrating biomechanics analysis into the design process, manufacturers can make informed decisions regarding tool size variations to accommodate a broader range of users. This approach promotes inclusivity, ensuring that tools are accessible and comfortable for individuals with different hand sizes and physical abilities. In addition, this research provides an evaluation of finger length, especially the length of the index and middle fingers, which plays a role in determining the optimal handle and control design of hand tools. Additionally, assessing finger circumference and grip strength is essential for designing handles with suitable diameters and grip surfaces that accommodate different hand sizes, establishing accordance with research e the anthropometric data is evaluated [10]. As the most critical part of this study, the initial biomechanics approach to non-powered hand tool size selection is a crucial step in achieving optimal ergonomic design. By considering the user's biomechanical requirements and incorporating scientific analysis, manufacturers can create tools that minimize the risk of MSDs, enhance user comfort, improve overall productivity, and teach workers by providing real-time feedback with new tools to evaluate specific tasks, in concordance with previous researches [5, 13].

5 Conclusions

Ergonomics managers will take care to choose tools carefully to safeguard employees from illness in order to achieve this goal due that if there is a wrong tool selection the industrial workers shall suffer a disease related to nerve compression, in this sense the correct manager activity assures the good hand health of industrial workers.

To execute activities requiring contact pressure subjection, the chosen tool must have a minimum dimension of 10.19 cm and a maximum diameter of 11.71 cm. Pinch grip submission requires a tool with a minimum dimension of 6.19 cm and a maximum dimension of 7.71 cm. The selected tool must have a minimum size of 4.46 cm and a maximum dimension of 5.74 cm for the assignments involving single-handle tool subjection and power grip tool subjection, respectively. To engage in double-hand tool subjection activities, the selected tool must be smaller than 7.11 cm. This study identified as the main limitation the lack of a specific established method focused on hand analysis due to the fact that the existing methods like RULA and REBA address the hand evaluation as a small part or step for complete body analysis. In future works, this study defines the starting point to understand the factors to establish a standardized method dedicated to evaluating specifically hand.

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Action and Lumbar Forces When Moving Hospital Beds – A Comparative Study

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Abstract. The study examines the action and lumbar forces when moving 12 hospital beds.

Eight subjects moved the beds along the test course of a hospital ward. The action forces are recorded using 3D force measurement grips. A motion analysis system records the posture of the test subjects during the test in order to calculate the spinal pressure forces between the 5th lumbar and the 1st sacral vertebra (L5/S1) using the biodynamic model "The Dortmunder".

The action forces reach values of 100.5 (±12.7) N to 177.3 (±21.0) N for the initial force and 41.6 (±5.0) N to 85.1 (±9.4) N for the constant force. The calculated spinal pressure forces L5/S1 partially exceed the guideline value for 60-year-old female employees of 1.8 kN and demonstrate a slightly increased to increased load for the caregivers.

Design measures, such as a 5th castor at the hospital bed, lead to a reduction in strain. Bed-Movers or active castors should be used for frequent transport of beds, for pushing over longer distances or for older employees or persons with pre-existing conditions.

Keywords: Action Force · Spine · Movement Analysis · Posture

1 Situation

Nurses are among the occupational groups most frequently affected by musculoskeletal disorders [1]. In addition to mobilizing patients, moving heavy medical equipment can also place a strain on the lower back. In particular, transporting patients in a hospital bed places high loads on the lumbar spine [2]. Studies to quantify these stresses and compare different hospital beds have not yet been sufficiently conducted.

In the following study, the action and lumbar forces when pulling and pushing 12 hospital beds in a real application environment are recorded and comparatively evaluated.

2 Method

The selection of hospital beds is based on a previously prepared market analysis. 12 beds (A–L) are included in the study. 10 beds have a 5th castor, which improves maneuverability and directional stability. Two beds (A and G) are not equipped with a 5th castor (Table 1).

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Table 1. List of hospital beds tested (A–L).

Alias	Manufacturer	Model	5th Castor
A	Wissner-Bosserhoff	Eleganza 1	-
B	Malsch	Impuls	X
C	Stiegelmeyer	Seta Pro	X
D	Stiegelmeyer	Evario	X
E	Stiegelmeyer	Puro	X
F	Völker	S966	X
G	Völker	S962–2	-
H	Wissner-Bosserhoff	Image 3	X
I	Wissner-Bosserhoff	Eleganza 2	X
J	Arjo	Enterprise 8000X	X
K	Stryker	SV-2	X
L	Hill Rom	900	X

To measure the action forces, eight caregivers move the beds in randomized order along a test course within hospital ward. This consists of the Sects. (1) maneuvering the bed out of a patient room (pulling backwards) and (2) pushing the bed 12 m along the corridor of a hospital ward, making a 90° turn after 6 m (pushing forwards). During the test, the beds are loaded with a weight of 107 kg to simulate a heavy patient (90th percentile male body weight). Three-dimensional force transducers (model 9809A from Kistler, Germany) are used to measure the action forces (Fig. 1). They are attached to the hospital bed and are individually adjusted to the height of the caregivers so that the grip height is centered between the wrist and elbow (with arms stretched downwards) [2].

Initial and constant forces are determined from the action forces. Initial forces are used to accelerate the beds and result from the 95th percentile of the measured action forces. Constant forces are used to maintain the movement and correspond to the 50th percentile of the measured values [3]. For the evaluation, arithmetic mean values and standard deviations are calculated for each bed and the min. and max. values for the individual sections of the test course are specified. The limit values for operating forces for medical beds according to IEC 60601-2-52 of 160 N and 85 N [4] are used to evaluate the initial and constant forces.

In addition, the caregiver's posture is recorded using a personal motion analysis system (Xsens Awinda, Movella Inc., USA) (Fig. 1). The spinal pressure forces between the 5th lumbar and the 1st sacral vertebra (L5/S1) are calculated from the action forces and the body postures using the biodynamic model "The Dortmunder" [5]. The results are displayed in box-plot diagrams.

The data were calculated and presented using the WIDAAN software from the Institute for Occupational Safety and Health of the German Social Accident Insurance in Berlin (Vers. 8/21). The revised Dortmund guideline value for 60-year-old women of

1.8 kN is used to assess the spinal compression forces L5/S1 [6]. This is also intended to detect possible overloads in older employees.

Fig. 1. Hospital bed with three-dimensional force transducers and caregiver with personal motion analysis system while maneuvering a bed out of the patient's room.

3 Results

During maneuvering, initial forces of min. 100.5 (±12.7) N to max. 127.0 (±5.7) N and constant forces of min. 41.6 (±5.0) N to max. 60.1 (±2.6) N were measured.

When pushing, the initial forces were min. 149.4 (±22.4) N to max. 177.3 (±21.0) N and the constant forces were min. 66.4 (±7.7) N to max. 85.1 (±9.4) N.

The spinal pressure forces L5/S1 for maneuvering and pushing the beds are shown in the following boxplot diagrams (Figs. 2 and 3). The Whiskers indicate the 5th and 95th percentile of the calculated values. The bar describes the range between the 25th and 75th percentile. The 50th percentile is represented by the dividing line of the bar. The solid line shows the reference value of the spinal compressive force L5/S1 for 60-year-old women in the amount of 1.8 kN.

4 Discussion

The action forces measured when maneuvering the beds are below the IEC 60601-2-52 limit values of 80 N and 160 N respectively. The limit values are not always complied with when pushing across the hospital corridor. The initial forces applied slightly exceed the limit value of 160 N.

The results show that the test subjects are exposed to greater action forces when pushing the beds across the hospital corridor than when pulling them backwards out

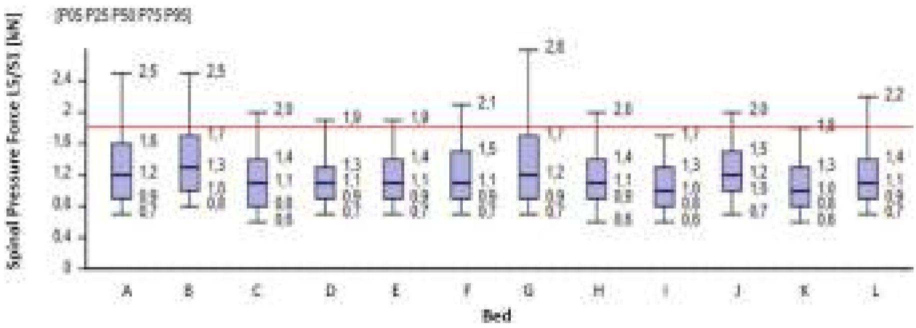

Fig. 2. Distribution of the spinal pressure forces L5/S1 when maneuvering the beds (A–L) by 8 test subjects with the revised Dortmund reference value for 60-year-old female employees of 1.8 kN (solid line).

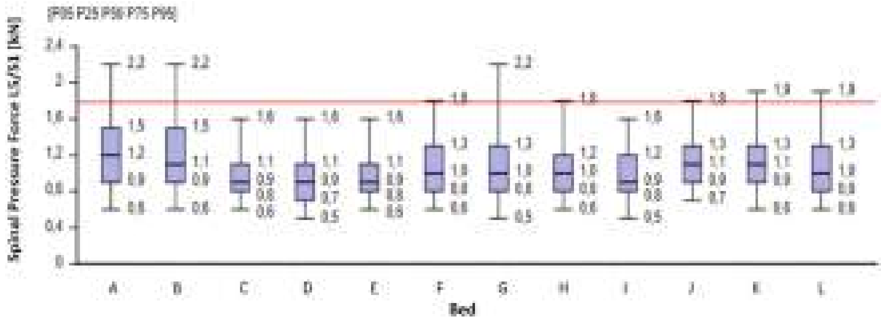

Fig. 3. Distribution of the spinal pressure forces L5/S1 when pushing the beds (A–L) by 8 test subjects with the revised Dortmund reference value for 60-year-old female employees of 1.8 kN (solid line).

of the patient's room. Due to the narrow width of the doorway, the bed in the patient's room must be positioned relatively precisely, which leads to a slower movement and therefore to lower initial forces. When pushing the bed across the corridor, these spatial restrictions do not exist, so that the test subjects can accelerate the beds more, which increases the initial forces.

The measured action forces show lower values compared to the study by Brütting et al. [2]. According to the authors, this can be explained by the differences in the test procedure. For example, in the study by Brütting et al. a used bed without a 5th castor was pushed across the corridor of an office building by novices. The maneuvering was not carried out from a patient room, but was simulated by moving the bed several times through 90° in an open area without spatial restrictions.

The study by Leban et al. [7] determined lower mean action forces when pushing a bed across the corridor of a hospital ward. However, a significant difference to the present study is that the action forces were only measured in two planes (x-, y-axis), so that no resulting force vector could be formed for the action force.

The calculation of the spinal pressure forces L5/S1 shows that the revised Dortmund guideline value of 1.8 kN is reached or exceeded by 11 of the 12 beds when maneuvering and by 8 when pushing. All exceedances were in the 75th to 95th percentile. This is interpreted by the authors as a slightly increased to increased load. The L5/S1 values show that the strain is higher when maneuvering the beds in the patient's room than when pushing them across the hospital corridor. When maneuvering the beds, the caregivers have to apply increased lateral action forces, which leads to a lateral flexion and torsion of the trunk. Despite the lower action forces compared to pushing, this results in higher spinal pressure forces L5/S1.

Beds A, B and G cause particularly high spinal pressure forces at L5/S1. Beds A and G do not have a 5th castor. On all other beds, this is located in the middle of the chassis under the bed's center of gravity. The 5th castor is fixed in place before the bed is moved, making it easier to turn and push straight ahead. On bed B, the 5th castor has been fitted by the bed manufacturer outside the center of gravity of the bed, so that it drags on the floor when cornering, which leads to higher action forces and spinal pressure forces L5/S1.

In this study, the hospital beds were only moved by one person instead of two, as recommended in occupational safety guidelines. When hospital beds are moved by two people, this is usually done in order to carry out the work faster or more precisely. This is the case, for example, when the bed is moved out of a patient room. Particularly time-consuming activities, such as transferring a patient to another ward or transporting them to an examination, are usually carried out by one person due to staff shortages and for economic reasons. An exception to this is a transport where there is a medical need to involve several people. This is the case, for example, when transferring intensive care patients with simultaneous transportation of several pieces of medical equipment. It is to be expected that the transportation of beds by two people will lead to a reduction in the action forces and spinal pressure forces L5/S1, even if this is not necessarily accompanied by a halving of the load due to coordination and coordination problems (so-called Ringelmann Effect).

Electrically operated bed transport systems (bed movers) offer a good option for relieving the load, especially for longer transport distances. Here, the hospital bed is coupled to an electric trolley which is controlled by the nurse. The disadvantages of bed movers include the additional purchase price, the limited compatibility with beds from different manufacturers and the additional construction volume, which can make transportation in an elevator, for example, more difficult. An interesting alternative are active or power-operated bed castors that are equipped with a motion sensor and detect when a bed is moved. The movement is then assisted by a motor integrated into the hub of the castor. These systems are currently under development and have the potential to provide simple and effective support for the transportation of hospital beds in the future.

5 Conclusion

Moving hospital beds by one person places a slightly increased to increased load on the lower back. The use of a 5th castor leads to a substantial reduction in strain. New hospital beds should be fitted with these in the interests of a healthy working environment.

Additional preventative measures should be taken to reduce the stresses and strains involved, particularly in the case of frequent transportation, long transport routes, inclines or older employees or people with pre-existing conditions. This includes the preferential use of technical aids such as bed movers or power-operated bed castors.

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Investigation of Ergonomic Risk-Assessment of Manual Forestry Work – Deriving a Reference-Concept

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Abstract. Conventional observation-based methods of ergonomic risk-assessment are not properly suited for the assessment of manual forestry work. The work activities and working conditions in the forest are not standardized and therefore difficult to assess. This paper describes a reference concept to investigate the influence of working conditions on physical workload based on biomechanical parameters during manual forestry work. For this purpose, a reference scenario consisting of the work activity manual skidding and the working conditions working posture, ground conditions and soil slope was selected. Furthermore, the biomechanical model of Jäger et al. [1] as well as a linear force sensor and inertial measurement units were selected for this reference concept based on a utility value analysis. A software-solution to calculate the compression and shear force on the L5/S1 intervertebral disc for the selected scenario was implemented. Evaluations show that the devised concept can assess risks more accurately compared to using an observation-based method and that some working conditions contribute towards higher physical workload on its own. This concept as well as the procedure to derive it can be used as a reference for similar investigations.

Keywords: WMDS · Biomechanics · Working conditions · Forestry work

1 Introduction

The work activities involved in manual forestry work are physically demanding. Work-related musculoskeletal disorders (WMSDs) and occupational accidents occur more frequently compared to other occupational groups. Overall, back pain has been proven to be the most common WMSD associated with manual load handling [2]. The health-risk of manual forestry work is difficult to assess using conventional observation-based risk assessment methods, even with those that not only take into account the working posture and handled load but also influencing environmental effects, such as ground conditions [3]. The main difficulty is that in the forest, working conditions often change dynamically within a working day and are drastically influenced by environmental factors. Therefore, working activities in manual forestry work are not standardized to a high degree, as opposed to e.g. work on the production shopfloor or in warehouses. New approaches to

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ergonomic risk assessment are hence needed to identify and reduce potential health-risks associated with manual forestry work.

Using force sensors and motion capture in conjunction with biomechanical models has the potential to provide very specific information about the health-risk of work activities in manual forestry work. To calculate biomechanical parameters, motion capture and force measurements are required as data input for biomechanical models. With regard to the human body, the biomechanical analysis of loads on the spine is particularly important, as irreversible damage can easily occur [4]. A literature analysis in the research field of biomechanics by Oxland [5] showed that despite the large amount of research on the essential load parameters of the spine, such as com-pression and shear forces and spinal stability – with the exception of compression force – there are no uniform findings, as different biomechanical models or approaches are used to explain the complexity of the human body. For example, the biomechanical models of Theado, Knapik, Marras [6] and Cholewicki, McGill [7] use EMG data as input and the models of Jäger et al. [1] and Kingma et al. [8] use external forces. However, the same biomechanical parameters can be calculated with these different models. For injury risks in the lower back, the compression and shear force on the L5/S1 intervertebral disc are usually examined. In order to assess whether there is a health risk, these biomechanical parameters can be compared with limit values for the compression forces according to Jäger [9] and for shear forces according to Gallagher, Marras [10].

The aim of this paper is to present a concept for assessing the influence of working conditions on the physical load during manual forestry work, which is based on biomechanical parameters. This concept includes the selection of a specific work scenario and the implementation of a software-solution to calculate the compression- and shear-forces acting on the intervertebral-disc L5/S1. This concept was used for an ergonomic investigation of the selected scenario in an empirical laboratory study and for the validation of the results in a quasi-experimental field study. This assessment method is compared to a common observation-based risk-assessment method, the Key Indicator Method (KIM) [3].

2 Methodology

For the design of the proposed reference concept, a systematic development process according to Lindemann [11] was implemented in successive steps. First, a suitable reference scenario to be investigated, consisting of a work activity and working conditions of manual forestry work, was selected. To investigate the selected scenario based on biomechanical parameters necessary, measurement technology and a bio-mechanical model were selected based on a utility value analysis in a second step. Third, a software solution was implemented to calculate the compression- and shear-forces acting on the intervertebral-disc L5/S1. In a final step, an empirical laboratory study and for the validation of the results a quasi-experimental field study were con-ducted to assess the influence of working conditions on the physical load during manual forestry work.

For selecting a suitable reference scenario, ergonomic risk assessments of manual forestry work were conducted using the KIM. The aim was to identify a reference work activity with medium risk potential according to the KIM, since it would be most problematic if a potential high-risk activity was misclassified as medium risk. Based on this rationale, manual skidding was selected as a suitable reference working activity for this scenario. Subsequently, the work and environmental conditions at-tributing to the risks were derived from this analysis and the conditions working posture, ground conditions and soil slope were identified as most relevant for this scenario. Hence, the selected scenario consists of the work activity manual skidding and the working conditions working posture, ground conditions and soil slope.

Investigating this scenario based on biomechanical parameters in laboratory and real circumstances makes it necessary to choose a robust measurement technology for capturing human motions as well as a biomechanical model. Because of poor lighting conditions and the possibility of optical occlusion in the forest, an inertial measurement system was selected to assess human motions. With the selection of a biomechanical model, a measurement technology for force measurement is selected at the same time, which can provide the required input data for the corresponding biomechanical model. In order to decide which combination of a biomechanical model and force measurement fits best for the selected scenario, a utility value analysis of four different biomechanical models was carried out. The models of Theado, Knapik, Marras [6] and Cholewicki, McGill [7] function with EMG data, whereas the models of Jäger et al. [1] and Kingma et al. [8] function with external force measurements. For the utility value analysis, five criteria were formulated.

The first criterion is compatibility of measurement technology. It was considered whether the measurement technologies for motion capturing and force measurements could interfere with each other and if synchronized recording is possible. Both available options for force measuring can be used synchronously with the IMU sensors, but EMG sensors could interfere to some extend with the IMU sensors. The second criterion is development complexity, which was estimated in terms of the effort required for the programming and implementation of the biomechanical modeling and features. The third criterion is the data input and was assessed by the quality of the raw data used for the biomechanical calculations. Fourthly, the scientific relevance of the biomechanical models represents a further decision criterion. It should be noted that all the biomechanical models presented are scientifically established. Nevertheless, there are differences in how often these models are used for scientific investigations and their number of citations. The last criterion is suitability for field testing. Measurement technology will be used in difficult environmental conditions in the forest for data collection.

Based on the selection of a suitable biomechanical model based on these 5 criteria, a software-solution to calculate the compression- and shear-force on the L5/S1 intervertebral-disc for the selected scenario was implemented and a plausibility test of the functionality and correctness of this software-solution was carried out.

Finally, an empirical laboratory study and validation of the findings in a quasi-experimental field study were carried out to investigate the relationship between selected working conditions and physical workload during manual skidding. In this context, the above-mentioned scenario of the work activity manual skidding and the working conditions working posture, ground conditions and soil slope was investigated using the implemented software-solution.

3 Results

The result of the utility value analysis based on the described criteria indicates that for the pre-selected scenario, a combination of a linear-force-sensor and the biomechanical-model based on Jäger et al. (2001) is best suited for risk assessment. Briefly outlined and summarized, the selected scenario consists of the work activity manual skidding and the working conditions working posture, ground conditions and soil slope. For motion capturing, inertial measurement units were used and for force measuring, a linear force sensor. Biomechanical calculations of the compression- and shear-force acting on the intervertebral-disc L5/S1 were conducted based on the model of Jäger et al. [1].

For the selected scenario, a software-solution was implemented. Figure 1 shows the output which displays the applied tensile force, the resulting compression- and shear-force on the L5/S1 intervertebral-disc, the angle of force application, the angle of the L5/S1 intervertebral-disc and the angle of the lower back in a graph over time. This output was used to determine the plausibility of the calculated values and to validate the data sets.

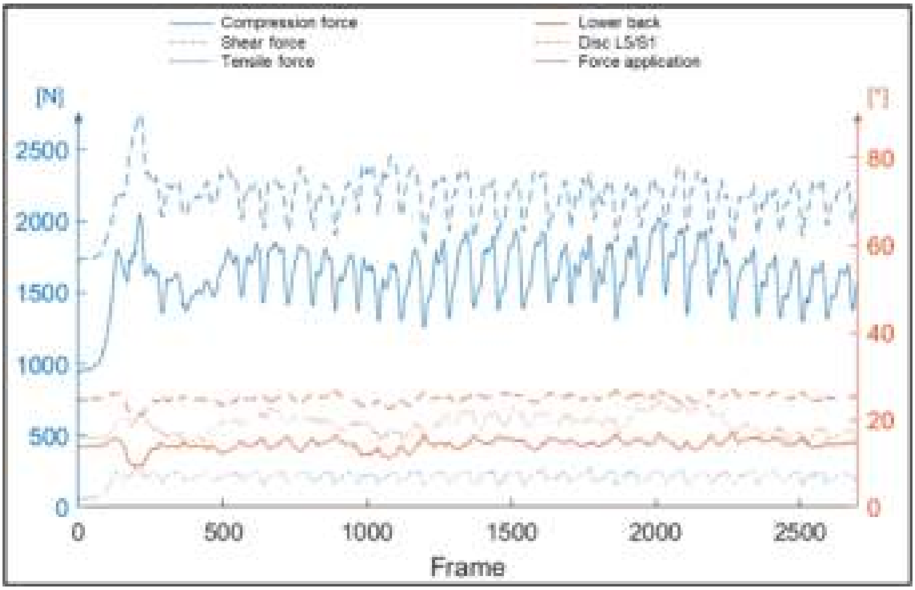

Fig. 1. Output of the software-solution.

This concept was used for an ergonomic investigation of the selected scenario in an empirical laboratory study (N = 42) and validated in a quasi-experimental field study with experts (N = 10). Overall, the mean values of the compression force of these studies show a medium risk compared to the limit values of Jäger [9] but the mean values of the shear force indicate a high risk compared to the limit values of Gallagher, Marras [10]. These findings are in contrast to the results of ergonomic risk assessment of the same scenario based on the observational method KIM, which indicated a medium risk and therefore seemingly underestimates a potential health risk.

4 Discussion and Conclusion

Based on a systematic development process, a reference-concept to investigate the influence of working conditions on physical workload with biomechanical parameters was derived. According to the proposed concept, a reference scenario of a suitable work activity of manual forestry work, working conditions to be investigated and a combination of a biomechanical model and measurement technology needs to be selected. In this example, the selected scenario consists of the working activity of manual skidding, the working conditions working posture, ground conditions and soil slope. The scenario was chosen based on a prior KIM analysis which indicated a medium risk. Second, a suitable biomechanical model and compatible measurement technologies need to be selected based on predetermined criteria. In this example, a linear-force-sensor as measurement technology and inertial-sensors are used for motion capture. For the selected scenario, a software-solution for calculating the com-pression- and shear-force on the L5/S1 intervertebral-disc using the biomechanical-model of Jäger was implemented. This concept combines conventional ergonomic risk-assessment based on the KIM and detailed analyses with biomechanical parameters. The assessments were empirically investigated in laboratory and validated in a quasi-experimental field study. Those results indicate an elevated risk of back injury related to the activity of manual skidding and also indicate working conditions that contribute towards this health risk. Hence, the proposed concept contributes towards improved risk assessment since it complements the traditional observation-based methods with more accurate assessments for specific activities.

The selected scenario only covers part of manual forestry work. However, conclusions about the working conditions and the methods used for ergonomic risk assessment are transferable to other forestry work activities or even to other areas. The extent to which the selected biomechanical parameters allow conclusions to be drawn about the effect of working conditions on physical workload during manual forestry work was tested with an empirical laboratory study and the results were validated in a quasi-experimental field study. This procedure and the conducted analysis with the derived concept can be used as a reference for similar investigations.

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A Decade Update on the Musculoskeletal Health of Office Employees in Hong Kong

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Abstract. The study was conducted to investigate the musculoskeletal health condition of office workers in Hong Kong, which included comparing past studies in a decade and understanding the trend of occupational health issues of office workers. Among the study samples, about 95% of them spent over six hours working on computing work, and approximately 75% reported musculoskeletal symptoms since 2015. The alarming results reminded us that the neck, lower back, and shoulders were the most commonly reported discomfort. The recent results of office workers working from home also reported that 83% of homeworkers worked with computers for six hours a day or longer, with 63% reporting musculoskeletal symptoms. For office workers and homeworkers, the neck, shoulder, and back were the three predominant body regions that suffered from discomfort. The top concern of musculoskeletal symptoms of office workers was shoulder (74%) but neck (51.4%) for homeworkers, possibly due to the high percentage of homeworkers who used laptop computers. Furthermore, among office workers and homeworkers suffering from musculoskeletal discomfort, 18% and 26% required medical consultation. Office-based employees' overall musculoskeletal health conditions have been the same high concern in the last decade, and the homeworker's statistics highlighted the new occupational health information on WFH conditions.

Keywords: Musculoskeletal Disorders · Office Workers · Work from Home · Computing Work · COVID-19

1 Introduction

Musculoskeletal health is the primary occupational health concern of office employees, a pervasive issue affecting a significant portion of the workforce. The musculoskeletal symptoms can include simple stiffness and weakness or more complicated problems with impaired coordination and chronic pain, affecting work performance and day-to-day activities. The musculoskeletal disorders of office employees incur a financial and non-financial burden to their employers. Employers are responsible for treatment expenses, and work absence affects productivity [1–3]. The legislative system in many countries includes musculoskeletal injuries as compensable work-related injuries, and the employers are responsible for the compensation [4–7].

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However, in the compensable occupational disease schedule in the Employees' Compensation Ordinance in Hong Kong, only the work-related hand, forearm, and elbow musculoskeletal injuries are relevant body regions to claim for repetitively overuse occupational disease. They are associated with the nature of the tasks involved in prolonged computing work. In other words, the most common musculoskeletal disorders, such as neck, shoulder, and back pain, are not listed as compensable occupational diseases except when caused by an incident such as an occupational injury under the Employees Compensation Ordinance [8, 9].

1.1 Musculoskeletal Health of Office Workers and Homeworkers

Work-related musculoskeletal health has been widely discussed in workers' occupational health. Due to office workers' work tasks, long computing work hours are typical in work activities in the office setting. The computer users reported mostly musculoskeletal concerns on the lower back, neck, and shoulders, and the studies were conducted in different countries [1, 8, 10, 11].

Past research data in Australia, Iran, Turkey, Lithuania, New Zealand, and Estonia revealed that the prevalence rate of office workers' neck, upper or lower back, and upper extremity pain was approximately 20% to 65% [1]. The researchers in the study defined different prevalence durations, such as the last 12 months, last 30 days, or last seven days, of musculoskeletal discomfort. A survey by Ardahan and Simsek [12] reported the prevalence of pain in the previous seven days of office workers, and the results were similar to other studies on longer prevalence duration with a high rate of reported discomfort on 68% of neck, 66% on upper back and 59% on lower back.

A study confirmed that over seven hours of computer use by office workers was associated with a greater reported rate of musculoskeletal discomfort across all body areas [12]. Likewise, a longer daily computer use period positively correlates with musculoskeletal pain in different body regions. Office workers with more static posture and more computer time are more likely to suffer from musculoskeletal problems [1].

1.2 Work from Home (WFH)

The relevance of this study to the current work environment of working from home cannot be understated. Office employees in Hong Kong, who traditionally spent prolonged hours in front of computers, have had to adapt their work arrangements at home since 2019 due to the COVID-19 pandemic. WFH has become a new work norm, especially during the COVID-19 season. Before the pandemic, only about 15% of Hong Kong office workers had the option to WFH [13]. In addition, Hong Kong residents lived in tiny home spaces. A WFH study discovered that 18% of homeworkers lived in 100 to 300 square feet of small flats. However, a small family in a flat with two to three occupants is most common in Hong Kong [14].

A small home space created a challenge for homeworkers to allocate sufficient space for working at home and personal living. Also, homeworkers may need more furniture options for computing work at home. A study on home workstation setups of homeworkers in Hong Kong found that most homeworkers worked at the dining table (40.9%) and the dining chair (34.1%). The dining table and chair were designed for short-term use during meal times. The dining furniture is usually of fixed height; comparatively, the office desk is fixed or adjustable, and the office chair is adjustable.

Suppose the homeworkers only have furniture that is not designed for computing work. In that case, homeworkers using a chair without a backrest or sitting on a sofa for computing work can predict a 2.6 times higher musculoskeletal discomfort risk [15]. In this regard, the update of the musculoskeletal health conditions of office employees working in the office and working in the WFH settings can show complete pictures of the musculoskeletal health status of office employees in Hong Kong.

2 Aims

The paper aims to report an update on the musculoskeletal health condition of office workers in Hong Kong from 2021 to 2023 and compare it with the previously published data from 2013 to 2019. The updated musculoskeletal health statistics also included the WFH data for 2022 and previously published data for 2020. The paper also compares the time spent on computing work, self-reported musculoskeletal symptoms, and seeking medical treatment statistics among office employees working in WFH settings. The paper discusses office employees' musculoskeletal health trends and work conditions in the past decade.

3 Methods

3.1 Office Employees' Statistics 2021 to 2023

The occupational health statistics of office employees were collected during the face-to-face structured questions by an ergonomics consultancy company in Hong Kong. The face-to-face interviews were conducted during the ergonomics workstation assessment from 2021 to 2023. A total of 98 cases were collected. The office employees were asked about the average working hours of computer use, self-reported body region with musculoskeletal discomfort, and whether medical treatment had been received.

3.2 Homeworkers' Statistics 2022

The homeworkers' WFH statistics were collected during the COVID-19 in 2022. The target population was office employees who used computers daily and were arranged to work at WFH during COVID-19 in Hong Kong for over one month at the time of data collection. The online structured questionnaires were used to collect the data on their length of WFH during COVID-19, computer time working at home, self-reported body region with musculoskeletal discomfort, and whether medical treatment had been received. The data collected were anonymous, and 185 valid questionnaires were used in this study.

4 Result and Discussion

The update on the musculoskeletal health condition of office employees from 2021 to 2023 and the discussion on the conditions of the last decade are highlighted below.

4.1 Time Spent on Computing Work

Table 1 showed that 73% of sample homeworkers had at least two months working from home, so the homeworkers were building up the experience and adaptation to the changes in the working environment of WFH.

The results showed that from 2021 to 2023, in Table 2, 95% of office employees spent at least six hours daily in computing work. The statistics found that since 2015, 9.5 out of ten office employees can be classified as prolonged computer users per the regulation's definition in Hong Kong [16]. Although the statistics from 2013 to 2014 showed that a lower percentage of office workers spent long hours on computing work than more recent studies, most office employees working long hours had been prominent practices in Hong Kong.

83% of homeworkers spend at least six hours daily on computing work. Comparing the results from 2020, in the earlier stage of the COVID-19 outbreak, less than 60% of homeworkers spent long hours on computing work. The WFH arrangements were more settled in the later time of the COVID-19 outbreak in 2022, and the change of WFH arrangement was re-arranged into a new work pattern.

The result further concluded that, on average, 12% fewer homeworkers spent at least six hours a day in computing work than the workers working in the office setting. The reason for less working time on computing work during WFH or COVID-19 was still being determined.

Table 1. Duration of WFH (in months)

Items	Frequency (N = 185)	Percent (%)
One to two months	50	27.0
Two to three months	58	42.2
Over three months	57	30.8

4.2 Time Spent on Computing Work – A Decade Trend

The time spent on computing work was on an upward trend in the first half of the last decade; however, from 2015 to 2017, approximately 95% of office workers spent long hours in computing work, and a flat trend high percentage continuously (Fig. 1).

4.3 Self-reported Musculoskeletal Symptoms

From 2021 to 2023, 76% of office workers reported musculoskeletal symptoms. The shoulder (74%) was most highly reported with discomfort, and the neck (43%) and back (31%) were the second and third highest reported discomfort. The results discovered that shoulder, neck, and lower back were most commonly reported with musculoskeletal symptoms in the past ten years. A high prevalence rate of office workers suffering from

Table 2. Time Spent on Computing Work of Office Workers (2013 to 2023) and Homeworkers (2020 and 2022)

Items	2013–14	2015–17	2018–19	**2021–23**	2020 WFH*	**2022 WFH^**
Sample Size (number of office employees)	245	1618	83	**98**	54*	**185**
Time Spent at least Six Hours a Day in Computing Work (%)	87%	96%	96%	**95%**	58%**	**83%**

References: [8, 17–19]
** The sample refers to work from home/study during the COVID-19 pandemic. The result relates to time spent at least four days a week working/studying with a computer/laptop at home during the COVID-19 pandemic*
^ Homeworkers who had over one month of experience for WFH at the time of study during the fifth wave of the COVID-19 pandemic

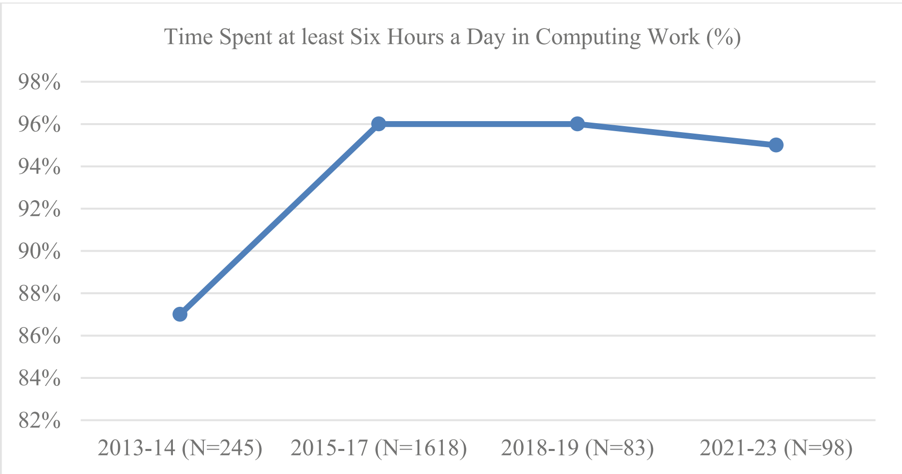

Fig. 1. Office workers time spent at least six hours a day in computing work (%) from 2013–14 to 2021–23

shoulder symptoms is related to the nature of the task and the workstation setup. The neck discomfort was lower from 2021 to 2023 than in two studies conducted in 2015 to 2017 and 2018 and 2019.

In a study conducted in Thailand, the results found that among 1,428 office workers, 63% self-reported musculoskeletal symptoms in the past 12 months, which head/neck (42%) mainly were reported with discomfort and followed by upper back (28%), wrists/hands (20%) and shoulders (16%) [20]. It showed the location differences between the statistics in Hong Kong and Thailand, in which Hong Kong office employees reported a higher prevalence of musculoskeletal symptoms. In addition, the major musculoskeletal issues of Hong Kong office employees have been on the shoulders, neck, and lower back.

In contrast, Thailand office employees suffered more problems with the head/neck, upper back, and wrist/hands. In particular, wrist/hands were not an issue in Hong Kong. The results may be caused by differences in workstation setup, furniture use, and computer type [15]. The real reason is unknown.

For the WFH statistics 2022, with those WFH for over one month, 63% reported musculoskeletal discomfort, 17% less than the results in 2020. The neck (51.4%) had the highest reported rate of discomfort compared to the back or shoulders. However, the neck, back, and shoulders were the top three with the highest reported body discomfort. The top three commonly reported discomfort-related body regions were the same between the homeworkers and office-based workers. Among the homeworkers' musculoskeletal statistics, 58.9% reported neck/lower back or shoulder discomfort.

By comparing the musculoskeletal health statistics between the office workers and homeworkers, the neck was the highest reported rate of discomfort for homeworkers. However, it was the second-highest reported rate of discomfort for office workers. In the study conducted at the University during COVID-19, most staff used laptop computers, which caused awkward wrist postures and unsupported forearms, putting stress on the upper back and neck flexed for looking down to see the laptop screen [21].

For the upper/lower back discomfort, the prevalence rate of homeworkers was higher than office workers statistics. The result showed the statistical difference between office workers and homeworkers, likely related to the difference between office and home workstation setups. For example, homeworkers may not have a backrest and height adjustable chair, a typical chair option in the office [15] (Table 3).

4.4 Self-Reported Musculoskeletal Symptoms – A Decade Trend

The trend of outcomes of the self-reported musculoskeletal statistics from 2015 to 2017 was constant for an overall rate of musculoskeletal symptoms and the percentage of reporting shoulder discomfort. For the reporting of neck discomfort, it had an increasing pattern from 2013 to 2019 and reached the highest point in the 2018/19 study. Most statistics show that the prevalence rate dropped significantly from 2015 to 2017. The decade trend of lower back discomfort of office workers did not show the pattern as it went up and down in the past studies. Since COVID-19, some office workers have spent time working from home, so future statistics may not purely represent the same work arrangements as previous studies of working full time in the office setting (Fig. 2).

4.5 Seeking of Medical Treatment

Employers are usually responsible for their employees' medical expenses as the employees' benefit. The result showed that from 2021 to 2023, 18% of the office workers were required to seek medical treatment for musculoskeletal symptoms. Comparing the statistics in the study from 2018 to 2019, the reported rate of seeking medical treatment has significantly increased by 10%.

Table 3. Self-reported Musculoskeletal Symptoms of Office Workers (2013 to 2023) and Homeworkers (2020 and 2022)

Items	2013–14	2015–17	2018–19	2021–23	2020 WFH*	2022 WFH^
Sample Size (number of office employees)	245	1618	83	98	50	185
Reported Musculoskeletal Symptoms (%)	91%	74%	78%	76%	80%	63%
Items	2013–14	2015–17	2018–19	2021–23	2020 WFH*	2022 WFH^
Commonly reported body region with discomfort (Top three)	Shoulder *(31%)* Lower Back *(26%)* Neck *(14%)*	Shoulder *(69%)* Neck *(49%)* Lower Back *(39%)*	Shoulder *(78%)* neck *(65%)* Lower Back *(26%)*	Shoulder *(74%)* Neck *(43%)* Lower Back *(31%)*	Neck *(17.5%)* Lower back *(15%)* Shoulder *(10%)* Others *(7.5%)*	Neck *(51.4%)* Upper Back & Lower Back *(47.6% & 46.5%)* Left Shoulder & Right Shoulder *(39.5% & 42.7%)*

References: [8, 17–19]

^ Homeworkers who had over one month of experience for WFH at the time of study during the fifth wave of the COVID-19 pandemic

** The sample refers to work from home/study during the COVID-19 pandemic. The result relates to time spent at least four days a week working/studying with a computer/laptop at home during the COVID-19 pandemic*

In the WFH duration, 26% of homeworkers had musculoskeletal discomfort and required medical treatment. Regarding homeworkers seeking medical treatment, the statistics showed similar results in 2020 and 2022, with one-fourth of homeworkers reporting musculoskeletal discomfort higher than office workers from 2018 to 2023 (Table 4).

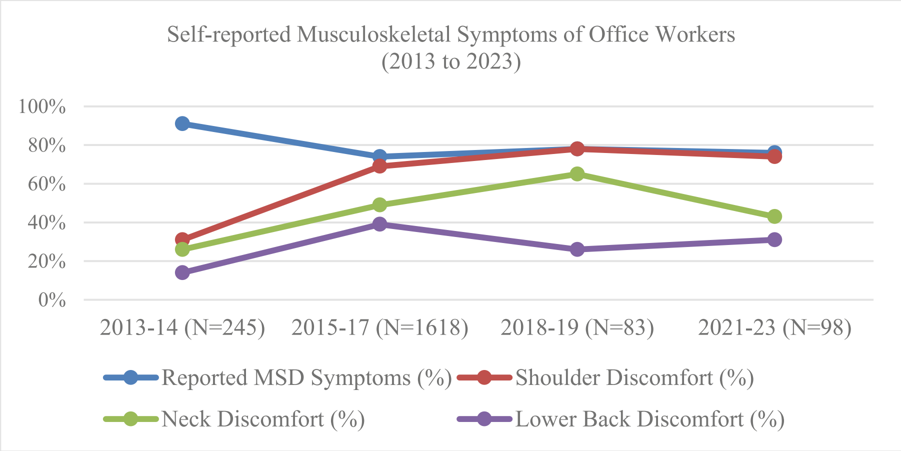

Fig. 2. Office workers self-reported musculoskeletal symptoms from 2013 to 2014 to 2021 to 2023

Table 4. Seeking Medical Treatment of Office Workers (2013 to 2023) and Homeworkers (2020 and 2022)

Items	2013–14	2015–17	2018–19	2021–23	2020 WFH*	2022 WFH^
Sample Size (number of office employees)	245	1618	83	98	50	185
Seeking Medical Treatment	42%	39%	8%	18%	23%	26%

References: [8, 17–19].
** The sample refers to work from home/study during the COVID-19 pandemic. The result relates to time spent at least four days a week working/studying with a computer/laptop at home during the COVID-19 pandemic*
^ Homeworkers who had over one month of experience for WFH at the time of study during the fifth wave of the COVID-19 pandemic

4.6 Seeking of Medical Treatment – A Decade Trend

The decade trend of office workers seeking medical treatment did not follow a precise pattern. In the first half of the last decade, the percentage of medical treatment required was steady. However, there was a substantial fall in survey participants seeking medical assistance from 2018 to 2019. However, the COVID-19 outbreak and reducing person-to-person contact may explain it. Finally, a slight increase in the percentage seeking medical assistance from 2021 to 2023 can be observed (Fig. 3).

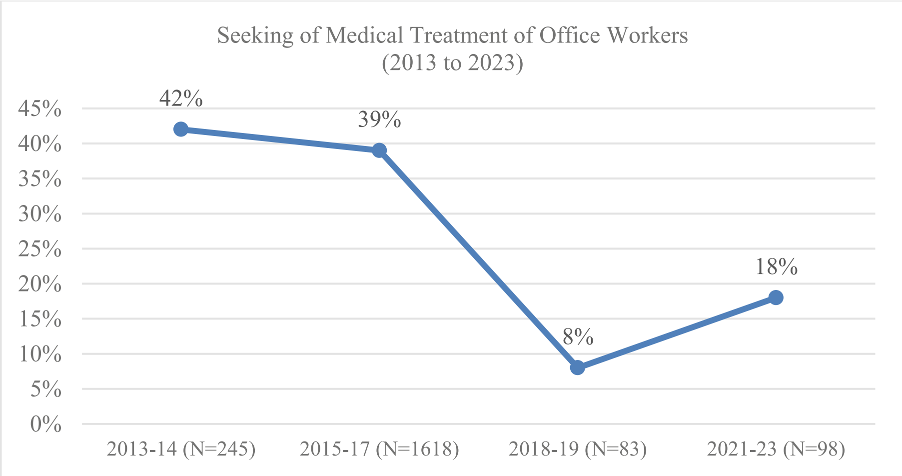

Fig. 3. Office workers seeking medical treatment from 2013–14 to 2021–23

5 Limitations

The limitation of the study is relevant to the case that the musculoskeletal health information, working hours on the computer, and needs for seeking medical assistance were self-reported. The study is focused on reporting the musculoskeletal health data rather than the linkage between the relationship of the reported discomfort and the working hours and furniture or workstation setup factors. The study is limited to identifying the trend in number instead of the cause of the musculoskeletal pain. A larger sample size for a survey of the prevalence rate of musculoskeletal health may create an even greater value for the study. Future research can be designed to tackle those limitations.

6 Conclusion

The study results showed the musculoskeletal health of office workers in Hong Kong in the past ten years and homeworker conditions in two studies in 2020 and 2022. A high percentage of office workers and homeworkers who spent prolonged hours in computing work reflected the high prevalence of reported musculoskeletal symptoms on the neck, shoulder, and back. The self-reported requirement for medical treatment among office workers increased, and homeworkers reported higher demand for medical assistance. With the new form of working arrangements between spending time with WFH, the musculoskeletal health conditions of Hong Kong office workers and homeworkers are continuously monitored as needed. The musculoskeletal health condition of Hong Kong office workers should be closely monitored and regularly reported. Due to the change in the working location of office workers working from home, the study showed additional information on homeworkers.

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Enhancing Arm-Support Exoskeleton Design for Improved Agricultural Efficiency: Investigating Optimal Support Angles

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Abstract. Musculoskeletal disorders (MSDs) are prevalent occupational diseases, particularly in agriculture. Occupational exoskeletons, such as arm-support exoskeletons (ASEs), have emerged as a promising solution to mitigate physical demands and reduce the incidence of MSDs. Despite evidence supporting the general benefits of exoskeletons, there is limited research on how specific design features, like support angles, impact their effectiveness. This lab-based study examined how different support angles affect ASE effectiveness during simulated agricultural tasks. The effects of a prototyped ASE were evaluated in terms of muscle activity, perceived exertion and discomfort, and task performance. Results indicated that higher support angles decrease muscle activity in specific muscle groups (i.e., anterior deltoid and biceps brachii) but increase perceived exertion and discomfort. Future research should focus on dynamic task assessments and involve larger sample sizes to refine the optimal support angle range for ASE design, ultimately enhancing worker well-being and productivity in agriculture. This study aims to deepen the understanding of how exoskeleton design can improve occupational health and safety.

Keywords: Ergonomic intervention · Wearable · Farming industry · Muscle activity

1 Introduction

Musculoskeletal disorders (MSDs) are prevalent occupational diseases found across various industries, with an exceptionally high incidence in agriculture [1, 2]. To lessen physical demands and mitigate the risk of MSDs, the integration of occupational exoskeletons has emerged as a promising ergonomic intervention.

While studies have highlighted the potential of exoskeletons in reducing musculoskeletal strain and injury risk among workers engaged in repetitive or physically demanding tasks [3–6], there remains a notable gap in understanding the nuanced impact of specific design features on their effectiveness. Existing research has predominantly focused on the general effectiveness of exoskeletons across different industries, but there is limited exploration of exoskeleton structure or design.

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Particularly lacking is a detailed analysis of the effects of design features, such as the angle of support, on the physical demands of arm-support exoskeletons (ASEs) during overhead work. Thus, while the broad benefits of exoskeletons are acknowledged, there is a significant need for further investigation into how specific design elements influence their performance.

This paper seeks to address this research gap by examining the specific influence of the angle of support on the physical demands experienced by workers utilizing ASEs during overhead tasks. By doing so, we aim to contribute to a deeper understanding of the role of exoskeleton design in enhancing occupational health and safety.

2 Methods

2.1 Participants

Four healthy, right-handed male participants, with a mean age of 26.0 ± 1.2 years, completed the study. All participants provided informed consent following procedures approved by the Institutional Review Board of Incheon National University.

2.2 ASE Tested

The study evaluated one prototype of passive ASE in a simulated agricultural environment. Developed for agricultural use, this ASE is worn as a backpack and consists of adjustable shoulder/waist straps and frames. It weighs approximately 3.2 kg.

2.3 Experimental Tasks and Procedures

The participants performed simulated agricultural tasks under four distinct angle of support conditions: without ASE, 60°, 90°, and 100°. These tasks were performed at shoulder height, overhead height, and 175 cm. The shoulder and overhead height were set to the participant's anthropometry. The overhead height was set as participants flexed their shoulders and elbows to 90°, following the method described by Sood, Nussbaum and Hager [7].

The experimental tasks, which included simulated pruning and harvesting, were designed to reflect common agricultural activities, such as those performed in orchards and greenhouse cultivation [8]. In the pruning task, participants cut 10 pieces of 3 mm wire using 210 g pruning shears (PSN-8G, CHIKAMASA, Japan). This task was designed to reflect activities common in the fruit farming industry, such as the year-round tasks of thinning and branch trimming. For the harvesting task, participants removed 20 Styrofoam balls, each with a diameter of 40 mm, attached to the workbench. This task was adapted from Kong, Park, Cho, Kim, Kim, Hyun, Bae, Choi, Ko and Choi [9]. A height-adjustable workbench with a maximum height of 200 cm was used for the simulated agricultural tasks. The participants used their dominant hand to perform experimental tasks.

To begin, participants had electromyography (EMG) electrodes attached to measure their muscle activity. They then performed maximum voluntary contractions (MVCs) of the targeted muscles to normalize the EMG signals. The test ASE was adjusted to fit each participant based on anthropometry. Before performing the simulated agricultural tasks, the participants underwent a practice session to familiarize themselves with the ASE. Following this, they performed various tasks under varying angles of support conditions at different working heights. After completing tasks at each height, participants rated their perceived exertion and discomfort. Minimizing the potential effects of residual fatigue from the previous condition, participants were provided with 3-min breaks. The order of presentation of the simulated agricultural tasks was counterbalanced for each participant (Fig. 1).

Fig. 1. The ASE tested

2.4 Outcome Measures

Muscle activity was measured using EMG to assess physical exertion across five muscles: the upper trapezius, anterior deltoid, biceps brachii, erector spinae, and vastus lateralis. Electrodes were placed bilaterally to the upper trapezius, anterior deltoid, erector spinae, and vastus lateralis, with an extra electrode on the dominant hand's biceps brachii. This resulted in EMG data collection from nine locations. Additionally, task completion time (in seconds) was recorded as a performance measure.

The perceived task load, rated after the experimental tasks, comprised perceived exertion for the entire body and perceived discomfort for nine body regions. The rating of perceived exertion (RPE) was measured using the Borg RPE scale, ranging from 6 to 20, to evaluate overall body exertion [10]. The rating of perceived discomfort (RPD) score was measured using the Borg CR10 scale (0–10) to assess discomfort in nine regions: neck, shoulders, upper back, lower back, elbows, wrists/hands, hips/thighs, knees, and ankles/feet [10].

The data were analyzed using a non-parametric analysis of variance (Kruskal-Wallis test), with a significance level set at 5%.

3 Results

Muscle activation levels during the simulated agricultural tasks showed similar trends across all task heights. ASE increased muscle activity in the left upper trapezius, regardless of the support angles. Moreover, a higher angle of support corresponded to a greater increase in muscle activity ($H(3) = 32.32$, $p < 0.001$). The 100-degree support angle significantly reduced muscle activity in the anterior deltoid compared to the 60-degree support angle (H(3) = 12.34, p = 0.006). Muscle activity in the biceps brachii tended to decrease as the angle of support increased (H(3) = 16.75, p < 0.001). No significant differences were observed in the muscle activity of the erector spinae and vastus lateralis, nor was task completion time. However, there was a tendency towards increased muscle activity in the vastus lateralis when using ASE. In contrast to the results on muscle activity, subjective ratings indicated higher scores for both RPE and RPD when participants used ASE (Figs. 2 and 3).

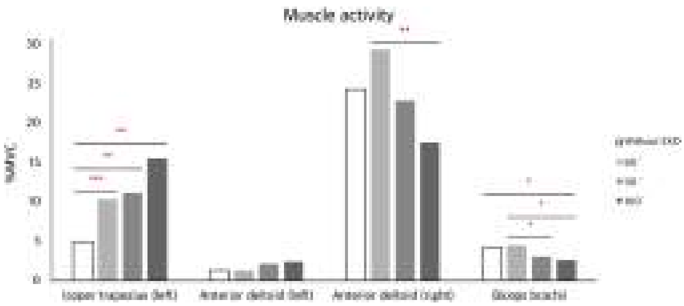

Fig. 2. Comparisons of mean muscle activity between the support angles conditions. Asterisks indicate statistical differences between the support angles condition (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Error bars refer to standard deviations.

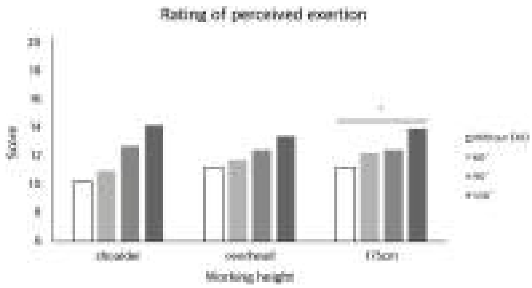

Fig. 3. Comparisons of RPE score between the support angles conditions. Asterisks indicate statistical differences between the support angles condition (* $p < 0.05$). Error bars refer to standard deviations.

4 Discussion and Conclusions

4.1 Muscle Activity

To effectively reduce muscle activity in the anterior deltoid and biceps brachii, it may be suggested that an angle of support exceeding 60 degrees is required. Given that a 100-degree angle of support resulted in a greater reduction in the anterior deltoid and biceps brachii muscle activity compared to a 60-degree support angle, a comprehensive study, including existing commercial ASEs, should be conducted to identify the minimum angle that effectively supports the arm before designing. In the study conducted by de Vries, Murphy, Könemann, Kingma and de Looze [11], although there were no statistically significant differences in biceps brachii muscle activity while maintaining a static arm position using an ASE, the ASE did lead to decreased muscle activity at a vertical arm elevation angle of 90 degrees compared to 60 degrees.

An adverse effect was observed on the left upper trapezius. This result is likely attributed to an angle of support higher than necessary, combined with a relatively low shoulder height.

4.2 Perceived Exertion and Discomfort

The use of the ASE maintained higher RPE scores when the support angle was set to 100 degrees. A previous study has shown that using ASEs significantly reduces RPE scores during tasks involving arm elevation above shoulder level [12, 13]. As a result, this suggests that the ASE could potentially impose additional strain on the body for tasks or postures that were not accounted for during its design phase.

4.3 Suggestions for ASE Design

In designing ASEs for overhead work, it is advantageous to ensure that assistive force is not generated below a specific angle, such as 90 degrees, as indicated in this study. This design choice optimizes support and minimizes unnecessary muscle strain. Although all right-handed participants used their right hand for tasks, a significant increase in muscle activity was observed in the left upper trapezius. Consequently, it is crucial to incorporate a feature that allows an unused arm support module to be fixed to the side or rear of an ASE, depending on the task requirements. Moreover, lower support angles were associated with increased shoulder muscle activity, highlighting the need for an adjustable assistive force tailored to each task to prevent such adverse effects.

4.4 Limitations

There are a few limitations in this study that should be noted. Firstly, the sample size of participants can also be seen as a limitation to generalizing the current pattern of results. Therefore, with the study conducted, there is still no evidence that the ASEs can provide actual benefits for agricultural task performance. Secondly, we used a fixed-angle approach for the angle of support in dynamic tasks, which may not reflect real-world scenarios. Lastly, our study focused on a specific ASE prototype, potentially limiting generalizability. Despite these limitations, our study sheds light on the potential advantages and drawbacks associated with the different support angles ASEs provide in reducing muscle activity. These insights can inform future research and development efforts to enhance work-related safety and efficiency in agricultural settings.

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The Influence of Backpack Weight on Student Posture and Body Discomfort

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Abstract. Students frequently bear heavy backpacks, potentially leading to musculoskeletal pain. This study explored the ergonomic aspects of backpack weight, its impact on student posture and function, and the importance of balance in injury prevention. A survey of 107 participants utilized the Nordic Musculoskeletal Questionnaire (NMQ). Results revealed significant correlations between carrying frequency ($p < 0.001$), weight ($p = 0.003$), duration ($p = 0.002$), and method ($p = 0.004$) with musculoskeletal disorders (MSDs). However, BMI ($p = 0.322$) and activity level ($p = 0.258$) were not significant factors. The lower back, upper back, shoulders, and neck were commonly affected areas. Targeting treatments to these specific areas is essential. Lowering backpack weight may alleviate musculoskeletal discomfort among students. This study underscores the pressing need to address the issue of heavy backpacks and their impact on student health. By identifying significant correlations between various factors related to backpack usage and musculoskeletal disorders, it provides valuable insights for preventive measures. Educating students on proper backpack usage and encouraging them to carry lighter loads could mitigate the risk of developing chronic pain or discomfort. Moreover, the study highlights the importance of considering ergonomic factors in designing backpacks. Manufacturers and educational institutions could collaborate to develop backpacks that distribute weight more evenly and minimize strain on the body. Additionally, promoting regular breaks and exercises to relieve stress on muscles and joints while carrying backpacks could further enhance students' overall well-being.

Keywords: Backpack Weight · Nordic Musculoskeletal Questionnaire · Musculoskeletal Disorders

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1 Introduction

Students of all ages regularly engage in the risky behavior of carrying heavy backpacks, which has been linked to the development of musculoskeletal pain. Musculoskeletal pain is the discomfort felt in the joints, tendons, ligaments, and muscles and has several potential causes, such as improper body alignment, overexertion, and stress.

Backpack-carrying students have been the focus of considerable research examining the incidence of musculoskeletal pain. According to a study by Sen and Singh [1], 73.33% of collegiate students claimed it was from lifting backpacks when asked about musculoskeletal pain. Higher rates of pain, especially in the lower back and shoulders, were also observed among students who carried heavy loads. Another study by Perrone et al. [2] indicated that 71% of high school students carrying backpacks daily experienced musculoskeletal pain. It also showed that having a backpack that weighs more than 10% of a person's body weight significantly increases that person's likelihood of experiencing pain. These findings suggest that students' everyday activities, academic performance, and quality of life can all be negatively impacted by musculoskeletal pain associated with carrying backpacks.

Despite the growing concern about the potential negative impact of backpack weight on musculoskeletal health, there remains a gap in the literature on the specific factors contributing to musculoskeletal pain development in college students who regularly carry backpacks. While previous research has examined the relationship between backpack weight and musculoskeletal pain, few studies have explored the impact of other variables, such as age, weight, physical activity level, and backpack-carrying method, on the risk of developing musculoskeletal pain. This study aims to address this research gap by providing a comprehensive analysis of the potential factors that may contribute to the development of musculoskeletal pain in students who carry backpacks. With this, the following are the aims of this study: First, to describe the distinctive characteristics of the backpacks that college students use, to explain the self-reported pain associated with backpack usage, and lastly, to assess the association between self-reported pain and frequency of backpack use, perceived backpack weight, duration of backpack use, and method of wearing a backpack.

2 Methodology

This framework indicates that the independent variables, such as backpack weight, frequency of backpack use, duration of backpack use, and backpack carrying method, may significantly impact the presence, location, and frequency of musculoskeletal pain reported by the participants using Nordic Musculoskeletal Questionnaire. Additionally, demographic variables such as age, height, and weight, as well as the level of physical activity, may also be important factors to consider in the analysis. The chi-square test was used to determine if there was a significant association between the independent variables and the dependent variables. The analysis output has identified the variables that have a statistically significant association with musculoskeletal pain (Fig. 1).

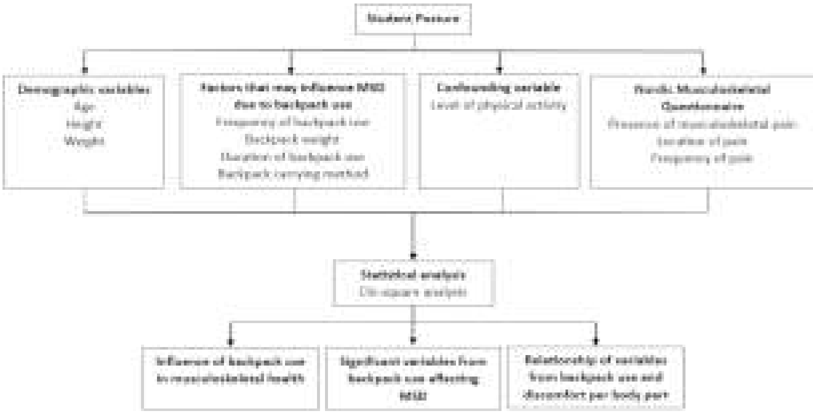

Fig. 1. Framework of the study

3 Results

The results showed that the majority of the respondents have a normal BMI (56%), and most of them use backpacks every day (46%) and several times a day (32%). Additionally, most of the weight of the bag they carry is 1 to less than 3 kgs (54%) and 3 to less than 5 kgs (27%) with a duration of 2–3 h (27%) and more than 3 h (33%). For the methods of carrying the bag, 6% carry by hand, 25% on one shoulder, and 69% on both shoulders. Lastly, the respondents' level of physical activity are low (e.g., light walking, light household chores) with 50%, moderate activity (e.g., brisk walking, gardening, cycling) with 25%, sedentary (little to no physical activity) with 15%, and high activity (e.g., running, high-intensity interval training, weightlifting) with 9%.

The Nordic Musculoskeletal Questionnaire shows the prevalence of MSD per body part for the past 12 months and the past seven days. The results revealed that for the past 12 months, the highest prevalence was lower back (59%), followed by the upper back (55%) and the shoulders (51%). While for the past seven days, the highest prevalence was also the lower back (48%), followed by the upper back (40%) and shoulders (36%).

Based on the results of a survey on the prevalence of musculoskeletal pain or discomfort among students who regularly carry a backpack, it can be seen that lower back pain or discomfort is the most prevalent complaint, reported by 59% of the respondents. This is followed by upper back pain or discomfort at 55%, shoulder pain or discomfort at 51%, and neck pain or discomfort at 44%.

For the musculoskeletal pain or discomfort experienced by students during the last 7 days, the results shows that 48% of the students reported lower back pain or discomfort, 40% for upper back, 36% for shoulders, and 31% for neck pain or discomfort. These results indicate that carrying a backpack regularly can cause pain or discomfort in different body areas, and it is not limited to the back alone.

The chi-square test was utilized to determine the association between the demographic and risk factors (BMI, frequency of carrying, weight of carrying the bag, duration of carrying the bag, method of carrying, and level of activity) to the MSD symptoms reported by the college students. The chi-square test revealed that factors that have a significant association with MSD symptoms reported by the respondents are frequency of carrying ($\chi 2 = 19.79$, $p < 0.001$), weight of carrying the bag ($\chi 2 = 11.51$, $p = 0.003$), duration of carrying the bag ($\chi 2 = 14.89$, $p = 0.002$), and method of carrying ($\chi 2 = 10.89$, $p = 0.004$). The results are shown in Table 1.

Table 1. Association of Risk Factors with MSD

Category	Subcategory	College students with reported MSD							
		Yes		No		Total		χ2	p-value
		N	%	N	%	N	%		
BMI	Underweight	14	18	5	18	19	18	3.418	0.322
	Normal	41	52	19	68	60	56		
	Overweight	17	22	2	7	19	18		
	Obese	7	9	2	7	9	8		
Frequency of carrying	Never	2	3	4	14	6	6	19.79	< 0.001*
	Rarely	17	22	1	4	18	17		
	Everyday	29	37	20	71	49	46		
	Several Times per day	31	39	3	11	34	32		
Weight of carrying bag	Less than 1 kg	10	13	10	36	20	19	11.51	0.003*
	1 to less than 3 kgs	42	53	16	57	58	54		
	3 to less than 5 kgs	27	34	2	7	29	27		
Duration of carrying bag	Less than 1 h	10	13	12	43	22	21	14.89	0.002*
	1–2 h	14	18	7	25	21	20		
	2–3 h	24	30	5	18	29	27		
	More than 3 h	31	39	4	14	35	33		
Method of carrying	Carried by hand	2	3	4	14	6	6	10.89	0.004*
	On one shoulder	16	20	11	39	27	25		
	Across both shoulder	61	77	13	46	74	69		
activity Level of	Sedentary	9	11	7	25	16	15	4.04	0.258
	Low Activity	41	52	13	46	54	50		
	Moderate Activity	20	25	7	25	27	25		
	High Activity	9	11	1	4	10	9		

* *p-value is significant at ≤ 0.01*

4 Discussion

Numerous studies have investigated how using a backpack affects musculoskeletal health. For instance, a study conducted by Chow et al. [3] discovered that students who wore backpacks weighing more than 10% of their body weight were more likely to have pain in their musculoskeletal systems than those who carried lighter backpacks. According to another research by Dockrell et al. [4], wearing a backpack improperly—on one shoulder, for example—or using a poorly designed backpack—can cause a curvature of the spine and raise your chance of developing musculoskeletal illnesses. According to the present study, the amount of time and weight carried by the respondents' backpacks significantly correlated with discomfort in their backs and other body parts. Increased strain is caused by increased backpack weight [5].

Regarding musculoskeletal balance, good posture is thought to include minor tension and strain on the body. Even though good posture is preferred, many people fail to exhibit it. According to Sen and Singh [1], prolonged static stress of the cervical spine and shoulder girdle during work or recreational activities is often the cause of postural neck discomfort. College students have a significant load on their spine when carrying a backpack. Recent studies have focused on college students' backpacks and their role in developing musculoskeletal pain [6, 7]. Reducing backpack weight has been proposed as one prevention strategy to reduce hiking-related injuries [8]. Previous research has suggested that the maximum load for healthy adult males should not exceed 30% of their body weight.

In the present study, Table 3 demonstrates the association of risk factors of college students with reported MSD. The results show that out of the six variables presented, the frequency of carrying (<0.001), the weight of carrying the bag (0.003), the duration of carrying the bag (0.002), and the method of carrying (0.004) are statistically significant because the computed p-value is < 0.05. Furthermore, the results also show a significant association in affecting musculoskeletal disorders (MSDs). On the other hand, the variables BMI (0.322) and level of activity (0.258) are not considered significant since the computed values exceeded the p-value level and have little to no effect on MSD.

This study proves that the risk factor with the most prominent effect on the prevalence of MSD in college students is the carrying frequency. Carrying a large bag around all day can be uncomfortable and downright painful for the shoulders, neck, and back muscles. According to Kadota [9], high rates of MSDs were found in all evaluated body parts, and there was some evidence to suggest that back pain and accompanying disability are related to multiple indicators of load-carrying, including duration, frequency, and weight. Moreover, the weight, duration, and method of carrying bags also contributed to the effects of MSD on college students.

Additionally, from the data presented in Table 3, the highest significant association out of all significant variables is the frequency of carrying bag with a p-value of less than 0.001. One possible explanation for why the frequency of carrying a backpack has the strongest association with MSD is that the cumulative mechanical load on the musculoskeletal system increases with the frequency of carrying a backpack, which can contribute to overuse injuries and pain. In addition, the frequency of backpack use may indicate a person's lifestyle or profession, which may be associated with increased physical activity or specific postures that may contribute to the development of MSD.

Therefore, the frequency of carrying a backpack may be a significant factor in developing MSD and should be considered when designing interventions to prevent or manage these conditions.

Several possible reasons have been proposed for the strong association between the frequency of carrying a backpack and musculoskeletal pain. One possible explanation is that carrying a backpack frequently can accumulate load on the spine and muscles, resulting in fatigue and pain. Additionally, frequent carrying of a heavy backpack can cause changes in posture and gait, leading to compensatory movements that may result in musculoskeletal pain. Finally, carrying a backpack frequently may lead to chronic musculoskeletal pain by causing microtrauma to the tissues, which can accumulate over time.

In conclusion, the strong association between the frequency of carrying a backpack and musculoskeletal pain in school-aged children and adolescents can be attributed to the accumulation of load on the spine and muscles, changes in posture and gait, and the development of chronic musculoskeletal pain due to microtrauma. These findings highlight the importance of minimizing the frequency and weight of backpacks carried by schoolchildren and adolescents to prevent the development of musculoskeletal pain.

5 Conclusion

The primary objective of the present study was to examine the association between musculoskeletal pain brought on by carrying a backpack and the physiological risk factors common among college students. Several factors, including body mass index, backpack use, backpack weight, backpack duration, backpack carry method, and activity level, have been linked to musculoskeletal pain. Back, neck, and shoulder pain are common complaints of those who carry heavy backpacks for long distances or who do it incorrectly. A lack of exercise, bad posture, and other lifestyle issues can all make this worse. Musculoskeletal pain can also be caused by the actual weight of the backpack and how it is carried.

In conclusion, the study found that carrying a backpack regularly can lead to musculoskeletal pain or discomfort, with the lower back, upper back, shoulders, and neck being the most commonly affected areas. These findings are important as they highlight the specific body areas most affected by carrying a backpack. The high prevalence of pain or discomfort in the lower back, upper back, shoulders, and neck underscores the need for interventions specifically targeting these areas. The findings also suggest that reducing the weight of backpacks may be crucial in preventing musculoskeletal pain or discomfort among students.

The prevention and treatment of musculoskeletal pain require an integrative strategy. Carrying a backpack correctly and exercising regularly to build muscles and prevent damage is crucial to fighting against and relieving pain. Muscle tension and pain can be reduced by taking frequent pauses from sitting or standing and wearing a heavy backpack. Physical therapists and chiropractors are two examples of medical professionals who can advise patients on avoiding and dealing with musculoskeletal discomfort. A person's chance of acquiring musculoskeletal pain can be decreased, and their quality of life can be enhanced if they take preventative measures to maintain a healthy lifestyle and avoid injury.

Further research can be conducted to investigate the effectiveness of different interventions to prevent and manage musculoskeletal pain or discomfort among students. For instance, future studies may compare the effectiveness of different backpack designs or carrying methods, such as rolling backpacks or carrying backpacks on one shoulder, in reducing pain or discomfort. Additionally, research can be conducted to explore the long-term effects of carrying heavy backpacks on musculoskeletal health.

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Prevalence of Musculoskeletal Disorders Among Seamstresses Workers: A Rapid Upper Limb Assessment

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Abstract. Musculoskeletal disorders (MSD) are a common occupational health problem, especially among labor workers who perform physically demanding tasks. Musculoskeletal diseases can be caused by several situations, including improper positioning of workers. With this, to determine the prevalence of musculoskeletal disorders among the 30 Two Angels' seamstresses, the REBA method was utilized by identifying the most awkward position of seamstresses and assessing the risk of musculoskeletal disorders. Subsequently, the researchers used the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) to further evaluate the pain and discomfort in various areas of the seamstresses' bodies. Additionally, correlation analysis was used to determine the relationship of body posture to the prevalence of MSD. The results showed that most of the the respondents' posture exposes them to a high to very high risk of musculoskeletal disorders, indicating the need for immediate changes in the practices. It was also found that the knee area experiences the most discomfort during tasks. However, it was found that all body postures only had minimal significance on the prevalence of MSD. With the results, it is recommended to reduce the awkward postures by implementing proper workstations, training of proper work practices, provision of proper tools, and regular rotations.

Keywords: Musculoskeletal disorders · body posture · REBA method · Cornell Musculoskeletal Discomfort Questionnaire

1 Introduction

Musculoskeletal diseases can be caused by several situations, including improper positioning of workers, an excessive number of jobs, and the use of equipment that is not ergonomically designed. According to the National Library of Medicine [1], musculoskeletal disorders are diverse conditions affecting bones, joints, muscles, and connective tissues; they can cause pain and loss of function and are among the most expensive

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and disabling conditions in the United States. Musculoskeletal disorders (MSD) are a common occupational health problem, especially among labor workers who perform physically demanding tasks [2].

Two Angels is a tailoring business founded in May 2018 in Baliuag, Bulacan. The school is the sewing company's target market, specializing in school uniforms such as polo blouses, skirts, and pants. Twelve employees of the Two Angels company range in age from 18 to 58. Typically, the business operates Monday through Saturday; however, if there is a rush order, they also operate on Sundays. Usually, sewists work six to eight hours daily, but when there is a rush order, they work eight to nine hours daily.

A seamstress is one of the occupations regarded to have a high risk of developing a musculoskeletal disorder, given that they typically sit for six to nine hours with limited break time [3]. This study's primary objective is to determine the prevalence of musculoskeletal disorder among Two Angels' employees and to identify ways to reduce the likelihood that they will develop MST disorder.

In spite of the rising number of studies on the evaluation of musculoskeletal diseases (MSDs) in a variety of occupational groups, there needs to be more research about the application of the Rapid Entire Assessment method specifically for the evaluation of MSDs among seamstresses. There has been research that has investigated the prevalence of work-related musculoskeletal disorders (MSDs) among seamstresses as well as the risk factors associated with these disorders; however, very few of these studies have utilized the REBA method, which is a tool that is extensively used for the ergonomic assessment of work-related MSDs [4]. Therefore, there is a need for additional research to investigate the efficacy of REBA in assessing MSDs among seamstresses and to identify potential interventions to prevent and manage these disorders in this population. Musculoskeletal disorders are a potential problem for seamstresses because their profession sometimes requires them to be in awkward positions [5]. These conditions are brought on by actions that are carried out repeatedly, postures that are maintained for extended periods, and movements that are awkward and put a strain on the muscles, tendons, ligaments, and nerves [6].

This study aims to understand better the factors that put employees of Two Angels at risk for musculoskeletal disorders. Specifically, this study aims to determine the prevalence of musculoskeletal disorders, identify the relationship between body posture and the prevalence of musculoskeletal disorders; and provide the solution in minimizing the risk of developing MST disorder among seamstresses.

2 Methodology

2.1 Conceptual Framework

Musculoskeletal diseases can be caused by several situations, including improper positioning of workers, an excessive number of jobs, and the use of equipment that is not ergonomically designed. According to the National Library of Medicine [1], musculoskeletal disorders are diverse conditions affecting bones, joints, muscles, and connective tissues; they can cause pain and loss of function and are among the most expensive and disabling conditions in the United States. Musculoskeletal disorders (MSD) are a common occupational health problem, especially among labor workers who perform physically demanding tasks [7] (Fig. 1).

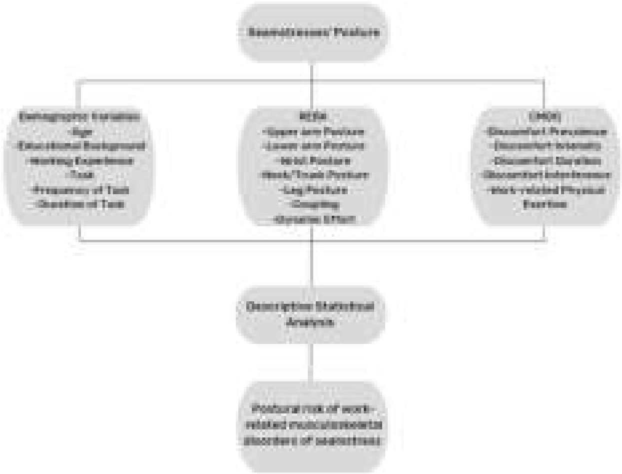

Fig. 1. Framework of the Study

The framework indicates that the independent variables, such as neck, trunk, leg, upper arm, lower arm, and wrist score measured by REBA method may significantly impact the CMDQ score that allows to identify the discomfort of the respondents when performing tasks. Moreover, demographic variables, such as age, educational background, working experience, tasks, frequency of tasks, and duration of tasks, may also be important factors to consider in the analysis. The descriptive statistical analysis was used to provide a clear and concise understanding of the data and allows for more accurate interpretations. With this, through correlation analysis, the output has identified that all body postures had a minimal significance on the prevalence of musculoskeletal disorders.

2.2 Respondents of the Study

This study's respondents are seamstresses from Two Angels, a tailoring enterprise located in Baliuag, Bulacan. The researchers collected information from thirty (30) seamstresses within the organization. The youngest seamstress is 18 years old, while the eldest is 58 years old. Most respondents are already in their forties and fifties.

2.3 Ergonomic Tools

The researchers used Rapid Entire Body Assessment (REBA) method and Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) to achieve this study's objectives. The Rapid Entire Body Assessment (REBA method) utilizes a systematic procedure to analyze the risks of musculoskeletal disorders to the entire body and ergonomic design risks related to work [4]. Researchers determined the most awkward position of seamstresses and assessed the risk of musculoskeletal disorders using the REBA method. After applying the REBA method to each seamstress, the researchers used the CMDQ to further evaluate the pain and discomfort in various areas of the seamstresses' bodies.

2.4 Statistical Treatment of Data

Descriptive statistical analysis was used to summarize and describe the characteristics of the collected data, which measured its central tendency, dispersion, and graphical representation. This allowed to compare the average scores of CMDQ and REBA to different body parts, which the demographics of the respondents were also included. Moreover, correlation analysis was also used to measure the strength and direction of the relationship between body posture and the prevalence of musculoskeletal disorders.

3 Results and Discussion

To evaluate the postures of the respondents in performing their tasks, the RULA method was utilized. As shown in Table 1, most of the respondents gained a REBA Score of 11+, which implies that the level of risk of having musculoskeletal disorders is very high. All respondents are categorized as being at a high to a very high level of risk of developing musculoskeletal disorders, with 1 respondent at a medium risk and 9 with a very high risk. None of the respondents are in the range of negligible to low risk, which signifies that all seamstresses are practicing poor postures during the operation. The RULA results show that immediate change should be implemented to correct the posture.

Table 1. Result of RULA.

Score	Level of Risk	Number	Percent (%)
1	Negligible risk	0	0
2–3	Low risk	0	0
4–7	Medium risk	0	0
8–10	High risk	3	10
≥11	Very high risk	27	90

To evaluate the postures of the respondents in performing their tasks, the RULA method was utilized. As shown in Table 1, most of the respondents gained a REBA Score of greater than 11, which implies that the level of risk of having musculoskeletal disorders is very high. All respondents are categorized as being at a high to a very high level of risk of developing musculoskeletal disorders, with 1 respondent at a medium risk and 9 with a very high risk. None of the respondents are in the range of negligible to low risk, which signifies that all seamstresses are practicing poor postures during the

Table 2. Average CMDQ Scores per Body Part.

Body Part	Average CMDQ Score	Percentage of Risk (%)	Cum. Percent (%)
Neck	4.15	6.81	6.81
Shoulder	6.95	11.41	18.22
Upper Back	2.1	3.45	21.67
Upper Arm	0.3	0.49	22.16
Lower Back	9.8	16.09	38.25
Forearm	2.6	4.27	42.52
Wrist	2.7	4.43	46.95
Hip/Buttocks	9.45	15.52	62.47
Thigh	4.6	7.55	70.02
Knee	10	16.42	86.44
Lower Leg	7.55	12.40	98.84
Foot	0.7	1.15	99.99

operation. The RULA results show that immediate change should be implemented to correct the posture.

Based on the CMDQ score results shown in Table 2, the knee score garnered the highest average CMDQ score of 10, indicating that this is the body region where respondents experience the most severe discomfort when performing tasks and the highest prevalence of MSD. It is followed by the lower back, hip/buttocks, lower leg, and shoulders with scores of 9.8, 9.45, 7.55, and 6.95, respectively. This is due to the prolonged sitting posture of the seamstress while continuously stepping on the treadle. On the other hand, the upper arm and foot are the least affected body areas, having a CMDQ score of 0.3 and 0.7.

Table 3. Correlation of REBA Scores per Body Part and CMDQ Scores.

REBA Score	Correlation Coefficient	Number
Neck Score	0.2537	Very weak positive
Trunk Score	0.1243	Very weak positive
Leg Score	−0.5043	Weak negative
Upper Arm Score	0.0269	Very weak positive
Lower Arm Score	0.2878	Very weak positive
Wrist Score	−0.0226	Very weak positive

To determine the relationship between body posture and the prevalence of musculoskeletal disorders, a correlation analysis was utilized between the REBA scores per body part and CMDQ scores. The data gathered, as presented in Table 3, shows that all REBA scores are in the range of a weak to very weak relationship with the CMDQ scores. This signifies that the body posture only has minimal significance on the discomfort of the respondents when performing tasks. Based on the results, the REBA leg score has the highest significance with a weak negative relationship. This indicates that the more awkward the leg posture is, the lower the level of discomfort is. This could imply that there are other risk factors affecting the prevalence of MSD. On the other hand, the REBA wrist score has the least significance with a very weak positive relationship. This suggests that a lower wrist score contributes to higher discomfort but only minimal.

4 Conclusion

To determine the prevalence of musculoskeletal disorders among seamstresses, the most awkward posture of 30 seamstresses from Two Angels was recorded and examined using the REBA method. Through this ergonomic tool, it was found from the results that the majority of the respondents' posture exposes them to a high to very high risk of musculoskeletal disorders. None of the respondents were free from risk, which indicates the need to implement immediate changes to the posture and other factors that cause the high risk of musculoskeletal disorders. Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was also utilized in order to identify the most affected body regions. The results show that the respondents feel the most discomfort in the knee area, with a 16.42% risk. Other highly exposed body areas to musculoskeletal disorders are the following: lower back (16.09%), hip/buttocks (15.52%), lower leg (12.40%), and shoulders (11.41%).

Correlation analysis was then utilized to identify the relationship between body posture and the prevalence of musculoskeletal disorders. It was found that leg posture had the most significance on the level of discomfort. It had a weak negative correlation, which indicates an inverse relationship. On the other hand, wrist posture was found to be the least significant in the prevalence of musculoskeletal disorders. However, overall, all body postures had minimal significance on the prevalence of musculoskeletal disorders.

5 Recommendation

Musculoskeletal disorders (MSDs) are a common health concern among seamstresses due to the repetitive and physically demanding nature of their work. Therefore, the study recommends proper ergonomic workstations that should be designed to promote good posture and reduce awkward body positions. This includes providing adjustable chairs, footrests, and work surfaces at an appropriate height. Also, encourage frequent breaks to rest and stretch their muscles. This will help the seamstresses to prevent fatigue and reduce the risk of developing MSDs. The company should provide training on seamstresses on safe work practices, including proper lifting techniques, posture, and stretching exercises, which may help to promote awareness of the risks associated with their work and provide them with the tools to minimize those risks. Moreover, it is recommended to use specialized tools and equipment that can help to reduce the physical strain associated with sewing. Lastly, regularly rotating seamstresses between different tasks can help to reduce the risk of developing MSDs by reducing repetitive motions and allowing for different muscle groups to be used. By implementing these measures, it is possible to prevent MSDs among seamstresses and promote a healthy and safe work environment. A study could be conducted to assess the effectiveness of these recommendations and identify any additional measures that may be necessary to prevent MSDs in this population.

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Development of Ergonomic Workstation to Reduce Musculoskeletal Disorders (MSDs) of Filipino Tattoo Artists: A Study Exploring Improved Posture and Health

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Abstract. The Philippines has a rich culture of tattooing dating back to pre-colonial times when warriors were tattooed for their courage and bravery. As the years go by, tattoos are seen as taboo and are associated with criminality of one's mindset. Breaking the stigma, today's modern tattoo industry has been booming for the past few years as tattooing has become more acceptable, especially among the younger generations. The growing industry of tattoo artistry in the Philippines stresses different postural challenges and musculoskeletal disorders. The researchers' methodology used is as follows: (1) survey questionnaires (2) Nordic Musculoskeletal Disorder Questionnaire (NMQ) (3) postural observation. Moreover, utilizing a goniometer for Rapid Entire Body Assessment (REBA) has been used to quantify the risk of MSDs among tattoo artists. Among the survey participants, the most affected areas were 70% lower back, 66% neck, and 60% wrist and a total REBA score of 7–10. This indicates that tattoo artists are at high risk and need action. This study focuses on providing a more efficient workstation layout to help the artists create a smoother and more organized workspace. The proposed layout is developed with the consideration of comfortability, client positioning, lighting, and tool setup.

Keywords: Rapid Entire Body Assessment · Musculoskeletal Disorders · Tattoo · Ergonomics

1 Introduction

The Philippines has a rich history of tattooing, dating back to pre-colonial times. Despite the stigma, the modern tattoo industry has been booming, especially among the younger generations. However, Filipino tattoo artists are facing increasing musculoskeletal disorders due to awkward postures and lack of ergonomic support (Keester & Sommerich

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2017). Tattoo artists are at high risk of developing Musculoskeletal Disorders (MSDs) due to the nature of artists' work. Musculoskeletal problems associated with the workplace can cause significant losses for the organization in terms of lost productivity, hiring new employees training costs, benefits expenditures, etc. (Anandakumar et al. 2021) When building a workspace to offer a comfortable working environment, ergonomic study is essential.

The objective of this study is to design a more efficient workstation layout for Filipino Tattoo artists based on the analysis of MSDs. Moreover, the researchers aim to identify and evaluate the ergonomic risks related to tattooing including identifying the common postural patterns when doing different tattooing techniques and the specific body regions that are highly affected. According to Rentech Digital (2024), there are a total of 2174 registered tattoo shops in the Philippines which is where the researchers will get the sample size. Moreover, as the proposed work layout was based on the tattoo shop residing in Muntinlupa City, it may not be possible for other shops. Nonetheless, the workstation may still be applicable to all types of shops in the Philippines. However, financial analysis for the proposed solution will not be included in this study.

2 Review of Related Literature

Despite tattooing is physically demanding, it provides many people with a distinctive and fulfilling career path. For the researchers to come up with fact-based research, this study uses the Rapid Entire Body Assessment (REBA) to give quantitative data on the level of risk to tattoo artists in terms of their working environment. The Rapid Entire Body Assessment (REBA) tool uses a systematic process to assess both upper and lower parts of the musculoskeletal system. It will be very useful for this research to identify those parts of the musculoskeletal that have a high chance of getting a disorder (Ergoplus 2012). Moreover, REBA is a convenient assessment scale to assess posture of jobs in several occupational settings, including industrial and health care jobs, construction, sawmill tasks, supermarket industries, school workshops, odonatological services and for firefighters and emergency medical technicians (Karelia BJ, et al. 2021).

There are prevalent occupational risks and ergonomic challenges faced by tattoo artists which affect their postures over the years of practicing the profession. Tattoo artists have a higher risk of Musculoskeletal pain than an average office worker (Weisman 2022). In their study entitled "Tattoo Artist and Dental Worker have similar musculoskeletal pain" they indicated that they used the extended version of the Nordic Musculoskeletal Questionnaire (NMQ) to assess the pain that the survey participants felt. Most of the tattoo artist respondents' pain sites are on their lower back, neck, and hand.

Tattoo artists are more prone to musculoskeletal disorder (MSDs) due to their repetitive movements, forced postures and awkward postures (Santos 2022). Ergonomically designed furniture and regular breaks may prevent body strain (Ozcan 2023). Evaluating the risk on various body parts with the use of Rapid Entire Body Assessment (REBA) identifies ways on how to improve the artist's posture. The study focuses on spreading awareness and developing an ergonomic workstation to prevent musculoskeletal disorder for tattoo artists in the Philippines so they can have a more conducive work environment.

3 Methodology

This research study concentrates on an ergonomically designed workstation for tattoo artists in the Philippines, using observation, anthropometry, and ergonomic evaluation methods. The researchers observed 4 tattoo artists from a registered shop in Muntinlupa City and surveyed 338 tattoo shops nationwide. A stratified random sampling was utilized to determine the sample size with a 5% margin of error. This study used a survey questionnaire to collect primary data, including demographic information and work history (Fig. 1).

Fig. 1. Conceptual Framework of the study

The Nordic Musculoskeletal Questionnaire (NMQ) was utilized to review work-related musculoskeletal conditions in Filipino tattoo artists. The postural evaluation was performed with the use of a goniometer sensor and the PASCO Capstone software program. Rapid Entire Body Assessment (REBA) is utilized to assess the risk of developing work-related musculoskeletal disorders. The data collected was carefully analyzed to establish an ideal layout of a workstation for Filipino tattoo artists. The study follows the Declaration of Helsinki's ethical principles, with participants given a free withdrawal policy.

4 Results and Discussion

4.1 Interpretation of Data

Based on the survey results, back and neck pain is the most demanding suffering of the tattoo artists. Considering its prominence in the graph, it is critical to give corrective actions and interventions top priority to lessen artists' suffering. Hence, this will be vital in the proposed solution for the MSDs of tattoo artists (Fig. 2).

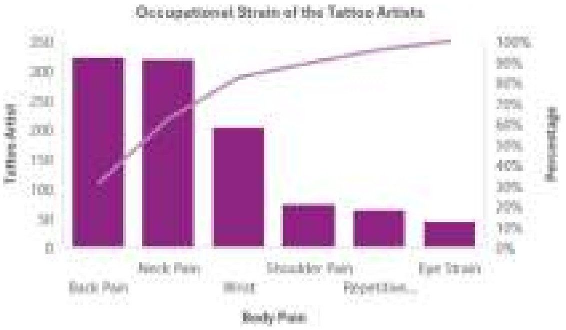

Fig. 2. Pareto Chart for Distribution of Occupational Strain experienced by the Tattoo Artists

Filipino tattoo artists are at risk of musculoskeletal disorders due to inefficient workstation setups. Based on the Ishikawa diagram that was utilized to know the causes of the MSDs among tattoo artists, factors like uncomfortable chairs, inappropriate table height, and inadequate lighting can strain the artist's musculoskeletal system, leading to discomfort and potential injury. Improper posture, inadequate training, and fatigue also contribute to these issues. Proper training and ergonomic principles are crucial. Extreme temperatures and limited workspace size can worsen existing issues. Implementing an efficient workstation could improve artists' health and work quality (Fig. 3).

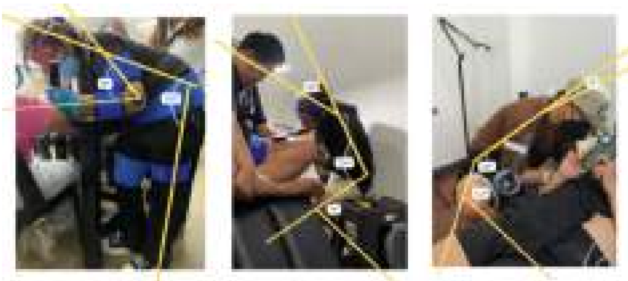

Fig. 3. Postures of Observed Tattoo Artists

Based on the results of NMQ, the neck, lower back and wrist have the highest median of 5 MSDs scores among all the body parts while the upper back, and shoulder remain at the median 4, and 3 respectively, which is shown in Fig. 4. These show that more tattoo artists feel severe to the worst possible pain in their neck, lower back, and wrist after 12 months of tattooing. Having a high level of pain on these parts can put some tattoo artists at risk of getting Musculoskeletal Disorders.

There was a total of 4 observed tattoo artists, the observation started from the preparation of the materials up until the finishing of the tattoo. With the final REBA scores ranging from 7 to 10 it was observed that the postures of the artists are at a high-risk category in which musculoskeletal disorder may be prevalent.

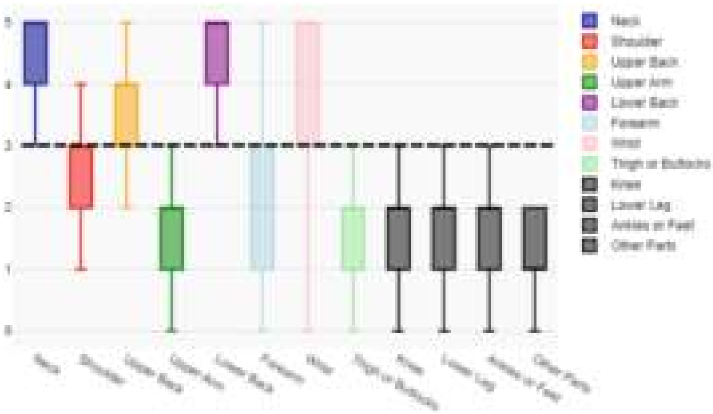

Fig. 4. Box Plot of Nordic Musculoskeletal Assessment after 12 months

4.2 Proposed Workstation for the Filipino Tattoo Artists

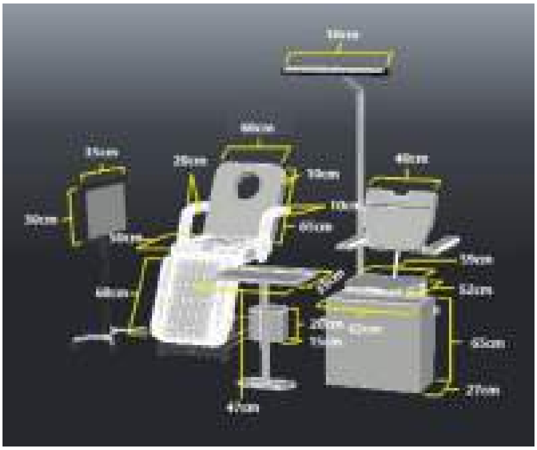

Fig. 5. Measurement of Proposed Ergonomic Workstation for Tattoo Artist

The researchers presented 3 different workstations and layouts and found this design to be the most favorable option based on the criteria weighting system that included factors like performance, reliability, durability, and convenience. Furthermore, the researchers use materials such as stainless steel, memory foam, and wood for the workstation, and based on the expected efficiency of the proposed solution the anticipated result of the REBA score would be 2 for the preparation of materials and stencil, REBA score during the tattooing is expected to be 3 and lastly the REBA score for the finishing is expected to be 3. The low scores signify a substantial reduction of risk compared to the previous score of 7, 10, and 9 accordingly (Fig. 5).

5 Conclusion

The researchers explored different methods to address the current problem of the tattoo industry in the Philippines which is the prevention and awareness of musculoskeletal disorders. Filipino tattoo artists make significant contributions to Philippine artistic talent. However, their work environment frequently causes musculoskeletal disorders (MSDs). This study includes data regarding the prevalence of MSDs among tattoo artists in the Philippines, specifically the lower back, neck, and wrists. Awkward postures sustained over time and a lack of ergonomic support cause these problems among tattoo artists. An ergonomically designed workstation may ensure the reduction of musculoskeletal disorders (MSDs) among Filipino tattoo artists. Major components of this workstation include adjustability to individual needs, client support, proper task lighting, and easy-reach tool organization. This proposed workstation presents the safety and comfort of tattoo artists without compromising their creativity or the quality of their work.

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Maximum Acceptable Weight of Lift Among Thai Youth Age Group Between 18–24 Years Old Using Psychophysical Approach

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Abstract. Manual material handling (MMH) is the most common cause of occupational fatigue and low back pain. This study aimed to determine the maximum acceptable weight of lift (MAWL) and rating of perceived exertion (RPE) among young workers using the psychophysical approach. Sixty healthy Thai youth aged 18–24 years old performed at five different lifting frequencies (1, 2, 4, 6, and 12 lifts/min) in the sagittal plane as followed the NIOSH lifting technique. The results indicated that the MAWL at five different lifting frequencies (12, 6, 4, 2, and 1 lifts/min) were 2.0, 2.29, 3.00, 4.50, and 5.50 Kilograms, respectively. The RPE of participants with 12 lifts/min of lifting frequency revealed that men and women had the highest means of RPE at 5.63 and 5.17, respectively. The reference mass of this study can be used as a guide to safe manual handling at work.

Keyword: Psychophysics · Thai youth · Manual material handling

1 Introduction

The manual material handling or MMH (lifting-lowering, pushing pulling, and carrying by a person) is one of the ergonomics risk factors and can develop to musculoskeletal disorders (MSDs) that affected to muscle and tendons pain on body such as hands, wrists, arms, shoulders and especially lower-back. Main cause of this problem are improper lifting postures, prolonged, and repetitive lifting. Health and Safety Executive [1] reported

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that 473,000 workers suffered from work-related MSDs in 2022/23, resulting in 6.6 million working days lost due to work-related MSDs. Manual material-handling tasks were the main cause and heavy lifting was the main attributed task of work-related MSDs. The report found that the highest prevalence of MSDs was back and upper limbs or neck area, accounting for 41% of back and upper limbs and 17% of lower limbs. Furthermore, the report identified that workers in industries administrative and support service activities, construction, and human health and social work activities were particularly prone to MSDs. The Workmen's Compensation Fund in Thailand for the years 2018 to 2022, it was reported that the primary disease resulting from work characteristics, work conditions, or occupation is work related-MSDs. During 2018–2022, 4,760 workers experienced work-related-MSDs, with 1.13% per year, 68.69% of cases resulted in absences from work for less than 3 days, followed by 29.51%of cases that led to absences from work for more than 3 days. The age group most affected by MSDs from 2018 to 2022 was individuals aged 25 to 29 years old, followed by 20 to 24 years old because of lacking experience and poor lifting technique. Furthermore, young workers have significantly higher rates of work-related injuries than older workers. According to the latest European data, the incidence of non-fatal workplace injuries is 40 percent higher among youth workers aged 18 to 24 than among adult workers [2]. Nevertheless, this age group does not have legal recognition or protection by the law like workers under 18 years old.

Lifting and moving heavy objects are required force exerted of worker who might be use over physical ability and expose other risk factors which are potential to cause to injury in the same time [3]. If workers must work in inappropriate conditions for a long time, it can affect body functions and lead to injury and fatigue [4]. According to the studies [5] recommend that the maximum acceptable weight of lifting should not exceed 23 kg, and the weight must be reduced when other risk factors are involved such as vertical heigh, horizontal distance, lifting posture, frequency, duration and gripping quality. This scenario may cause the maximum acceptable weight of lifting is only 4–5 kg. In 2004, Thailand has issued a Minitrial Regulation Prescribing Weight for Employees to perform as Employer Required which defined the maximum weight limit of lifting at 55 kg for males and 25 kg for females regardless of other risk factors that might cause injury when workers perform lifting and moving the objects.

For this reason, Thailand must study the maximum acceptable wight of lift among young workers. This study aimed to determine the maximum acceptable weight of lift (MAWL) and determine the rating of perceived exertion (RPE) for five different lifting frequencies among Thai youth age group between 18–24 years using the psychophysical approach. The findings of this study will be used as a guideline for lifting tasks with physical exertion and as a guide for improving the ministerial regulation on determining and improving the rate of weightlifting in Thailand.

2 Methodology

2.1 Psychophysical Approach

To determine the maximum acceptable weight of lift in this study, the psychophysical approach was applied. Previous studies [6, 7] applied psychophysical approach to find the MAWLs in manual material handling tasks. It was considered that these values were perceived from the sensation of the musculoskeletal and cardiovascular systems as a whole [8]. Determining the maximum acceptable weight of lift for safe is based on the percentage of population acceptance, at least 75% of the female group, not less than 99% of male, and 90% of all workers' acceptation which the population consist of 50% male and 50% female [9].

2.2 Participants

Sixty healthy participants of this study were male and female with the average of 20.59 ± 1.33 and 20.63 ± 1.45 years old, respectively. They did not have congenital disease and neurological and musculoskeletal abnormality. The participants signed an informed consent before study participation. The participants were interviewed the readiness of the subjects to do the physical activity followed by PAR-Q+2019 Thai version (Physical Activity Readiness Questionnaire) and measured resting heart rate and blood pressure before experimenting. In addition, the participants were instructed to do the physical fitness test, including leg dynamometer test, arm lift test, and handgrip – endurance test. The research protocol was approved by the Human Research Ethics Committee of Thammasat University (Science) (code: 66PU037).

2.3 Experimental Design and Equipment

This study conducted a psychophysical approach to study reference mass considered for determining the recommended weight limit in manual lifting of one person among Thai youth (18–24 years old). The workstation used in the lifting test could be adjusted following the height of the subjects to avoid stoop posture while lifting. The horizontal distance and the handle level were according to NIOSH recommendations and based on ISO 11228, Ergonomics-Manual Handling-Part 1(2003).

The container was plastic (25 × 33 × 14 cm.). Inside the basket contained metal pellets in bags of 0.5 kg per bag. In experiment, there was a predetermined frequency to be a signal for lift. The work characteristic was only lifting from the lifting point (origin) to the lower point (destination). Five different lifting frequencies (1, 2, 4, 6, and 12 lifts/min) were investigated. Each participant performed lifting for all five experimental conditions in a random sequence. The participants were required to lift the object using both hands from the knuckle height to elbow height level without moving their feet. The environmental conditions in the laboratory while doing an experiment was 25 °C (dry temperature, 55%–65% humidity, and air velocity less than 0.2 m/s).

2.4 Experimental Procedure

The participants were asked to lift the object for 20 min in each five different lifting frequencies. The initial weight of the object was obtained from the recommended weight of lift which was calculated from NIOSH Lifting Equation (NLE). During 20 min, the participants had to project that they performed the lifting task 8 working times in each lifting frequency trial and they had to decide to increase or decrease the weight inside the basket until the weight reaches the appropriate weight (maximum acceptable weight of lift) using their perception of lifting capability. The maximum weight would not cause subjects to be unusually tired, overheated, or out of breath. At the end of each lifting task, the participant was asked to RPE using the Borg Category Ratio-10 (CR-10) scale. Afterwards, analyzed the maximum acceptable weight of lift of subjects using statistic within acceptable lifting capacity of about 99% of male subjects, 75% of female subjects and 90% of all subjects [10].

2.5 Data Analysis

The researcher established dummy table, validated data and recorded data on statistical package and then analyzed data using descriptive statistic, including number, percent, percentiles, mean and standard deviation (SD) to describe subject characteristics, lifting weight decision, reference mass, and rating of perceived exertion.

3 Results

3.1 Maximum Acceptable Weight of Lift (MAWL)

The results of the study on lifting tasks to determine the Maximum Acceptable Weight of Lift (MAWL) for a group of Thai youth under appropriate working conditions using psychophysical approach revealed that at five different lifting frequencies (12, 6, 4, 2, and 1 lifts/min), for male the MAWLs were 6.10, 7.23, 8.38, 9.95, and 11.88 Kilograms, respectively. On the other hand, females could lift a maximum average weight of 3.02, 3.73, 4.67, 5.70, and 6.85 kg, respectively. Details were shown in Table 1. It is evident that the MAWL for male is higher than female at every frequency (Fig. 1).

Table 1. Maximum acceptable weight of lift (MAWL) categorized by frequency and gender (n = 60)

Frequency (lifts/min)	MAWL (kilograms)							
	Male (n = 30)				Female (n = 30)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
12	2.0	14.0	6.10	2.87	1.50	6.50	3.02	1.39
6	2.0	16.50	7.23	3.59	1.50	8.50	3.73	1.55
4	3.0	18.0	8.38	3.54	2.0	8.50	4.67	1.64
2	4.50	19.50	9.95	3.94	3.0	10.0	5.70	1.53
1	6.0	25.50	11.88	4.74	4.0	11.50	6.85	1.73

3.2 The Percentile of Maximum Acceptable Weight of Lift

Psychophysical approach considered the percentage of population acceptance, at least 75% of the female group, not less than 99% of male, and 90% of all workers' acceptation

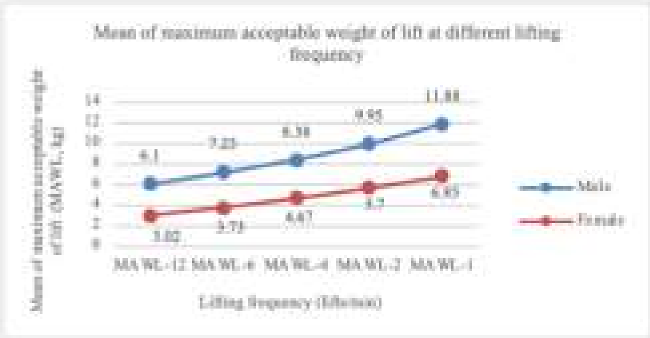

Fig. 1. The mean of MAWL at different lifting frequencies, separated by gender.

(males and females are equal). Selecting the lowest value to be the maximum acceptable weight of lift from three criteria. Therefore, the maximum acceptable weight of lift of this study classified by five different lifting frequencies (12, 6, 4, 2, and 1 lifts/min) were 2, 2.29, 3, 4.5, and 5.5 kg, respectively. Details are shown in Table 2.

Table 2. Maximum acceptable weight of lift (MAWL) using psychophysical approach categorized by frequency (kilogram)

Frequency (lifts/min)	MAWL of about 99% of male subjects	MAWL of about 75% of female subjects	MAWL of about 90% of both male and female subjects	MAWL of Thai youth (18–24 years old)
12	**2.0**	**2.0**	**2.0**	2.0
6	**2.29**	3.5	2.5	2.29
4	3.29	3.5	**3.0**	3.0
2	4.65	5.0	**4.5**	4.5
1	6.0	5.63	**5.5**	5.5

3.3 Rating of Perceived Exertion from Lifting Task

In this study, it was found that the rating of perceived exertion from lifting task of subjects found frequency at 5 s/lift, male and female subjects reported the highest rating of perceived exertion, with averages of 5.63 and 5.17, respectively, as shown in Fig. 2.

4 Discussion

The results of this study found that the mean MAWL decreased when increased lifting frequency corresponded with studying the maximum acceptable weight of lift in adolescents aged 15 to less than 18 years old [11] found that the MAWL of 90% both male and

Fig. 2. Rating of perceived exertion categorized by lifting frequency and gender (n = 60).

female adolescence classified by lifting frequency at 12, 6, 4, 2, and 1 lifts/minwas 5.5 6 7.5 6 and 10.5 kg, respectively. This is in agreement with the results of the previous studies [12, 13]. For the reason that when increased lifting frequency, subjects need to lift rapidly result of heart rate and metabolic energy expenditure increased [7, 13] so subjects were easier fatigued or out of breath than low lifting frequency, including when high lifting frequency, subjects must use their muscles continuously for repetitive tasks, with intervals for rest and muscle recovery getting shorter. These might lead to a reduction in muscle endurance, resulting in a decreased ability to lift heavy objects. The reason for the difference in the MAWL value between the current study and the previous studies was due to the difference in the participants' characteristics, such as age group, BMI, and strength, the difference in the experimental conditions, such as lifting frequencies, lifting posture, and lifting duration and the difference in the environmental conditions, such as the temperature, air velocity, and the humidity.

Comparing the MAWLs for Thai youth of this study with the mean recommended weight limits (RWLs) which were calculated from the NIOSH lifting equation (1991) and were used to be the beginning weight of lifting at each lifting frequency, found that at high lifting frequencies (6 and 12 lifts/min) the MAWLs were higher than the mean RWLs and at lower lifting frequency (1, 2, and 4 lifts/min) the MAWLs were less than the mean RWLs since this study applied solely the psychophysical criterion to find the MAWL. The participants were instructed to lift with the beginning weight (RWL), they had to project that they performed the lifting task 8 working times in each lifting frequency trial and they had to decide to increase or decrease the weight inside the basket until the weight reaches the appropriate weight (maximum acceptable weight of lift) using their perception of lifting capability. This approach differs from the NIOSH methodology, which used physiological, biomechanical, and psychophysical criteria to create an equation for RWL calculation. As a result, the mean RWLs and the MAWLs for Thai youth are not equal. In addition, using the NIOSH equations to assess the risk of manual lifting at high frequencies may be an underestimate. On the other hand, low frequencies may be overestimated. Because the variables in NIOSH equations are about task and material characteristics, the personal characteristics like gender or physical strengths are not considered so caution must be taken in using the RWLs at low-frequency lifting. It can be concluded that the NIOSH equations to assess the risk of manual lifting can be used by Thai youth for high lifting frequency more than low frequency. However, applying the MAWLs of this study to use, should consider the other variables apart from the lifting frequency such as horizontal distance, vertical distance and asymmetric angle.

The mean MAWL of male participants were higher than females at every lifting frequency, which corresponded with previous research of [11] they found that the MAWL of male children were significantly higher than female children at every lifting frequency. This may be explained that since males and females have different body structures, with males having larger and more numerous muscles, males are generally able to generate more energy for various activities compared to females. In cases where they receive the same training for muscle usage, females can produce only approximately 70% of the force generated by males, due to the relatively smaller muscle size in females. In addition, males being stronger than women because of physical differences, the culture of Thai also makes men have to be stronger than women since Thai culture which has existed for a long time teaches men to work or exert more energy than women since childhood, for example, boys must help their father carry things while girls must help their mother wash the dishes, boys must be Thai Reserve Officer Training Corps Students (TROTCS) when they were 16 years old, which requires intense training to pass the exam, result in boys have to be strong all times while girls do not have to be like that. Therefore, it is not surprising that boys grow up to be able to lift heavier objects than girls. Thai law also specified the lifting weight of men higher than women because there is a belief that men are stronger than women. Psychosocial factors may influence lifting capacity that is the men who help the women lift the heavy objects are called 'gentlemen' and are complimented by the women resulting in giving men a sense of satisfaction and self-esteem for being able to help others who are less strong. Therefore, the current study reported that regular the mean MAWL of male participants were higher than females.

The rating of perceived exertion in this study investigated that the mean of rating of perceived exertion tended to increase both males and females, although MAWL were lower. The frequency of 5 s per lift (12 lifts per minute) resulted in the highest level of perceived exertion. These results aligned with the research conducted by [11] and were consistent with international studies [12, 14]. The study's outcomes suggested that the lifting frequency significantly impacts the body's fatigue levels, even when the weight being lifted is relatively low. This may be attributed to the limited time available for the muscle fibers involved in the lifting process to recover and prepare for the next lifting frequency trial. Additionally, the body requires oxygen for energy production, which necessitates increased breathing frequency. Consequently, this might lead the participants to feel more fatigued when lifting at higher frequencies.

The maximum of recommended weight limit of Thai regulation (55 kg for males and 25 kg for females over 18 years old) is higher than the MAWLs of this study for both males and females so the weight limits should be considered to improve since they are not suitable for performing lifting tasks of Thai youth and cannot prevent the MSD injuries. These findings suggest that should consider the recommended weight limits using the NIOSH lifting equation (NLE) in order to work safety and well-being among Thai youth.

5 Conclusion

This study found that increasing lifting frequency, decreasing the maximum acceptable weight of lift. On the other hand, increasing lifting frequency, increasing the rating of perceived exertion. Further study should consider the MAWL using biomechanical and physiological approaches to comprehensively address all ergonomic issues.

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Suggestion for Optimal Camera Location in Monocular 3D Markerless Motion Capture: Focusing on Accuracy Comparison with Marker-Based Model

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Abstract. The purpose of this study is to evaluate the accuracy of monocular marker-less 3D motion capture based on camera location and plane by comparing the range of motion (ROM) angles of the right arm joints using a marker-based 3D motion capture system. The ROM for each degree of freedom of the right-side shoulder and elbow joints was simultaneously measured using a marker-based 3D motion capture system and the monocular markerless 3D motion capture model, MediaPipe. The camera location and plane were considered as independent variables. As a dependent variable, this study analyzed the mean absolute error from the angles measured by between the systems and performed a two-way ANOVA. The results showed that the camera location and plane had a significant effect on the accuracy of marker-less motion capture for each joint. The accuracy of the shoulder was generally higher under the experimental conditions of 315°, frontal at 0°, 180°, and sagittal at 315°. The accuracy of the elbow was higher under the experimental conditions of 90° and 135°. This study found that positioning the camera diagonally relative to the body yielded higher accuracy. Therefore, this study suggested that the camera location should be positioned at 135° and 315° for monocular 3D markerless motion capture of the arm.

Keywords: Camera Location · Monocular · Markerless · Motion Capture · Range of Motion

1 Introduction

The marker-based 3D motion capture system is a common method for analyzing joint movements [1]. However, since numerous markers must be attached to the subject's body, the experimental process becomes cumbersome, affects natural movements, and can cause fatigue in the subjects. And if the markers are incorrectly positioned or fall off during the subject's movement, it can cause issues in the experiment [2].

Recently, the emergence of markerless motion capture systems has enabled simple measurement and analysis of human movement. Markerless 3D motion capture aims to

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accurately estimate the positions of human joints using computer vision without markers, allowing for flexible application in various environments and conditions [3]. Many researchers are conducting various studies and accuracy validations using markerless methods. Representatively, Nakano et al. [4] validated the accuracy of a multi-view 3D markerless motion capture system using OpenPose by comparing it with a marker-based motion capture system through the MAE (mean absolute error).

However, most of the previous studies on markerless motion capture used RGB-D cameras instead of regular cameras to validate. Additionally, most video-based markerless models used only 2D coordinates to visually compare the angular change trajectories of simple movements. Practical accuracy validation regarding the impact of camera location on the accuracy of specific joints when using an RGB camera-based monocular 3D markerless motion capture system in real environments is still insufficient.

This study aims to validate the optimal camera locations for different planes by analyzing the accuracy of the monocular markerless 3D motion capture model, MediaPipe, based on the comparison of the clinical ROM (range of motion) angles of the right shoulder and elbow joints with a marker-based 3D motion capture system.

2 Method

2.1 Subjects

Five male subjects participated in this study. All subjects gave written informed consent form. They have no history of musculoskeletal disorders or injuries in the past 12 months and were familiarized with the overall experimental protocol. The mean (standard deviation) of their age, height, and body weight were 27.2 (±1.6) years, 1716.0 (±63.8) mm, 82.6 (±5.8) kg, respectively.

2.2 Apparatus

A marker-based 3D motion capture system was used to measure the ROM angles of the right shoulder and elbow joints. Ten 1.3-megapixel Flex13 motion capture cameras (Natural Point, Inc. Optitrack, USA) were used, and eight 1.2-megapixel cell phones were used for video recording. The sampling rate of the marker-based motion capture system was set to 30Hz to match the sampling rate of the videos analyzed using the markerless 3D motion capture system.

2.3 Experimental Design

To evaluate the accuracy of monocular markerless 3D motion capture for joint movements based on plane and camera location during clinical ROM measurement tasks, the independent variables were considered as the human body's planes (frontal, sagittal, transverse) and the camera locations relative to the subject (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). All experimental conditions were randomized and repeated three times. The dependent variable was considered as the MAE (absolute joint angle difference) per frame between the two motion capture systems.

2.4 Procedure

Thirty-nine markers were attached to the subjects' bodies according to the plug-in gait full body model marker set. For the shoulder joint, the subjects performed abduction/adduction (frontal) by lifting the arm sideways away from the body and then lowering it back down, flexion/extension (sagittal) by raising the arm forward as much as possible and then extending it back, and internal rotation/external rotation (transverse) by keeping the elbow against the torso, bending it vertically, and moving the hand horizontally outward and then inward. For the elbow joint, the subjects performed flexion/extension (sagittal) by bending the elbow as much as possible and then straightening it, while keeping the shoulder in a vertical position.

2.5 Data Processing

The signals from the markers measured by the marker-based 3D motion capture system were processed using MOTIVE 2.1.0 (Natural Point, Inc. Optitrack, USA). The monocular markerless 3D motion capture system used MediaPipe, a framework developed by Google that serves as a monocular 3D markerless motion capture model. The joint angles measured by the two motion capture systems were calculated using the cosine similarity of vectors [5]. The trajectory data from both systems were filtered using a 4th order Butterworth filter with a cutoff frequency of 6Hz [6]. To statistically analyze the significant differences in MAE according to camera location and plane, a two-way ANOVA and Scheffe test for post-hoc analysis were performed at a significance level of 0.05. All data processing and statistical analyses were conducted using Python 3.10.13.

3 Result

3.1 Shoulder

The results of the ANOVA for the shoulder between the two systems based on camera location and plane showed that both the main effects and interactions were statistically significant. According to the post-hoc test of the main effects, the MAE was 27.0 (±26.0)° at the 315° camera location, the lowest value, and 54.0 (±31.8)° at 90°, the highest value (Table 1). In the sagittal plane, the MAE was 30.9 (±24.1)°, the lowest value, while in the transverse plane, the MAE was 45.3 (±32.8)°, the highest value. Additionally, the post-hoc test of the interaction effects revealed that the MAE was lowest under the experimental conditions in the frontal plane at 0°, 180° and in the sagittal plane at 315°. Conversely, the post-hoc test showed that the MAE was highest under the experimental conditions in the frontal plane at 90°, 270°, and in the transverse plane at 270° (Fig. 1).

3.2 Elbow

The ANOVA results for the elbow between the two systems according to camera location revealed that the main effect was statistically significant. According to the post-hoc test of the main effects, the MAE was 31.4 (±21.9)° at the 90° camera location and 31.7 (±24.8)° at 135°, the lowest values (Table 2). Conversely, the MAE was 66.2 (±51.2)° at 0° and 60.7 (±48.5)° at 180°, the highest values (Fig. 2).

Table 1. The mean and standard deviation of MAE for the shoulder

Plane (post-hoc)	Camera location(post-hoc)								
	0°(ab)	45°(c)	90°(e)	135°(b)	180°(b)	225°(c)	270°(d)	315°(a)	Avg
Frontal (b)	15.4 (±12.5) (ab)	38.5 (±19.8) (gh)	60.2 (±21.2) (l)	23.8 (±11.9) (cde)	13.5 (±1.0) (a)	26.0 (±19.9) (de)	56.0 (±37.3) (kl)	22.8 (±17.3) (cd)	32.0 (±26.3)
Sagittal (a)	27.3 (±17.4) (de)	37.3 (±17.3) (g)	51.8 (±22.4) (jk)	21.5 (±14.6) (bcd)	25.6 (±24.3) (dejk)	36.0 (±30.9) (fg)	30.2 (±26.6) (ef)	17.9 (±16.0) (abc)	30.9 (±24.1)
Transverse (c)	46.0 (±21.4) (ij)	26.7 (±13.7) (de)	49.9 (±46.7) (jk)	49.0 (±35.9) (ij)	52.0 (±30.0) (k)	37.7 (±25.5) (gh)	58.8 (±31.9) (l)	42.7 (±35.3) (hi)	45.3 (±32.8)
Average	29.0 (±21.2)	34.5 (±18.0)	54.0 (±31.8)	30.5 (±25.7)	29.6 (±27.6)	33.2 (±26.5)	47.4 (±34.7)	27.0 (±26.0)	35.6 (±28.4)

Note: Alphabetical order represents the Scheffe test

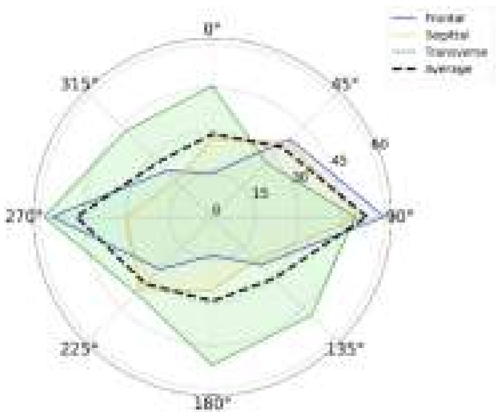

Fig. 1. MAE of the plane by camera location for the shoulder.

Table 2. The mean and standard deviation of MAE for the elbow

Plane	Camera location(post-hoc)								
	0°(e)	45°(cd)	90°(a)	135°(a)	180°(de)	225°(bc)	270°(b)	315°(cd)	Avg
Sagittal	66.2 (±51.2)	58.1 (±39.4)	31.4 (±21.9)	31.7 (±24.8)	60.7 (±48.5)	52.7 (±41.7)	48.9 (±24.0)	48.9 (±24.0)	50.6 (±38.5)

Note: Alphabetical order represents the Scheffe test

Fig. 2. MAE of the sagittal plane by camera location for the elbow.

4 Discussion

This study analyzed the accuracy of monocular markerless 3D motion capture based on camera location and plane by comparing the clinical ROM angles of the right arm joints with a marker-based 3D motion capture system.

The shoulder generally showed the highest accuracy in the movements at the 315° camera location and in the sagittal plane. The interaction effects revealed that the movements in the frontal plane at 0°, 180°, as well as in the sagittal plane at 315°, also showed relatively high accuracy. Conversely, the overall accuracy was lowest in the transverse plane at the 90° camera location. The interaction effects showed that the accuracy was low in the frontal plane at 90°, likely because the Abduction/Adduction movements of the subjects were not well visible. Additionally, the inclination algorithm of MediaPipe tends to tilt the body parts closer to the camera towards the camera and those further away in the opposite direction. It is speculated that the lack of training data for hand height resulted in decreased estimation ability as the hands were raised above the head [7]. The accuracy was lowest in the transverse plane at 90°, 270°. This is because calculating the rotation angles in the transverse plane involves using the left and right shoulder key points. At 90°, the left shoulder was not visible, and at 270°, the right shoulder was not visible [8]. In summary, for the shoulder, capturing from a diagonal direction generally results in higher accuracy, while vertical directions should be avoided. Specifically, capturing at 315° provides the highest accuracy, whereas capturing at 90° and 270° should be avoided.

For the elbow, the accuracy was highest at 90°, 135°, and lowest at 0° and 180°. This is likely because the Flexion/Extension movements are not well captured at 0°, 180° [8]. Therefore, capturing at 90°, 135° provides the highest accuracy, while capturing at 0°, 180° should be avoided.

The results of this study evaluated the accuracy of joint angle measurements between the two systems, identifying the optimal camera location angles for joint assessment when using a general camera. To enhance the reliability of the study results, additional subjects should be included in future research. Additionally, it is considered necessary to apply an appropriate algorithm to correct for outliers caused by occlusion when measuring continuous angle data in a monocular markerless 3D motion capture system.

5 Conclusion

This study analyzed the MAE between the two motion capture systems to identify the optimal camera locations for each joint plane. As a result, the shoulder showed generally higher accuracy when captured from diagonal directions relative to the body, with the highest accuracy at 315°. For the elbow, the highest accuracy was observed when captured at 90°, 135° relative to the body. Considering the overall accuracy of the right arm, this study suggested to position the camera at 135°, 315°.

The results of this study suggest that by utilizing the optimal camera positions, more accurate motion analysis can be achieved even in conditions where multi-camera systems are not available. This can be applied in various fields such as sports and rehabilitation therapy. Additionally, these findings can serve as guidelines for future research aimed at improving the accuracy of specific joints at certain camera locations.

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The Effects of Delivery Truck Design on Lumbar and Posture Workload Reduction During Loading Tasks: A Comparative Study of Conventional, Low-Entry, and Newly Designed Delivery Trucks

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Abstract. The recent growth of the logistics industry and increased demand for parcel delivery services have led to a surge in parcel volumes, significantly increasing the workloads for delivery workers. This heightened workload, particularly from the strain on the back due to the use of low-entry trucks, has caused serious musculoskeletal disorders. Thus, there is a need for newly designed delivery trucks to alleviate this burden. This study aims to assess the impact of vehicle design on occupational health risks by analyzing the back workloads and posture of delivery workers during loading tasks on three types of trucks (conventional, low-entry, and newly designed). Ten adult males with parcel delivery experience and no musculoskeletal disorders participated in loading 10 kg boxes. The XSENS, 3D-SSPP, and AutoChecklist programs were applied to measure and evaluate the lumbar flexion angles, L5/S1 compression forces, and posture scores (RULA, REBA, AWBA), respectively. The results showed the lowest lumbar flexion angle and compression force for the newly designed truck, indicating a reduced workload during loading tasks. AutoChecklist analysis also revealed the lowest risk levels for the newly designed truck. Overall, the study suggests that loading tasks on the newly designed truck can reduce workload compared to conventional and low-entry trucks, providing evidence for workload reduction effects and offering foundational data for future delivery vehicle development and evaluation.

Keywords: Work-Related Musculoskeletal Disorders (WMSDs) · Delivery Trucks · Workloads · 3D Motion Analysis · Compression Force · Posture Analysis

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1 Introduction

The recent increase in parcel volume has led to a corresponding rise in the workload of delivery workers, exacerbating the issue of physical burdens. Delivery workers experience work-related musculoskeletal disorders due to tasks such as loading and unloading parcels and repetitive stair climbing. These tasks involve manual material handling, repetitive movements, and improper working postures, which are major contributors to musculoskeletal disorders (Lee 2019; Cho and Beak 2021; Kim and Choi 2021).

In addition, the types of delivery vehicles used have also emerged as an important factor affecting the risk to delivery workers. The height of underground parking lots in newly developed residential complexes is lower than that of conventional delivery trucks. To address this, low-entry delivery trucks that can access these parking lots have recently been introduced. However, the cargo compartment height of the low-entry trucks is only about 1,270–1,400 mm. Thus, workers have to maintain a stooped posture during loading and unloading tasks, which increases their physical load. Additionally, the reduced height of the cargo results in decreased cargo capacity, leading to economic losses. Therefore, the development and introduction of new delivery vehicles are needed to address these issues.

This study aimed to analyze the workload of delivery workers for conventional trucks, low-entry trucks, and newly designed trucks by evaluating body angles, compression force at the L5/S1 disc, and working posture during loading tasks.

2 Methods

2.1 Participants

Ten healthy adult males with parcel delivery experience and no history of musculoskeletal disorders were recruited. The mean values (standard deviation: SD) of age, height, and body mass were 36.9 (3.5) years, 175.7 (1.9) cm, and 77.0 (3.0) kg, respectively.

2.2 Experimental Conditions

In this study, three types of vehicles were evaluated to compare the physical burden on workers according to the type of vehicle: a conventional truck, a low-entry truck, and a newly designed truck that combines the advantages of conventional trucks while addressing the shortcomings of low-entry trucks. A conventional truck and a low-entry truck closely resemble the specifications of trucks commonly used in the delivery industry, while the Newly designed truck was specifically manufactured by the Korea Railroad Research Institute to reduce the workload on workers for the purpose of this study. The specifications of the vehicles used in this study are presented in Table 1.

2.3 Experimental Procedures

The experimental procedures were approved by the Institutional Review Board of Sungkyunkwan University and were performed in accordance with the Declaration of

Table 1. Specifications for three types of delivery trucks

	Conventional truck	Low-entry truck	Newly Designed truck
Height from the ground (mm)	700	700	340
Height (mm)	1,580	1,270	1,386–1,682
Length (mm)	2,400	2,810	3,435
Width (mm)	1,670	1,640	1,860

Helsinki (approval#: SKKU 2022-10-051). Prior to the experiment, all the participants were informed of the study's purpose, procedures, tasks, and potential risks. After the participants gave their written consent, demographic and anthropometric data, including age, body mass, height, and foot length, were collected.

Then, the participants were instrumented with 3-dimensional motion capture inertial measurement unit (IMU) sensors, which were calibrated afterward. Loading tasks in the three types of vehicles were randomly conducted and divided into two sessions to ensure data accuracy. To minimize muscle fatigue, a 5-min rest period was provided after completing the loading tasks for one vehicle before starting the tasks for another vehicle.

Participants loaded a total of 48 boxes per vehicle by moving two 5 kg boxes per cycle (totaling 4 boxes) over 12 cycles. For a conventional truck and a low-entry truck, with a floor height of 700 mm from the ground, participants placed two boxes twice (totaling four boxes) at the entrance of the cargo compartment, then climbed into the truck to load the four boxes inside. In contrast, for the newly designed truck with a floor height of 340 mm from the ground, participants directly entered the vehicle and loaded two boxes each without separately placing them at the cargo entrance.

2.4 Outcome Measures

Body Angles

The back flexion angles were collected using a 3-dimensional motion capture system (MVN Awinda; Xsens Technology; Netherlands) with 17 inertia measurement unit (IMU) sensors at a 60 Hz sampling rate, as shown in Fig. 1 (A). All sensors and segment orientations were calibrated using the same process as in the previous study (Robert-Lachaine et al. 2017). The back flexion angles were summarized as mean values.

Compression Force

To evaluate the lumbar compression force for each vehicle based on the body angle data obtained from IMU motion sensors, the compression force at the L5/S1 level was analyzed using the 3D Static Strength Prediction Program (3D-SSPP, USA). When calculating the lumbar compression force, a total weight of 98N (49N in each hand) was applied, considering two boxes each weighing 10kg (Fig. 1B). The compression force was summarized as mean and maximum values.

Working Posture
To evaluate the overall working posture during loading tasks according to three types of delivery trucks, automated evaluations using AutoChecklist (Kim et al. 2022) were conducted for three assessment tools: Rapid Upper Limb Assessment (RULA; McAtamney and Corlett 1993), Rapid Entire Body Assessment (REBA; Hignett and McAtamney 2000), and Agricultural Whole-body Assessment (AWBA; Kong et al. 2020) (Fig. 1C).

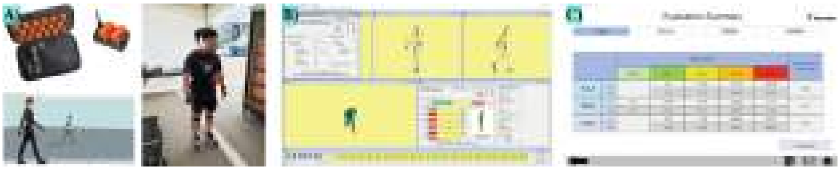

Fig. 1. IMU motion capture and locations of IMU motion sensor attachments (A), 3D-SSPP program (B), AutoChecklist program (C)

2.5 Statistical Data Analysis

All the statistical analyses were performed using SPSS 20 (SPSS Inc, Chicago, Illinois, USA). The dependent variables included back flexion angle, compression force at L5/S1, and working posture. The independent variable was the three types of delivery trucks. One-way ANOVA was conducted for back flexion angle, lumbar compression force, and working posture according to the types of vehicles. For the evaluation of working posture, a two-way ANOVA was performed for each assessment tool, considering both the type of delivery vehicle and the assessment tool. Statistical significance was noted when a p-value was less than 0.05. Then, a post-hoc analysis was performed using Tukey's HSD.

3 Results

3.1 Back Flexion Angle

During loading tasks, the type of vehicle had a statistically significant factor affecting the worker's back flexion angle ($p < 0.05$). Post hoc analysis using the Tukey test also revealed statistically significant differences (Fig. 2, left). Particularly, the low-entry truck, which has the lowest cargo height, exhibited the highest back flexion angle of 63.6°, followed by the conventional truck with 49.9°. In contrast, the Newly designed truck, which combines the advantages of both conventional and low-entry trucks, showed the lowest back flexion angle of 37.7°. Compared to the others, the Newly designed truck reduced the back flexion angle by approximately 24.5–40.7%.

3.2 Compression Force at L5/S1

The analysis of 3D-SSPP indicated that the type of vehicle was also a statistically significant factor affecting lumbar compression force ($p < 0.05$). Post hoc analysis using the Tukey test revealed that the Newly designed truck had the lowest compression force (1621.5N), while the low-entry truck had the highest (1982.0N), followed by the conventional truck (1850.4N). The Newly designed truck was found to reduce compression force by approximately 9% to 18.2% compared to the others (Fig. 2, right).

Fig. 2. Back flexion angles associated with car types (left), L5/S1 Compression force associated with car types(right). *[Note: A, B, and C indicate the significant statistical groupings; α = 0.05.]*

3.3 Working Posture Assessment

The analysis of working posture using the AutoChecklist program showed statistically significant differences in the mean scores among vehicle groups across the three assessment tools, RULA, REBA, and AWBA ($p < 0.05$). All three assessment tools exhibited similar trends, with the evaluation scores for the Newly designed truck tending to be relatively lower compared to conventional and low-entry trucks (Table 2).

Table 2. Working posture assessment for three types of delivery trucks. *[Note: A, B, and C indicate the significant statistical groupings; α = 0.05.]*

	RULA	REBA	AWBA	Average
Conventional truck	3.53^{B}	2.28^{B}	3.24^{B}	3.02
Low-entry truck	3.64^{A}	2.47^{A}	3.36^{A}	3.15
Newly designed truck	3.34^{C}	2.12^{C}	3.19^{C}	2.89

4 Discussion and Conclusions

This study evaluated the back flexion angle, compression force, and working posture for conventional, low-entry, and newly designed trucks to analyze the workload of the delivery workers according to the type of delivery vehicle.

According to the body angle analysis results, the back flexion angle was higher in vehicles such as a low-entry truck with the lowest heights of the cargo compartments. This seems to be because workers have to bend their backs more to perform loading tasks in the cargo compartment. The lumbar compression force analysis results showed that similar to the motion analysis results, vehicles with lower heights of cargo compartments exhibited higher workloads. Consequently, the compression force at L5/S1 was lower in the Newly designed truck compared to the other trucks, indicating a reduction in lumbar load by 9% to 18.2%. The working posture evaluation results indicated that, compared to other trucks (Conventional truck: 3.02 level; Low-entry truck: 3.15 level), the Newly designed truck had an average level of 2.89, which is relatively lower in terms of action levels. However, the result of the newly-designed truck exceeding levels 2 and 3 suggests that the loading task remains a burden that requires ergonomic intervention or monitoring as soon as possible. Therefore, it appears that improvements in working posture are necessary to prevent musculoskeletal disorders among workers during loading tasks in the future.

The Newly designed truck, which lowered the floor height from the ground and increased the floor height of the cargo area, required a back bending angle of about 12.2° to 25.9° less than other trucks. As a result, the lumbar compression force was reduced by 228.9N to 360.5N, and the average working posture was the lowest. Therefore, the workload reduction effect was the largest among the three vehicles.

This study is expected to be used as verification data to reduce the physical workloads of the newly designed truck and as fundamental data on the method and process of evaluating the worker's workload according to the vehicle type.

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Analysis of Variable Sit-to-Stand Assist Chair

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Abstract. Recent studies indicate that back diseases are increasing annually due to various factors such as poor lifestyle habits, aging, pregnancy, and accidents. Patients with such conditions often experience difficulty in managing their backs, leading to a lower quality of life as they endure back pain when sitting for prolonged periods or when transitioning between sitting and standing positions. Sit-to-Stand (STS) movement is particularly challenging for these patients. In response, this study proposes a variable assist chair that supports the user's STS movements. Non-powered assist chairs using the first-class lever mechanism can be advantageous due to their light weight and low cost. Additionally, the chair's variable design enables it to be universally applicable across a wide range of environments and users. This research demonstrates the effectiveness of the new mechanism in assisting users' transitions between sitting and standing positions. Furthermore, it highlights the need for further research to explore the applicability of the mechanism to a diverse range of users.

Keywords: Sit-to-Stand Movement · Variable Assist Chair · Ergonomics Analysis · Simulation Exercises

1 Sit-to-Stand Movement

1.1 The Importance of Sit-to-Stand Ability in Daily Living

Due to population growth and aging, the global incidence of low back pain (LBP) is steadily increasing. According to the World Health Organization (WHO), an estimated 619 million people worldwide suffered from LBP in 2020, projected to rise to 843 million by 2050. LBP is the most prevalent musculoskeletal condition and a leading cause of disability worldwide. Moreover, it can result from various factors, including lifestyle habits, pregnancy, accidents, strokes, and Parkinson's disease, affecting individuals across all demographics. Back difficulties can cause pain during prolonged sitting or when transitioning from sitting to standing, significantly impacting quality of life [1]. Sit-to-stand (STS) movement, transitioning from sitting to standing, is crucial for daily activities, particularly for the elderly. Impaired STS function can lead to limitations in daily activities, reduced mobility, and increased mortality risk [2].

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1.2 Phases of STS Movement

Sit-to-stand (STS) movement requires a combination of complex abilities. As the body's center of gravity (COG) shifts, trunk control becomes essential. Additionally, dynamic balance is necessary to prevent falls caused by sudden changes in the base of support and the acceleration of the body's center, ensuring stable limb movements [3]. The ability to place and maintain both feet on the ground and generate extension in the lower limbs is also crucial.

STS process is divided into four phases based on changes in the center of gravity (COG) and hips position. The first phase, flexion-momentum, starts with the initiation of movement and ends just before the hips lift off the chair. The second phase, momentum-transfer, spans from the moment the hips leave the chair until the maximum dorsiflexion (DF) of the ankles. The third phase, extension, follows maximum DF and involves lifting the body vertically until hip extension ends. During phases 2 and 3, the COG shifts from the chair to the feet, presenting the greatest challenge for older adults and individuals with disabilities. Additionally, in phase 3, the trunk must move forward, and the hips must be lifted using the strength of the thigh muscles, but this is hindered by weakness in the spinal erector muscles and quadriceps [1]. The final phase, stabilization, begins after hip extension is complete and ends when all movement ceases [2].

2 Design of Variable STS Assist Chair

Existing assist chairs are often designed for specific patients or the elderly, typically equipped with motors and batteries, making them heavier and more expensive compared to standard chairs. Furthermore, rehabilitation experts caution that motorized lift devices could accelerate muscle degeneration [4]. Studies indicate that elderly individuals and those with limited lumbar mobility tend to struggle with phase 3 of STS, requiring them to grasp their knees or the chair's armrests for support when rising [5]. We used a first-class lever mechanism in the chair to address this dependency on armrests for weight-bearing during STS. As illustrated in Fig. 2, pressing the armrest causes the seat to rise, providing support to the hips and lumbar. The chair can provide users with more flexible support through this variable mechanism. The effort point of the lever, corresponding to the armrest, is set while the chair's bottom frame acts as the fulcrum and the backrest frame as the load point that raises the seat and the backrest. Springs are installed on the armrest and backrest frame to ensure the mechanism returns to its initial state after operation. Based on this design, we made a 1:1 scale prototype using aluminum profiles, as depicted in Fig. 1b.

3 Ergonomic Analysis with Simulation Exercises

3.1 Analysis Method of Variable Assist Chair

The Importance of Ergonomic Analysis. Given that the variable chair is designed to assist STS movements, it necessitates ergonomic analysis for its evaluation. In a study on elderly individuals evaluating a variable assist chair, participants performed Back-to-Sit (BTS) movements after a 3-s pause following Sit-to-Stand (STS) action. The study analyzed knee and pelvis angles [4].

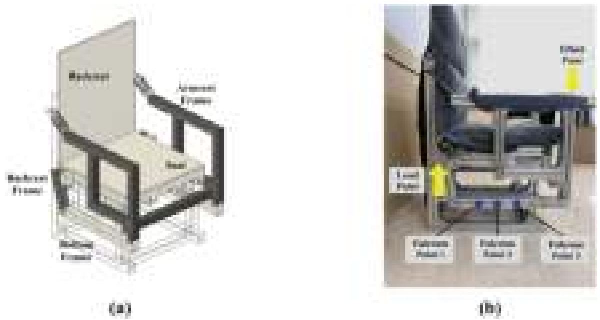

Fig. 1. Design of the Variable STS Assist Chair: **(a)** Modeling of the chair. **(b)** 1:1 scale of prototype chair with aluminum profiles.

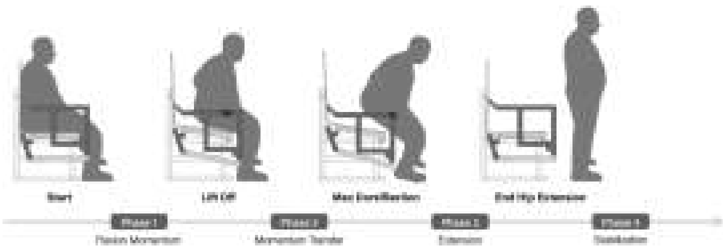

Fig. 2. The chair assists the user according to the stages of STS movement.

Simulation Exercises. In experiments involving the testing of a new chair structure on elderly and disabled individuals, the risk of injury exists, prompting the adoption of simulation exercises [6]. Simulation exercise methodology involves setting up conditions resembling real-life scenarios to facilitate experiential testing, allowing immersion into the actual user experience and incorporating insights into the design [7]. A study utilizing Maternity-Simulation Jackets to prevent potential adverse effects on pregnant women and fetuses, and a study utilizing AGNES (Age Gain Now Empathy System) elderly simulation suits at MIT AGELAB serve as typical examples of simulation exercises [8, 9].

3.2 Experiments

Experimental Protocol. The participants' behaviors were analyzed based on their heights, with cameras positioned 2 m away capturing frontal and side views of their Sit-to-Stand (STS) process. After receiving instructions, participants stood in front of the assist chair and performed STS movements according to cues from the facilitator. The experiment involved random sequences of four chair conditions: a standard chair with no assistance (Without Mechanism), and three variations of fulcrum points—designated as Fulcrum Point 1, 2, and 3, representing the shortest to longest distance from the fulcrum point to the load point, respectively. Participants performed STS under both restricted (wearing a lumbar restraint device) and unrestricted conditions for all chair types, totaling eight trials per participant.

Data Processing. We used Google Teachable Machine to capture and analyze participant movements from the front and side as depicted in Fig. 3. In the STS process, phase 2 (momentum-transfer) begins when the hips lift off the chair seat, and phase 3 (extension) starts when the hands leave the armrests. Pelvic angles and knee angles were measured from the extracted images and summarized in Tables 1 and 2.

Fig. 3. STS Phase 2 of Fulcrum Point 1 to 3 analyzed by Google Teachable Machine: (a) Without Lumbar Restraint Device, (b) With Lumbar Restraint Device

3.3 Results

Wearing the lumbar restraint device on the standard chair without the mechanism generally results in increased angles of the knees and pelvis compared to when there were no restrictions. In both Phase 2 and Phase 3, without the restraint device, the angles of the pelvis and knees tended to increase as the distance from the fulcrum to the effort point decreased, following Fulcrum Points 1, 2, and 3. However, no consistent pattern was observed in the results based on the fulcrum position when the lumbar restraint device was worn.

Table 1. Body Angles of Participants in Experiment without Lumbar Restraint Device

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
Without Mechanism	Phase 2	Pelvis	74.1	68.7	63.3	72.5	58.5	80.0
		Knee	108.0	117.0	107.2	100.8	101.6	100.3
	Phase 3	Pelvis	123.9	117.1	136.9	111.8	120.8	134.3
		Knee	141.6	148.2	149.9	142.8	123.8	137.1
Fulcrum Point 1	Phase 2	Pelvis	90.4	51.9	68.4	77.0	67.2	62.3

(*continued*)

Table 1. (*continued*)

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
		Knee	105.0	114.5	104.0	96.9	103.2	101.1
	Phase 3	Pelvis	143.0	121.6	126.5	119.2	82.3	132.3
		Knee	141.8	158.0	159.9	146.2	115.9	143.5
Fulcrum Point 2	Phase 2	Pelvis	65.5	67.3	70.2	77.7	76.4	72.4
		Knee	106.4	121.3	104.2	98.6	104.0	104.8
	Phase 3	Pelvis	121.3	108.6	117.8	122.1	128.7	130.3
		Knee	139.0	158.4	150.8	149.1	137.2	148.4
Fulcrum Point 3	Phase 2	Pelvis	78.2	68.2	66.4	65.6	87.0	73.9
		Knee	111.4	110.7	106.7	97.2	103.7	103.5
	Phase 3	Pelvis	132.5	127.2	111.6	114.8	131.1	122.4
		Knee	148.5	166.2	141.1	140.1	135.2	150.0

Table 2. Body Angles of Participants in Experiment with Lumbar Restraint Device

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
Without Mechanism	Phase 2	Pelvis	93.4	68.8	70.4	83.6	87.3	107.4
		Knee	128.9	120.8	116.5	104.4	97.7	166.6
	Phase 3	Pelvis	158.1	121.3	105.5	107.5	142.5	139.3
		Knee	153.2	166.1	153.1	139.6	138.1	169.5
Fulcrum Point 1	Phase 2	Pelvis	93.2	58.0	62.9	70.0	68.7	78.9
		Knee	132.2	86.3	96.9	104.1	97.2	86.4
	Phase 3	Pelvis	140.4	129.2	126.8	105.4	145.3	125.5
		Knee	146.5	167.7	160.6	130.8	137.4	151.6
Fulcrum Point 2	Phase 2	Pelvis	82.3	59.0	81.6	72.4	73.7	74.8
		Knee	110.6	108.6	106.5	97.5	102.3	104.9
	Phase 3	Pelvis	134.2	136.9	123.3	123.9	119.6	112.1
		Knee	148.6	165.6	153.6	140.2	129.3	148.1

(*continued*)

Table 2. (*continued*)

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
Fulcrum Point 3	Phase 2	Pelvis	96.1	54.8	81.9	77.9	84.2	78.7
		Knee	117.4	110.7	109.3	109.8	109.5	109.6
	Phase 3	Pelvis	142.9	130.1	116.8	106.8	147.6	135.6
		Knee	149.4	160.5	145.0	136.9	148.5	151.9

4 Discussion

The participants reported feeling assisted by the chair during STS motion both with and without the lumbar restraint device. However, they felt significantly more comfortable with the restraint device. Measurements indicated that wearing the lumbar restraint device generally increased the angles of the knee and pelvis compared to not wearing the device. This increase in angles is hypothesized to cause greater moments, potentially leading to increased difficulty in movement. The type of fulcrum point that participants found most comfortable differed according to their height. Relatively shorter participants preferred the fulcrum point to be positioned towards the front. Indeed, these participants tended to have reduced knee and pelvis angles in this case. This is because they sit towards the front of the seat, placing their sitting area within the seat's upward motion range.

Analysis of recorded videos and angle results showed that participants' movements were unstable when wearing the lumbar restraint device, indicating discomfort during STS. This highlights the value of using simulation exercises to assess different STS movements. However, since there is a lack of regularity revealed in the movement in an uncomfortable state, additional data collection is necessary. Also, while this study analyzed the knee and pelvis angles during STS movement using motion capture, additional experiments, such as examining COG movement, may be necessary and could require extra sensors like pressure sensors.

If further validation in future studies confirms the widespread adoption of chairs incorporating this new variable mechanism, it is anticipated that not only individuals with disabilities or the elderly but also the general population would benefit from its utilization.

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Ergonomic Evaluation of a Packing Collapsible Tubes Workstation with Emphasis on the Prevention of Musculoskeletal Disorders: A Case from a Small Colombian Company

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Abstract. This study evaluated the risk of musculoskeletal disorders (MSDs) associated with the workstation packing of collapsible tubes in a Colombian production line. In this company, musculoskeletal problems were the main cause of medical disability and the second highest cause of absenteeism. We analyzed MSD risk in selected tasks using the Individual Risk Assessment method (ERIN, in Spanish). Field visits collected data, including video recordings and pictures. Four workers were surveyed for body discomfort using the Spanish version of the Standardized Nordic Questionnaire (SNQ). The wrist/hand and lower back had the highest discomfort frequency. The ERIN score was 30, indicating a very high risk of MSDs. The wrist and neck showed high risk, whereas the trunk and arms showed moderate risk. Recommendations included improving the workstation design by considering ergonomic principles. An adjustable industrial chair and conveyor belt were proposed. An ergonomic hook-type hand tool was designed to improve grip and reduce wrist deviation using the 3D modeling software Tinkercad.

Keywords: Musculoskeletal Disorders · Workstation Design · Individual Risk Assessment · Packaging Industry

1 Introduction

According to the World Health Organization, Musculoskeletal Disorders (MSDs) are the leading cause of occupational disability worldwide, with approximately 1.71 billion people suffering from MSDs [1]. In Colombia, MSDs are also the leading cause of disability among workers. Approximately 52% of all occupational diseases are diseases of the musculoskeletal system and connective tissue: carpal tunnel syndrome, lumbar disk disorder, rotator cuff syndrome, and epicondylitis [2]. However, these statistics only include the formal economy sector. Therefore, the overall situation could worsen.

The origin of MSDs is associated with deficiencies in the design of workplaces and the work system. The risk of developing MSDs is higher for tasks involving repetitive movements and exertion, including specific risk factors such as use of force, awkward posture, and lack of recovery periods [3]. To guarantee a sustainable prevention of MSDs,

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it is necessary to incorporate the principles of ergonomics into the evaluation and design of workstations and the work system.

In a small company in the Colombian packaging industry where collapsible tubes for creams are produced, musculoskeletal problems were the main cause of medical disability and the second highest number of days of absenteeism. Different tasks on the packaging line are performed manually. Workers have reported discomfort and pain in some body areas, and the workstation design shows gaps from an ergonomic viewpoint. Considering all the signs mentioned above, we decided to conduct an ergonomic evaluation of the workstation "packing of collapsible tubes" to assess the risk of MSDs and propose improvement measures from an ergonomic viewpoint.

2 Methodology

Four site visits were made to collect data and information about the workstation under study. The visits lasted approximately 2 h, totaling 8 h of fieldwork. During these visits, 30 min of videos were recorded, and several photos were taken for further analysis. Unstructured interviews were conducted with four workers and one supervisor. The Standardized Nordic Questionnaire (SNQ) was administered to report musculoskeletal symptoms [4]. The SNQ is an easy-to-use, low-cost tool for determining musculoskeletal symptoms. It is a valid and reliable tool for estimating musculoskeletal symptoms in both formal and informal working populations [5]. In the study, we used the general version of the SNQ, which consists of nine anatomical regions represented in a figure of the human body from behind (see Fig. 1). The questionnaire was administered as an interview to the four workers. We used the Spanish version published by the Institute of Public Health of Chile [6].

The assessment of MSDs risk was performed using the ERIN method [7]. ERIN is a practical tool developed for nonexperts to assess exposure to MSDs risk factors based on available ergonomic and epidemiological evidence and the joint International Ergonomics Association-World Health Organization project guidelines for developing MSDs risk management in IDCs. Critical postures were selected for each body region to apply ERIN.

The proposals for ergonomic redesign of the workstations in the production line were modeled using Tinkercad. A specialized 3D design program that allows for more detailed visual representations of the proposals for improvement. This program is available free of charge online. This allows for a basic outline of the proposals. In this way, proposals can be previewed before they are executed.

Fig. 1. The Spanish version of the SNQ published by the Institute of Public Health of Chile.

Although the project included the analysis and proposals for redesigning the production line and its four workstations, only the results associated with the workstation "packing of collapsible tubes" are presented in this article. This job was selected for presentation here because it represents, in some ways, the most challenging from an ergonomic point of view.

3 Results

3.1 Standardized Nordic Questionnaire (SNQ)

The four workers to whom SNQ was administered reported discomfort in various body regions (see Table 1). In the case of the lower back, all four workers reported discomfort, while three of the four workers reported discomfort in the right wrist. Shoulders, knees, and ankles are also reported.

Table 1. Results of the application of the SNQ.

Have you at any time during the last 12 months had troubles in (pain, discomfort, discomfort)?				
	Worker 1	Worker 2	Worker 3	Worker 4
Neck	no	no	no	no
Shoulders	**yes left**	no	no	no
Elbows	no	no	no	yes right
Wrists/hands	**yes right**	no	**yes right**	**yes right**
Upper back	no	no	no	no
Low back	**yes**	**yes**	**yes**	**yes**
Hips/thighs	no	no	no	no
Knees	no	**yes**	no	no
Ankles/feet	no	no	**yes**	no

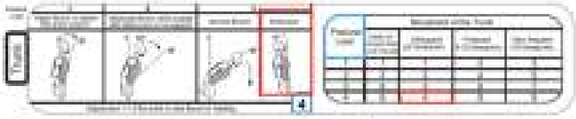
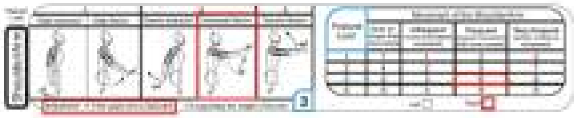
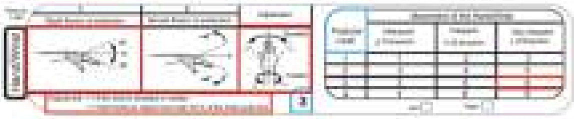
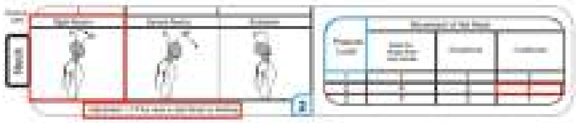
3.2 MSDs Risk Evaluation Using ERIN

The evaluation of postures and movements using the ERIN method resulted in a score of 30, representing a very high risk level according to the rating scale proposed by this method (see Table 2). The wrist and neck were the body regions with the highest ERIN scores, followed by the trunk and arms with moderate risk. The workers rated effort with a value of 3 on the Borg-10 scale, while the overall assessment of the job was considered not very stressful. The task can be classified as repetitive for the upper extremities, while extended periods of seated work are also present. The work chair is unsuitable for industrial work, and there is limited room for the legs under the workstation. Grasping the tool to remove the collapsible tubes from the conveyor belt and placing them in the cardboard box leads to ulnar wrist deviation.

3.3 Intervention Measures

Several interventions to improve the workplace have been proposed, including introducing an adjustable industrial chair and a height-adjustable conveyor belt to improve worker positioning. During the design proposal stage, specifications such as fitting ranges based on anthropometric measurements of the population were provided. A significant emphasis was placed on the design of an ergonomic hook-type hand tool for picking up collapsible tubes. This is to improve the grip in terms of wrist deviation of the hand. The workstations and an ergonomic hand tool were redesigned using Tinkercad (see Fig. 2).

Table 2. Results of the application of ERIN.

Evaluation	Posture
 Trunk with extension and lateral rotation, frequency less than five times per minute.	
 Arm with extension between 45 ° and 90° and with separation from the body.	
 Postural load with flexion and extension between 0° and 20° plus wrist deviation.	
 The neck has slight flexion between 0° and 20° plus lateral neck torsion.	

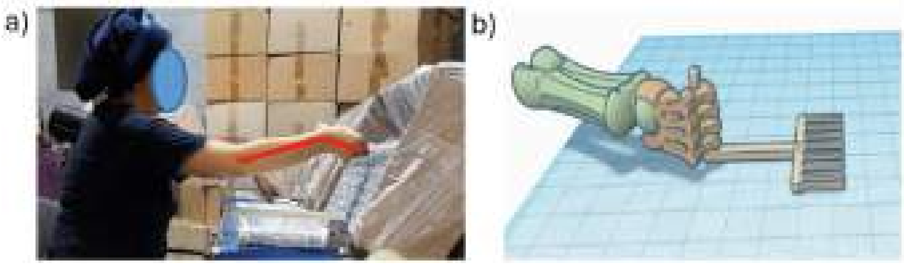


Fig. 2. **a)** Current tool that causes wrist deviation, **b)** Proposed tool design with an ergonomic handler to improve wrist posture.

4 Discussion

The upper distal extremities, particularly the wrist, were highly compromised in the task under study. The SNQ and ERIN evaluations show that the wrist is a body region of significant concern. Repetitiveness and ulnar wrist deviation were identified as risk factors. Concerning the lower back, this body region was not among the highest risk according to ERIN results. However, all four workers reported back discomfort in the SNQ. This discomfort may be due to prolonged periods of sitting and the adoption of awkward trunk postures as a co-exposure factor [8] rather than sitting while at work alone [9]. ERIN does not appear to be sensitive to the latter. Shoulder discomfort could be due to moderate flexion, which was identified with ERIN. This flexion occurs during the placement of the collapsible tubes in the last level of the cardboard box. Discomfort in the lower extremities may be associated with the lack of space under the conveyor belt, which restricts leg movements. It could be argued that the analysis could have benefited from including methods more focused on repetitive upper extremity tasks, such as the Strain Index or OCRA, along with the use of ERIN. But these methods also add complexity to the analysis process.

5 Conclusion

There are reports of discomfort in various body regions among workers, particularly the wrists and lower back. The results of the evaluation using the ERIN method showed a very high risk of MSDs. The wrist and neck were the body parts with the relatively highest scores. Ulnar deviation of the wrist originates from the poor design of the tool for moving the collapsible tubes. Other identified influencing factors were prolonged sitting position in conjunction with awkward postures of the trunk (low back pain) and lack of space for the lower limbs under the workstation (lower limb discomfort). The proposed solutions focus on improving working conditions using ergonomic principles.

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Gravel Collectors in Algeria's South-West: Work-Related Musculoskeletal Issues and Risk Factors

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Abstract. Some people are compelled to pay for labour taxing in developing countries when employment opportunities are scarce in order to earn a living. Some people gather gravel in the southwest of Algeria (Adrar and Timimoun provinces) and sell it to generate income. This study illuminates this work and those engaged in it. To achieve this goal, the study will answer the following questions:

1. In Algeria, who does the work of gathering gravel?
2. Which body parts are impacted by this work?
3. What risks do persons who gather gravel face?

Research was conducted in the provinces of Adrar and Timimoun. It appeared that women were the only ones in charge of gathering gravel in these locations. A sample of 13 women were chosen for the PLIBEL questionnaire (checklist).

The majority of respondents are over 40, have only primary education, are widowed, have had a job for more than five years, and are from low-income backgrounds.

The elbow, forearm, and hands experienced the most musculoskeletal symptoms, according to the PLIBEL checklist.

It has been found that women working in gravel collection in Adrar and Timimoun are exposed to many risks. The physical risks (including extreme heat, extreme cold, scorching sunlight, noise, and dusty winds), the biological risks especially those transmitted by poisonous insects, reptiles and plants, and the risks of Insect-borne Diseases.

Gravel collection is a profession that is barely acknowledged despite the fact that it exists in many poor countries where people struggle to find jobs.

Keywords: Gravel Collectors · South-West of Algeria · PLIBEL Questionnaire · Work-Related Musculoskeletal Disorders

1 Introduction

Unemployment is a problem in many nations around the world [1]. Work holds a significant place in life since it allows a person to provide for themselves and their families in a decent manner without having to turn to others for support. The capacity to work helps

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people maintain their psychological and financial security. In summary, work plays a significant role in both the life of the person and societal dynamics. However, unemployment is one of the major issues that might pose a threat to any civilization. The severity of this issue is economic. Individuals' social and psychological problems are significantly impacted.

A person who looks for work but is unable to find it may cause a lot of societal issues. Thus, unemployment is dangerous for both the individual and society [1].

Securing gainful employment now often entails a lengthy and laborious process. More than ever, people must look for work on their own rather than depending on government assistance.

In this perspective, it is important to note that many impoverished people, both sexes, in developing nations collect gravel in natural settings (such as fields, gardens, rivers, etc.) in order to sell it and pay for basic necessities. These people are coerced into doing this labor, despite how difficult it is, to escape poverty [2].

Despite the fact that many people have been engaged in this endeavor for a long time, nothing is known about it. Additionally, little is known about persons who perform this labor. This research was conducted to gain further insights into the job and the individuals who perform it.

Therefore, the purpose of this research is to identify the individuals responsible for collecting gravel in the provinces of Adrar and Timimoun (Southwest Algeria). Furthermore, to investigate the impact of work on people as well as the hazards that workers face on the job.

1.1 Research Questions

The following questions are addressed by this study:

1. Who performs the labor of collecting gravel in Algeria?
2. Which sections of the body is this work affecting?
3. What dangers exist for those who collect gravel?

2 Methodology

2.1 Method

The descriptive survey method was employed since it is the most suitable.

2.2 Sample

To establish the research sample, two researchers (M.S. & B.M.) visited each of the provinces of Adrar and Timimoun on a field trip to find out who is responsible for collecting gravel. It seems that women were solely responsible for collecting gravel in these places. As a result, 13 women were selected as a sample using the convenience sampling approach. Table 1 reveals their traits.

Table 1. Demographic characteristics of women collecting gravel (n = 13).

Characteristic	Options	Values	%
Age (years)	<40 years	03	23
	>40 years	10	77
Educational level	Read & write	04	31
	Primary Education	09	69
Marital Status	Married	03	23
	Widowed	07	54
	Divorced	03	23
Work Experience (Years)	<05 years	05	38
	>05 years	08	62
Feeling poor	Yes	13	100
	No	00	00

Table 2. PLIBEL Checklist results of women involved in doing the gravel collection occupation.

Body area	Neck, Shoulder, & Upper back	Elbows, Forearms, Hands & wrists	Feet	Knees & Hips	Low Back
Number of complaints	12	13	12	12	11
% of complaints	92	100	92	92	85

2.3 Data Gathering Instruments

The PLIBEL (Plan for Identifiering av Belastningsfaktorer) questionnaire which is an observational technique, was used to gather data. It has been employed by many researchers and is advised for usage in outdoor jobs such as collecting gravel [3].

3 Results

The following three questions are the focus of this study:

3.1 Who Performs the Labor of Collecting Gravel in Algeria?

Table 1 displays a number of results related to the sample members, such as age, educational level, social life, work experience, and extent of feeling of poverty.

3.2 Which Sections of the Body is this Work Affecting?

The task is carried out over a sizable area. Sweeping the area is the initial step in the collection procedure, after which gravel is gathered in small heaps. When there are windy conditions, workers rely on it to separate the gravel from sand and dirt. When there is no wind, gravel is sorted using a riddle. Then gravel is gathered in bulk for truck transport.

According to the PLIBEL checklist, the most common musculoskeletal symptoms were experienced in the elbows, forearms, wrists and hands. The percentage of complaints for these areas reached 100%, meaning that all respondents expressed pain in these areas. The percentage of complaints for low back was 85%. The PLIBEL checklist found that it was the lowest proportion. However, the complaints of (Neck, Shoulder, & Upper Back), (Feet), (Knees & Hips), and (Low Back) were 92%, ranking them between the lowest (85%) and the highest (100) (Table 2).

3.3 What Dangers Exist for Those Who Collect Gravel?

Three different categories of dangers have been identified as being present for women working in the gravel collection industry in Adrar and Timimoun. These are:

1. **The physical dangers.** Such as dusty winds, intense heat, intense cold, and blazing sunlight.
2. **The biological dangers.** These include diseases that can be spread by venomous snakes, spiders, scorpions, stinging insects, and other venomous reptiles and insects, as well as poisonous plants.
3. **The dangers of disease caused by insects.** Insects like ticks or mosquitoes can spread vector-borne diseases to workers

4 Discussion

4.1 Why Do Women Work as Gravel Collectors?

The fact that women may not have found a better job than this one is the first possible factor. Financial necessity can be the second factor. It turns out that the ladies are entirely responsible for themselves and for their families. They therefore strive to acquire what they can to meet their daily requirements and the wants of their family members. Thirdly, gravel work is a low-skilled job. No formal training or specialized abilities are needed for someone to be able to collect gravel. As a result, it is a job that employs workers without special skills. Let's not lose sight of the fact that work, any labor, contributes to the happiness of people who perform it. Layard [4] noted that having a job is preferable to being unemployed. Grun et al. [5] found that this is true even for low-quality jobs. Women who work in the gravel industry prefer this line of work as long as it provides for their own sustenance as well as the sustenance of family members.

4.2 Which Sections of the Body is this Work Affecting?

Work involving the upper extremities is required for gravel gathering. As a result, discomfort was experienced by women in all areas of the upper extremities (elbows, forearms, hands, and wrists). Women feel pain because they perform the following job-related tasks. i.e., sweeping the area where the gravel is collected, sifting the dirt to remove the gravel, piling the gravel, and then collecting it in a truck and selling it. These sub-tasks need to be completed using the upper limbs. We find that the task of collecting gravel is characterized as a manual-intensive function in terms of the use of the hands by taking into account the complaints of all female workers. The results from the PLIBEL questionnaire were confirmed by the researchers using the stress index. The result showed that working in gravel collecting resulted in a stress index of (13.5).

The fact that it does so indicates that the work is dangerous. Research has shown a relationship between repetitive hand-related work exposure and musculoskeletal disorders, particularly in tasks involving a lot of force. The findings of this study are consistent with those of earlier scholars. It agrees, for instance, with what was discovered in the study by Simonsson & Rwamamara [6] that the majority of respondents who work in the conventional technique of using concrete reported experiencing pain in their necks, shoulders, and upper backs. The lower back then complains after that. Not much was spoken about the feet, knees, or hips. The elbows, forearms, hands, and wrists were the areas where complaints were most prevalent.

4.3 What Dangers Exist for Those Who Collect Gravel?

Due to the fact that gravel collection work is conducted outdoors across a wide area, it can be an unsafe job according to Toscano's standards [7]. Many researchers have indicated that outdoor work in general is hazardous [8].

Gravel collection job is done in remote desert places; therefore, it stands to reason that there are many risks involved.

These results are consistent with the findings of a number of previous researchers. Madadin, et al. [9] found that increasing numbers of people who live and work in deserts and wilds are infected with stings from scorpions, snakes, and other insects. What could threaten human health more is that rural areas are more isolated and health services are limited. Adrar region (including Timimoun), where this research was carried out, is categorized as B (Dry), W (Arid Desert), and h (Hot) or BWh under the Köppen Scheme [10]. Adrar is one of the hottest cities in the world due to the average maximum temperatures of 46 to 48 °C (July). Workers engaged in outdoor activities are exposed to significant heat stress during the warmer months of the (May, June, July, and September), with the high temperature serving as one of the main health threats [11].

5 Conclusion

In this study, we shed light on a group of women who work in the gravel collection industry. Though it exists in many nations, particularly poor ones where some people struggle to find employment; it is a profession that is hardly acknowledged. Despite the difficulties of their job, they were forced to undertake it to provide for their families. They provide for their families' needs financially. People who are aware of this occupation may feel sorry for women and advise stopping them from working because it is dangerous and difficult work. In actuality, ergonomics does not adhere to this perspective. Even if a task is tough, ergonomics does not preclude individuals from performing it. The goal of ergonomics is to make work more user-friendly and adaptable to the needs of the worker by modifying what can be altered about it.

In light of this, we suggest changing the gravel gathering profession to make it less demanding and hazardous. Flexibility in work hours will enable working women to do so during periods of cool, pleasant weather. Providing industrial gloves to female workers so they can shield their hands and fingers from insects, reptiles, and other potential hazards while working.

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Characteristics of Standing Work in the Colombian Working Population

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Abstract. Standing work is common in various industries and services and has been associated with lower limb and lower back pain, increased leg swelling, and adverse vascular effects. This study aimed to characterize standing work within a Colombian labor population. An online questionnaire was given to participants of a virtual event organized by the Directorate of Surveillance and Control of the Ministry of Labor of Colombia. A total of 2,936 individuals registered for the conference, with 1,111 attendees. Among the registrants, 415 provided valid responses. The main results were: 60% of the companies have standing workers in confined spaces with limited mobility for prolonged periods. Concrete (71.6%) and pavement (51.6%) are the most common work surfaces. Safety boots, described as curved sole/unstable (41.2%) and flat (34.5%), were the most reported footwear. 65.5% of the companies have workers standing for more than 4 h in total. The majority of participating companies have workers standing on production lines (52.8%) and in customer service (45.3%). The findings of our study provide initial data that may encourage further research and the development of actions aimed at improving working conditions in standing activities.

Keywords: Standing work · Occupational risk factors · musculoskeletal disorders · lower extremity · low back pain

1 Introduction

Standing work is shared across a wide range of activities in both industry and services, and it has been associated with reports of lower limb and lower back pain, increased leg volume, and adverse vascular effects [1, 2]. Key factors to consider when characterizing standing work include low mobility standing posture [1, 3–5], duration of standing [1, 2, 6, 7], type of footwear used [8–12], and type of surface [10, 13–16], among other factors. No formal study has been conducted in Colombia to characterize standing work within companies, even though many activities require standing work.

The aim of this study was to characterize standing work within a Colombian labor population. An online questionnaire was administered to participants of a virtual event organized by the Directorate of Surveillance and Control of the Ministry of Labor of Colombia.

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2 Materials and Methods

A descriptive exploratory study was carried out to analyze standing work in a Colombian labor force. An online questionnaire was created using Microsoft Forms to aid this analysis. The questionnaire comprised 27 questions organized into five sections. For each question, the participant had two response options: YES, the working condition was present, or NO, the working condition was not present. The factors included in the questionnaire were: type of posture adopted (6 questions), standing time (3 questions), type of surface (7 questions), type of footwear (8 questions), and job profile (3 questions).

This questionnaire was sent to legal representatives and occupational safety and health staff of Colombian companies who registered for a virtual conference entitled "Standing work: Risks and Consequences," organized by the Department of Surveillance and Control by the Ministry of Labor of Colombia. On the conference day, attendees were asked again to complete the questionnaire. Participation was voluntary and anonymous, and no incentives were offered. The questionnaire was open to receiving responses for 18 days (from September 7 to 25, 2023) and allowed only one response per participant.

3 Results

A total of 2,936 individuals registered for the conference, and 1,111 attended. From the registered participants, 415 valid responses were obtained, representing 14.1% of the registrants. The main results are shown in Table 1.

4 Discussion

In this study, standing work was characterized in a sample of Colombian companies. Some of the features reported by respondents as present have been described in the scientific literature as factors associated with lower limb and lower back pain, increased leg volume, and potential cardiovascular problems, among others [1, 2]. These characteristics may influence the increase or decrease of symptoms perceived by workers who stand for long periods; however, it is unknown in which scenarios or combinations of these characteristics their influence might be greater or lesser.

The static standing posture in confined spaces with limited mobility for prolonged periods (<20 cm) has been reported as a working condition that precedes the onset of musculoskeletal symptoms in the lower limbs and lower back [2]. In our study, 60% of the companies reported having workers in this posture during the workday. Companies should pay greater attention to prolonged static standing in confined spaces due to its potential adverse effects.

Another relevant characteristic related to standing work is time. According to Dutch work guidelines [7], if a worker stands for at least one continuous hour or four hours in total, there is a moderate risk, and improvement actions should be recommended. In our study, 61.4% of the companies reported having workers who stand for more than one continuous hour, and 65.5% have workers who stand throughout the entire workday. Therefore, according to the Dutch guidelines, workers in the companies participating in this study would be at moderate risk due to the prolonged standing time.

Table 1. Characteristics of standing work in the companies participating in this study. N = 415.

Work features			Responses	
			Yes (%)	No (%)
Posture	Standing: mobility restricted to 20 cm around		250 (60.2)	165 (39.8)
	Standing with mobility more than 1m around		396 (94.7)	22 (5.3)
	Standing: with lifting or pushing/pulling of loads		314 (75.7)	101 (24.3)
	Standing: with trunk flexions and extensions		346 (83.4)	69 (16.6)
	Standing: with the need to bend or squat		288 (69.4)	127 (30.6)
	Standing: with the option of sitting or resting when desired		347 (83.6)	68 (16.4)
Time	Standing: less than one hour continuously		255 (61.4)	160 (38.6)
	Standing: more than 4 h in total		272 (65.5)	143 (34.5)
	Standing: less than 4 h in total		251 (60.5)	164 (39.5)
Worksurface	Hard	Steel	46 (11.1)	369 (88.9)
		Concrete (floor)	297 (71.6)	118 (28.4)
		Pavement	214 (51.6)	201 (48.4)
	Soft	Wood	53 (12.8)	362 (87.2)
		Anti-fatigue mat	32 (7.7)	383 (92.3)
		Cardboard	7 (1.7)	408 (98.3)
		Rubber	22 (5.3)	393 (94.7)
Type of footwear used	Safety boots with flat soles		143 (34.5)	272 (65.5)
	Safety boots with curved sole/unstable soles		171 (41.2)	244 (58.9)
	Tennis with flat soles		65 (15.7)	350 (84.3)
	Tennis with curved soles/unstable soles		64 (15.4)	351 (84.6)
	Shoes with flat soles		82 (19.8)	333 (80.2)
	Shoes with curved soles/unstable soles		62 (14.9)	353 (85.1)
	Women's footwear with heels over 3 cm high		8 (1.9)	407 (98.1)

(*continued*)

Table 1. (*continued*)

Work features		Responses	
		Yes (%)	No (%)
	Women's footwear with heels less than 3 cm high	33 (8)	382 (92)
Job type	Production line	219 (52.8)	196 (47.2)
	Customer service	188 (45.3)	227 (54.7)
	Security guards	14 (3.4)	401 (96.6)
	Logistics	40 (9.6)	375 (90.4)
	Maintenance	25 (6)	390 (94)

Working on hard surfaces can negatively affect the lower limbs and lower back [10, 12]. Our study reported that most workers are on hard surfaces: concrete (71.6%) and pavement (51.6%). In this regard, a recommendation in the scientific literature is to use soft surfaces instead of hard ones [1, 10]. However, it has been noted that in studies analyzing the use of soft work surfaces, the technical characteristics of the type of surface and footwear used need to be described in detail [10].

According to some research, using unstable footwear reduces self-reported symptoms in the lower limbs, lower back, and muscle activity [11, 17, 18]. In our study, the most reported footwear was safety boots: unstable (41.2%) and flat (34.5%). It should be noted that less than 50% of the companies that responded to the questionnaire use unstable footwear despite its potential advantages [11, 17, 18]. However, the low reported percentage of safety boot use may be because, in many companies participating in this study, workers are not required to wear safety boots.

In our study, most participating companies have workers in production lines (52.8%) and customer service (45.3%). These results are similar to those of other studies on standing work [19–22]. Based on this, future studies on standing work in Colombia should primarily focus on the workforce in the industrial and customer service sectors.

The findings of this study are significant for the Colombian population, as standing work has yet to be explored in the country. The preliminary information obtained in this study can be used to formulate public policies for the musculoskeletal health care of Colombian workers. However, a limitation of this study is that the results cannot be generalized to the entire Colombian population due to the methodological design of the study. Therefore, it is necessary to expand the scope of this study in the future to include more economic sectors and to more accurately assess the number of workers who stand, as well as other characteristics such as posture, work duration, and breaks, type of work surface, and type of footwear, among others.

Finally, the authors would like to thank the Directorate of Surveillance and Control of the Ministry of Labor for facilitating the development of this study.

5 Conclusions

This study provides an overview of the main characteristics of standing work in a Colombian labor population. This information may help develop policies and actions to improve working conditions in standing activities.

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Ergonomic Assessment of Work Activities for an Industrial-Oriented Wrist Exoskeleton

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Abstract. Musculoskeletal disorders (MSD) are the most common cause of work-related injuries and lost production involving approximately 1.7 billion people world-wide and mainly affect low back (more than 50%) and upper limbs (more than 40%). It has a profound effect on both the workers affected and the company. This paper provides an ergonomic assessment of different work activities in a horse saddle-making company, involving 5 workers. This aim guides the design of a wrist exoskeleton to reduce the risk of musculoskeletal diseases wherever it is impossible to automate the production process. This evaluation is done either through subjective and objective measurement, respectively using questionnaires and by measurement of muscle activation with sEMG sensors.

Keywords: Wrist Ergonomics Assessment · Hand Activity Level · Visual Hand Pain Mapping · sEMG · Work-related Musculoskeletal Disorders

1 Introduction

Prolonged, violent, irregular motions and incorrect postures in the working environment can cause a variety of common musculoskeletal diseases, which can be episodic or chronic in duration. They can progress from mild to severe and impair the quality of life of workers, by reducing mobility and dexterity in activities of daily living (ADL).

As reported by the European Agency for Safety and Health at Work (EU-OSHA) [1] the majority of these accidents affects low back (more than 50%) and upper limbs (more than 40%). In this end, exoskeletons and wearable robotics technologies are gaining attention to support workers in strenuous manual activities wherever it is impossible to automate the production process. However, an ergonomic assessment of the working environment and activity is necessary to design these devices effectively, guaranteeing reliability, compliance, accurate assistance, and safety, and justify the introduction of an assistive device.

This study aims to provide an ergonomic assessment of the musculoskeletal risk to the hand and wrist, arising from work activities in a horse saddle production plant. Since

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most of the activities are handcrafts and require excellent manual skills, which cannot be transferred to a robot, exoskeletons specifically designed to reduce biomechanical overload on workers may form an excellent technological alternative [2–4].

2 Methodology

In this study, the participants are craftsmen skilled in the production of horse saddles. The activities done in their manufacturing plant are laborious, and one of the major causes of injuries (e.g. carpal tunnel syndrome) and absence from work. Five healthy male subjects (age range: [25, 45] years) were recruited in the same day. Four of them are identified as right-handed and only one as left-handed [5]. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Liguria (protocol reference number: CER Liguria 001/2019). The protocol respects users' right to privacy in accordance with the General Data Protection Regulation (GDPR) [6].

Five working tasks, from 'a' to'e' as shown in Fig. 1, are identified by the industrial hygienist of the company to be more strenuous during the work shift. Not all the subjects performed the same activities, in particular: the participants P1 and P3 conducted tasks 'a' and 'b'; the participants P2, P4, and P5 conducted tasks 'c', 'd', and 'e', respectively. All these activities are different but they have in common the use of force with the hand and wrist, the placement of the wrist in non-ergonomic positions, and the grasping of a work tool.

Fig. 1. Working tasks assessed: seat preparation (a) and assembly (b), cushion covering (c), cushion mounting (d), and sewing (e).

Before each experimental session, Maximum muscle Voluntary Contraction (MVC) is measured for the following 5 wrist activities: wrist flexion, wrist extension, wrist radial deviation, wrist ulnar deviation, and grasping. This provides a baseline to be compared with the muscle activation during actual work. To ensure correct parallelism with the ground, each participant is seated comfortably on a chair and with the elbow and forearm placed on a table, leaving only the wrist free to move [7]. Participants receive visual instructions asking them to apply as much force as possible against a contrasting element while performing a wrist gesture. To detect and measure the hand/wrist muscular effort made during the work, the electrical muscle activation of each subject's forearm is recorded with a Myo Armband (Thalmic Labs), which is a commercially available 8-channel, dry-electrode, low-sampling rate (200 Hz), and low-cost electromyography (EMG) sensor. Because electromyography signals are notoriously noisy, they are pre-treated before being used [5]. They are first rectified, then filtered with a cutoff frequency of 5 Hz, and finally normalized to the 98% percentile of the MVC to make them comparable among different subjects.

For each experimental session, participants perform their typical work activity for 3 to 5 min, while muscle activation measurements are acquired using EMG sensors on both the left and right arms. Once the task is completed, under the administrator's supervision, participants are asked to complete a series of scales and questionnaires for subjective validation of the perceived level of fatigue experienced and effort required while performing the task. These assessments included: NASA Task Load Index (TLX), the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) for Hand Activity (HAL), and Visual Hand Pain Mapping (VHPM).

3 Results

Data from the questionnaires (subjective assessment of perceived fatigue) and the measurements of electrical muscle activation (objective assessment of muscle fatigue) are collected and combined to search for a correlation between what is perceived by the subject and what is measured. This analysis gives a more objective perspective on the impact of that task on the worker's health. It is an essential step in preventing occupational accidents.

NASA TLX is a widely used subjective assessment tool that rates perceived workload [8]. The data acquired by administering the NASA TLX are reported in Fig. 2. It can be seen that subjects tend to define the tasks as moderately or highly strenuous, performing them at a near-optimal level of performance.

As suggested in the technical report ISO/TR 12295:2014 for the application of ISO ergonomic standards for manual handling of loads (ISO 11228) and static working postures (ISO 11226) [9, 10], the HAL/ACGIH TLV may provide insight on the assessment of musculoskeletal risk factors associated with the hand and wrist during multi-task work. It estimates the level of manual activity in terms of repetitiveness of movements and relative duration of the task compared to breaks, and the intensity of the applied force, which can be assessed with EMG or, more simply, with the CR-10 (Borg) scale. To compare between objective and subjective perception, the applied force is evaluated using respectively the EMG measurements and the Borg scale. Hereafter, the results of the HAL/ACGIH TLV analysis are presented in Fig. 3, reporting both the old threshold limits (dated back to 2001) and the updated version (2018) [11]. As can be seen, the level of action limits (AL) has been lowered in the new version, thus widening the risk zone (yellow + purple in Fig. 3). All activities rated below the AL line are considered non-hazardous; those rated between the AL and TLV limits are of significant risk and require monitoring; while those above the TLV (red area in Fig. 3) are at high risk and require timely action to improve working conditions.

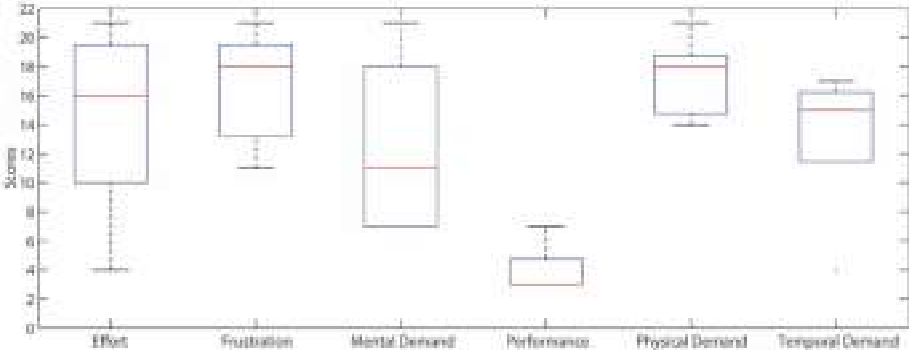

Fig. 2. NASA Task Load Index is divided into six subjective sub-scales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration). These scales score perceived fatigue from "Very Low"(1) to "Very High" (21), except for "Performance", with which a task is performed, which is rated from "Perfect" (1) to "Failure" (21). In all cases lower values represents better scores.

Overall subjectively perceived fatigue by workers is high and above the threshold limit value (white triangles in Fig. 3). Starting from the EMG measurements, the Normalized Peak Force (NPF) has been estimated considering the average value of the predominant channel during the task normalized for its MVC. Objectively, there is a tendency to detect medium to high fatigue, with values around the threshold limit, but still lower than what the person perceives at the subjective level.

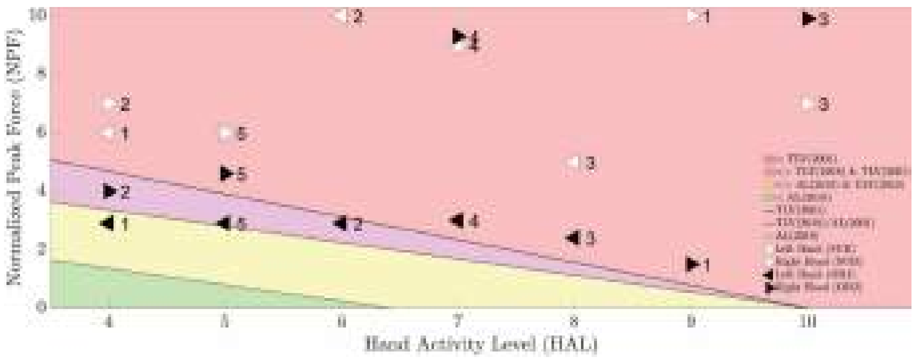

Fig. 3. HAL/ACGIH TLV assessment. The graph shows the maximum normalized force values (NPF) of 5 subjects exerted by the right hand and left hand while performing work activities, reporting both the old (2001) and updated (2018) threshold limits. White triangles report subjective (SUB) measures assessed by administering a CR-10 Borg scale to subjects; while black triangles report objective (OBJ) measures derived from an analysis of EMG data.

Finally, following the guidelines proposed by the VHPM protocol [12], subjects were asked to indicate and judge in which areas of their hands and wrists they experienced the major discomfort during the activity.

4 Discussion

The results obtained correlate worker-perceived fatigue and electromyography sensor measurements. As known in the literature, amplitude-based measures such as the maximum value, the average rectified value and the root mean square value of the EMG signal have generally been shown to increase with fatigue, leading to a decline in the muscle output force and performance exerted by a limb. Despite the limitations of this work, such as short duration of the task-performing, the number of participants and repetitions, which will be extended in future, the results of the HAL/ACGIH TLV assessment reported in Sect. 3 show that subjects tend to perceive greater fatigue than is actually objectively detected at the level of muscle activity. This difference can also be explained by the fact that the NASA TLX results show that subjects, in addition to physical exertion, also perceive medium to high mental demand, temporal demand, and frustration, which cannot be measured by processing muscle activation signals. Overall, the muscle fatigue to which workers are subjected is medium to high, and through a VHPM analysis, they highlight discomfort in their hands and wrists at critical points such as the carpal bones of the wrist, ulna and radius joints, in the thumb, the index and middle fingers. These are considered significant sites of interest for the onset of musculoskeletal disorders such as carpal tunnel syndrome, strains, tendinitis, and tenosynovitis. These findings are of enormous value in designing a wrist exoskeleton, selecting movements to actuate, choosing sensors, and positioning them according to the most active forearm muscles, as well as for the design of exoskeleton garments with the addition of elastic, soft or hard interfaces to protect the most delicate parts of the limb.

5 Conclusions

This study forms the basis for an ergonomic assessment of working tasks involving hand/wrist manipulation actions, either through subjective (questionnaires, scales and personal opinions) or objective measurements (sEMG data). Results can be effective in identifying critical tasks for worker's health and may suggest that adopting new technological solutions could prevent or reduce the onset of work-related musculoskeletal disorders, although the application of exoskeletons to task involving precise hand movements is still a challenging area. To this end, future work include the design of an exoskeleton to assist the most frequent wrist movements per-formed by workers and the addition of interfaces to protect the most delicate parts of the limb.

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A sEMG Analysis to Assess the Efficiency of a New Lorry Design for Reducing the Biomechanical Risk of Waste Collection Workers

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Abstract. The paper aims to examine the redesign of a truck to decrease the biomechanical load on kerbside waste collection workers. Two workers (one man and one woman) simulated unloading 10 kg bins inside the vehicle using five techniques at varying heights and horizontal distances.

We estimated bilateral mean muscle activity as a percentage of Maximum Voluntary Contraction (%MVC) from Anterior Deltoideus, Lateral Deltoideus, Upper Trapezius, and Erector Spinae using sEMG.

The trunk muscles of both workers exhibited the highest %MVC at a height of 145cm. For male, we observed the lowest %MVC values (16% for ESdx and 23% for ESsx) at 105 cm and 135 cm heights. For women, techniques with less overloading with the lowest %MVC values are 105 cm and 185 cm heights. Nonetheless, the combined %MVC values were still high (65%).

At a height of 105 cm, both workers showed the lowest %MVC values for their shoulders.

The highest %MVCs for anterior deltoids were observed in men at a height of 145 cm, while both trapezius muscles showed the highest overall %MVCs at 145 cm and 185 cm heights.

Women exhibited the highest %MVCs for shoulder muscles on the left side at a height of 145 cm, and all TRdx values exceeded 40%. We found that the most overloading was 185 cm height.

Handling techniques at 200 cm height has not been investigated. Workers refused to simulate because too high.

The study findings revealed both negative and positive effects.

We observed adverse effects when workers pulled a wire to open the backdoor of a lorry at a height of 145 cm, which resulted in increased biomechanical load on the shoulders and into a waste of time.

Handle bins at 145 results in a high %MVC due to an increased horizontal distance of 35 cm.

Positive, concern lowering of whole lorry to reduce load for lower limbs in repeated hop on hop off and a reduced handling height of container (135 cm Vs. 105 cm). Additionally, the use of homologated containers will optimize collection round times.

Despite these improvements, there is still a high biomechanical risk, particularly for women. Limitation of the study is the small sample size.

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Keywords: waste recycle · door to door · garbage · ergonomics · musckuloskeletal disorders · MSDs

1 Introduction

Biomechanical load in waste collection workers it's a well know problem. The first paper in literature that showed high presence of musculoskeletal disorders for workers is from 1975 [1]. Since 1975 several papers from all the world investigated musculoskeletal disorders in waste collection workers.

On this basis we have already investigated biomechanical load in this activity under several point of view.

In a first paper [2] we investigated handling the bin inside a lorry in four different techniques through 3DSSPP software [3]. We found that the most overloading technique was emptying the bin directly in the lorry from the back, followed by the technique of handling from a lateral window. The less overloading techniques was emptying the bin in a non-homologated container that, however, presented problems concerning trunk flexion. Handling inside a homologated container showed organizational problems dues to its reduced capacity leading to a considerable increase of the collection round duration.

We investigated [4] the same lorry configuration also through the dynamic REBA protocol [5, 6] analyzing all the task from rising the bin from the floor to its emptying in the lorry. Results of this paper confirmed our previous results indicating the handling inside the lorry from the back as the most demanding technique and handling in the homologated container as the less overloading one but with the same organizational problems dues to its reduced capacity.

Our results are still confirmed also through surface electromyography [7].

We have also assessed all the waste collection round through heart rate monitors [7, 8] founding high levels of Relative Cardiac Cost [9, 10].

The present research, although similar to the previous ones in terms of method (surface electromyography) and aims, differs due to different design features (height and horizontal distance) of the investigated lorries. We did a simulation on two vehicles, an old one that was being dismantled and a newer one designed with the aim to reduce the biomechanical load in waste collection workers.

Purpose of the study is to assess the effectiveness of lorry redesign to reduce the biomechanical overload risk of waste collection workers.

2 Materials and Method

The task consisted of unloading a 10 kg bin within two lorries using different techniques. Bin weight was 10 kg, it was lower than the 11.38 kg recommended by Oaxley [11] as the maximum weight limit for eight consecutive working hours with two lifts per minute. Our load is close to Botti's [12] mean weight (9.4kg). The lorries used in the simulation were the ones normally used, the old one (Fig. 1) and the new one (Fig. 2).

We acquired two workers (a female, 167 cm and 60 kg; a male, 176 cm and 74 kg). The workers did three acquisitions for each of the handling techniques. The task included lifting phase, transport, and the unloading of the bin. The handling techniques were:

Fig. 1. (left). Figure shows the old lorry for waste collection. The container in the back is not certified for the placement of the picture when lorry moves

Fig. 2. (right). The new lorry for waste collection. Is it possible to add a container in the back because is certified

1. in a certified container routinely unloaded in the lorry (new lorry; h 105 cm);
2. in a non-certified container routinely unloaded in the lorry (old lorry; h 135 cm);
3. in the lorry backside (backdoor down; new lorry; h 145 cm);
4. in the lorry backside (new lorry; h 185 cm);
5. in the lorry backside (old lorry; h 200 cm).

Figure 3 shows the workers during the simulations. They are wearing sEMG wireless probes

We investigated surface electromyography (sEMG) signals through simulations in the rubbish dump. We computed bilateral mean muscle activities, as a percentage of Maximum Voluntary Contraction (%MVC), from Anterior Deltoideus (DAdx, DAsx), Lateral Deltoideus (DLdx, DLsx), Upper Trapezius (TSdx, TSsx) and Erector Spinae

Fig. 3. Figure shows the two workers simulating the unloading of the bin in the four tested techniques

(ESdx, ESsx). MVC exercises and probes placement were in according to the Atlas of Muscle Innervation Zones [13].

Muscle activity was recorded by a Wi-Fi surface electromyograph (FreeEMG 300, BTS SpA) at a sampling rate of 1 kHz. After skin preparation, the electromyographic signals were acquired by two disposable Ag/AgCl electrodes for each muscle (H124SG, Kendall ARBO). Electromyographic signals were processed through rectification, integration with a sliding window of 125 ms, filtered with a low-pass filter at 5 Hz, and then normalized to the mean peak of two MVC acquisitions peaks for each muscle.

3 Results

We did not test technique 5, as workers rejected it due to excessive height.

Figure 4 shows the %MVC values obtained for the investigated muscles, for both workers in the four analyzed technique.

Trunk muscles (ESsx and ESdx) presented all the highest mean values in technique 3 (145 cm) in both acquired workers. In the male, techniques 1 and 2 (105 and 135 cm) showed the lowest muscle activation values (around 16% ESdx, around. 23% ESsx). For the woman, the techniques for less overloading for the trunk were 1 and 4 (105 and 185 cm). The combined muscle activation values between right and left were still high (around 65% MCV).

As regards the shoulders, the woman showed the highest values on all muscles on the left side in technique 3 (h 145), while the lowest values were all in technique 1 (105 cm). TRdx had all values exceeding 40%, making it the most engaged muscle with the overall maximum value (57.54% MCV). Technique 4 (h 185) was the most overloading overall; technique 1 (h 105) was the less overloading.

All man's shoulder muscles, save for the DMdx, showed the lowest muscle activation levels with technique 1 (105 cm). The highest values occurred in both anterior deltoids with technique 3 (145 cm); both trapezii showed the highest overall activation values with techniques 3 and 4 (145 and 185 cm).

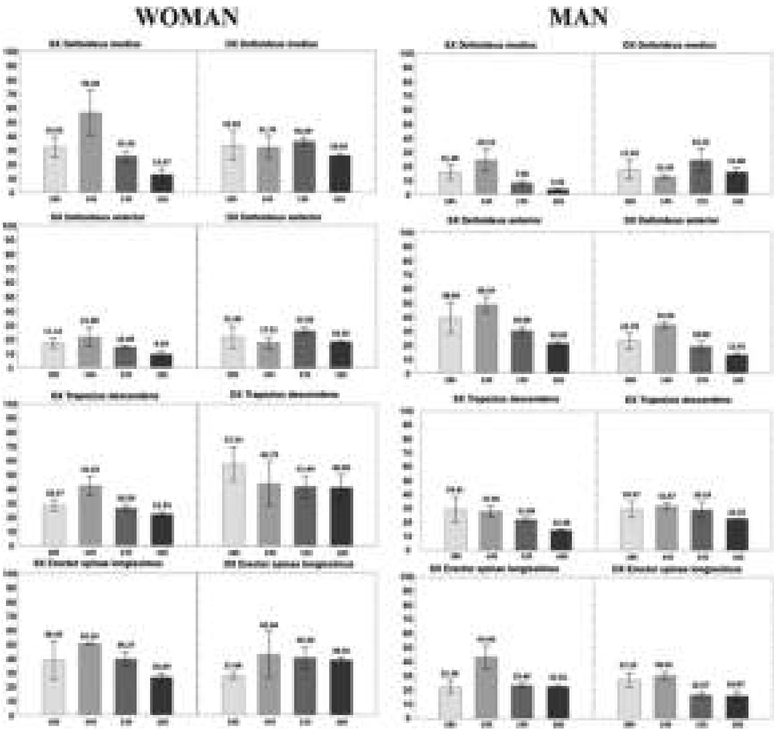

Fig. 4. The image shows electromyographic results for the eight muscles recorded from the two workers, expressed as %MCV, for the four techniques investigated.

4 Conclusion

Findings revealed some positive, as well as negative aspects regarding lorry modifications. The negative issues concern the installation of an iron wire to pull to allow the open the backdoor of the lorry (Fig. 5). This tool results in an increased biomechanical load of the shoulders. Moreover, handling the bins with this technique (technique 3), also results in a increased muscle activity, notably on the trunk muscles, caused by an increased horizontal distance of 35 cm.

The advantages concern the lowering of the whole lorry. This results in reduced load on the lower limbs in repeated hop on hop off task and a decreased height when handling the bin inside the container (135 cm old lorry Vs. 105 cm new lorry). Homologation of mounting an adequate capacity container in the new lorry leads to a reduced biomechanical overload risk for workers and optimization of collection round times. Collection round times is a relevant issue for workers as reported in a previous paper [14].

Although the introduction of these improvements, biomechanical overload risk for workers, mainly in women, remains high.

Limitations of the study regards the small sample size. We investigated only two workers because we did this study in a small city with few healthy workers. Another limitation, for a whole biomechanical risk assessment of waste collection workers, is that

Fig. 5. Red circle in the image highlights the iron wire used to open the backdoor of the lorry (Color figure online)

we investigated only one standardized task that they usually do in the collection round. We did not investigated push and pull activities because it's impossible to standardize this task in terms of weight handled pathway (length and type of flooring) and presence of stairs. Biomechanical load increase when waste collection is made in city with high density population and few public spaces for garbage container obliging workers along long paths, also with climbing stairs (Fig. 6). To avoid this, it could be advisable to introduce restricted areas (Fig. 7) for placing the garbage avoiding the workers to make long path with high load. In our case scenario it is also impossible to introduce pneumatic system dues to the morphology of the city [15].

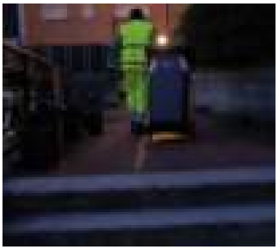

Fig. 6. (left). Image show worker while handling a bin for a long path after going up and down the stairs

Fig.7. (right). Image shows a worker taking rubbish bags from a designated restricted area

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Ergonomic Associated Factors and Risk Assessment on Musculoskeletal Disorders Among Farmers in Thailand

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Abstract. Musculoskeletal disorders (MSDs) represent the most significant work-related health in occupational workers. This study aimed at determining the ergonomic factors associated with MSDs and risk assessment among farmers in Thailand. A cross-sectional analytical study was conducted of 71 farmers. The risk matrix assessment was used to identify risk levels. The finding found that 43 (60.6%) farmers were male, and 28 (39.4%) farmers were female. The association analysis demonstrated that education level, cigarette smoking, and work experience were majorly associated with the past 12-month of any MSDs ($p < 0.05$). Farmers reported the highest prevalence of MSDs in the lower back (35.2%), followed by knees (33.8%), and shoulders (25.8%). In any MSDs, farmers reported 50.7% in the past 12-month. In ergonomics risk assessment, a matrix combining the risk levels of MSDs over the past 12 months with the Rapid Entire Body Assessment (REBA) risk levels revealed that among farmers, 8.6% individuals had an acceptable risk, 53.3% had low risk, 16.9% had moderate risk, 14.1% had severe risk, and 7.1% had a very severe risk level. The study suggests implementing ergonomics training among high to very high-risk farmers to prevent MSDs.

Keywords: Musculoskeletal Disorders · Farmers · Risk Assessment

1 Introduction

Musculoskeletal disorders (MSDs) are global public health concerns among occupational workers. They encompass pains or injuries affecting the muscles, joints, cartilage, nerves, and tendons, resulting in a poor quality of life and reduced productivity [1]. Farmers are commonly exposed to various types of ergonomics risk factors including repetition, awkward posture, forceful exertions, stationary position, direct pressure, mechanical vibration, extreme temperature, noise, and work stress [2]. The risk factors for MSDs are often multifaceted. They can be broadly categorized as individual-related

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factors, including gender, age, sleep, and physical activity [3]. In the years 2022–2023, the Health and Safety Executive (HSE) documented that over 473,000 workers were suffering from work-related MSDs [4]. The prevalence of MSDs on lower back pain was higher in Asia (54.16%) than South/Central America (28.52%) [5]. Many studies have reported risk factors affecting MSDs symptoms in agricultural laborers. The highest prevalence rates of MSDs were observed in the lower extremities (65.4%), lower back (42.6%), and shoulders (29.9%) [6]. Various ergonomic risk assessment tools can be employed to evaluate the probability of exposure to associated ergonomic risk factors and identify the risk level. Conversely, the Standardized Nordic Questionnaire (SNQ) serves primarily as an observational tool to assess prevalence of MSDs. The application of health risk assessment matrix technique on observational tool probably differentiated the likelihood of MSDs risk level [7]. However, many studies typically rely solely on surveys to identify ergonomic problems, whereas this study employs a risk matrix assessment technique to predict ergonomic risk level. Thus, this study aimed at determining the factors associated with MSDs and identify risk level using health risk matrix model among farmers in Thailand.

2 Methods

2.1 Study Design and Participants

A cross-sectional analytical study was conducted on a total of 71 farmers in Nakhon Ratchasima province, Thailand during September to October 2022. The eligibility of this study was included both male and female farmers with aged 20–59 years. There were excluded participants having pregnancy, arthritis, rheumatoid arthritis, gout, and history of bone fracture which reevaluated by medical records. This study protocol was approved by the Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University, Thailand (COA No. 157/65).

2.2 General Information, MSDs, and Ergonomic Risk Assessment

Demographic and work characteristics data collected used questionnaire. MSDs evaluation used the SNQ [8]. According to the MSDs, participants were requested to report whether "No = no pain" and "Yes = pain". Then, if they had pain at least a region of body classified as any MSDs. Finally, MSDs risk level was classified into no = 1 (no pain), mild = 2 (1–3 pain of body regions), moderate = 3 (4–6 pain of body regions), and severe = 4 (7–9 pain of body regions). The Rapid Entire Body Assessment (REBA) tool was used to assess ergonomics risk for both lower and upper limbs [9]. The risk assessment matrix was created to categorize the MSDs risk levels at past 12 months from multiplying row of REBA risk levels in the health risk matrix [7]. The principle total risk interpretation can be explained that the final ranked of the matrix of combined risk level of between MSDs risk level at past 12 months and REBA risk level among the farmers consisted of 0 score = acceptable risk, 1–2 scores = low risk, 3–4 scores = moderate risk, 6–8 scores = high risk, and 9–16 scores = very high-risk levels.

2.3 Statistical Analysis

The data analysis was accelerated through licensed IBM SPSS software (version 28.0.0.0). All study variables were analyzed by descriptive statistics. Fisher's exact test was used for analyzing the association between factors and any MSDs among farmers in Thailand. A p-value <0.05 was considered as statistical significance.

3 Results

Among 71 farmers, 60.6% were male, and 39.4% were female. The average(±SD) age of them was found to be 51.65.5(±6.31) years. Most of them graduated primary school (83.1%). The body mass index (BMI) was found at the mean(±SD) of 24.57(±3.79) kg/m^2. Only a few of the workers drink alcohol (28.2%) and smoke cigarettes (22.5%). The average(±SD) work experience and farm size were 13.32(±9.09) years, and 12.79(±29.07) Acres, respectively. The association between factors and any MSDs by Fisher's exact analysis demonstrated that education level ($p < 0.05$), cigarette smoking ($p < 0.01$), and work experience ($p < 0.05$) were majorly associated with past 12-month of any MSDs (Table 1).

Table 1. Demographic and work characteristics (n = 71)

Demographic and work characteristics	n (%)	Any MSDs at the past 12 months
		F (p-value)
Gender		3.45 (0.09)
Male	43 (60.6)	
Female	28 (39.4)	
Age		1.14 (0.34)
Less than or equal 52 years	36 (50.7)	
More than 52 years	35 (49.3)	
Mean/median ± SD = 51.65/52.00 ± 6.31; max-min = 32–59 years)		
Education level		6.63 (0.03) *
Primary school	59 (83.1)	
High school and higher	12 (16.9)	
BMI		0.2 9 (1.00)
Less than or equal 22.99 kg/m^2	25 (35.2)	
More than 22.99 kg/m^2	46 (64.8)	
Mean/median ± SD = 24.57/24.22 ± 3.79; max-min = 14.52–36.72 kg/m^2		

(*continued*)

Table 1. (*continued*)

Demographic and work characteristics	n (%)	Any MSDs at the past 12 months F (*p*-value)
Alcohol drinking		1.28 (0.30)
No	51 (78.1)	
Yes	20 (28.2)	
Cigarette smoking		13.21 (0.00) **
No	55 (77.5)	
Yes	16 (22.5)	
Work experience		5.16 (0.03) *
Less than or equal 10 years	31 (43.7)	
More than 10 years	40 (56.3)	
Mean/median ± SD = 13.32/12.00 ± 9.09; max-min = 2–40 years		
Farm size		0.07 (1.00)
Less than or equal 13.04 Acres	47 (66.2)	
More than 13.04 Acres	24 (33.8)	
Mean/median ± SD = 12.79/25.00 ± 29.07; max-min = 1.19–50.99 Acres		

Note: Statistically significant at *p*-value of < 0.05* and < 0.01** using Fisher's exact test

Farmers reported the highest prevalence of MSDs in the lower back (35.2%), followed by knees (33.8%), and shoulders (25.8%). In any MSDs, farmers reported 50.7% in the past 12 months (Fig. 1).

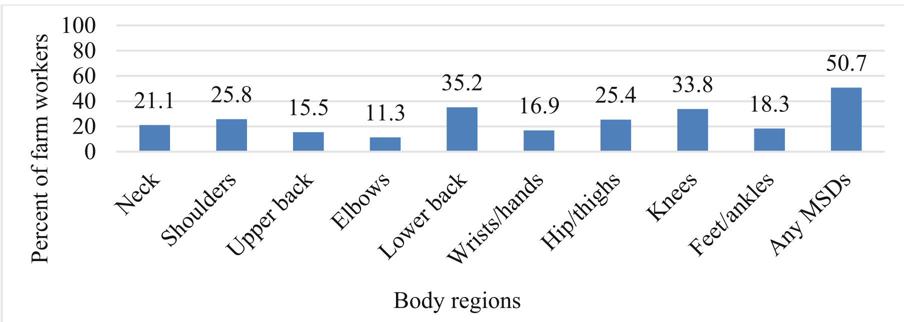

Fig. 1. Occurrence of MSDs at the past 12 months (n = 71)

Table 2 illustrates the risk levels among farmers during various farm processes. In the land preparation process, 39.4% faced no risk, 31.0% had a medium risk, and 29.6% had a high risk. During the sowing of seeds, 42.3% faced a medium risk while 57.7% faced a high risk. All farmers encountered a very high risk during the rice transplanting and harvesting processes. Regarding pesticide spraying process, 29.6% faced no risk, while 70.4% were at a high-risk level according to REBA.

Table 2. Rapid Entire Body Assessment (REBA) (n = 71)

Farm processing	Picture	Risk levels (REBA score) n(%)				Recommendation
		No (0)	**Medium** (4-7)	**High** (8-10)	**Very high** (11-15)	
Land preparation						
Not work	-	28 (39.4)	-		-	-
Walking tractor		-	-	21 (29.6)	-	Investigate and implement change
Tractor		-	22 (31.0)	-	-	Further investigation, change soon
Sowing of seed and fertilizer						
Manual spreader		-	30 (42.3)	-	-	Further investigation, change soon
Machine spreader		-	-	41 (57.7)	-	Investigate and implement change
Transplanted rice						
Transplanted by hands		-	-	-	100 (100.0)	Implement change
Pesticide spraying						
Not work	-	21 (29.6)	-	-	-	-
Manual sprayer		-	-	7 (9.8)	-	Investigate and implement change
Machine sprayer		-	-	43 (60.6)	-	Investigate and implement change
Harvesting						
Manual harvest by sickle		-	-	-	100 (100.0)	Implement change

A matrix combining the risk levels of MSDs over the past 12 months with the REBA risk levels showed that among farmers, 8.6% individuals had an acceptable risk, 25.7% had low risk, 16.9% had moderate risk, 14.1% had severe risk, and 7.1% had a very severe risk level (Table 3).

Table 3. Matrix of combined risk level of between MSDs at past 12 months and REBA risk levels (n = 71)

Risk assessment		REBA risk level				Total
MSDs risk level		1 (Low)	2 (Medium)	3 (High)	4 (Very High)	
Past 12 months	3 (Severe)	3 (Moderate) (n=0, 0.0%)	6 (Severe) (n=3, 4.3%)	9 (Very severe) (n=2, 2.8%)	12 (Very severe) (n=3, 4.3%)	8 (11.4%)
	2 (Moderate)	2 (Low) (n=0, 0.0%)	4 (Moderate) (n=2, 2.8%)	6 (Severe) (n=2, 2.8%)	8 (Severe) (n=5, 7.0%)	9 (12.6%)
	1 (Mild)	1 (Low) (n=0, 0.0%)	2 (Low) (n=9, 12.5%)	3 (Moderate) (n=2, 2.8%)	4 (Moderate) (n=8, 11.3%)	19 (26.6%)
	0 (No)	0 (Acceptable) (n=0, 0.0%)	0 (Acceptable) (n=6, 8.6%)	1 (Low)* (n=22, 31.0%)	2 (Low)* (n=7, 9.8%)	35 (49.4%)
Total		0 (0.0%)	20 (28.2%)	28 (39.4%)	23 (32.4%)	71 (100.0%)

*Note: low risk when workers rated no MSDs risk level, and RERB indicated high to very high risk [10]

4 Discussion

The prevalence of MSDs reported in the lower back, knee, shoulders, and neck. The results indicated education level, cigarette smoking, and working experience were significantly associated with the occurrence of MSDs. The finding consisted with prior studied [11] explained that more age, smoking habits, drinking alcohol habits, working years, type of work, awkward position, non-ergonomic equipment, repetitive movements, and lifting heavy loads were common factors associated with MSDs. Additionally, another study found that the risk of persistent neck and shoulder complaints rises with the number of years spent working in this occupation [12]. This may explain that MSDs in acute trauma disorder repetitively can be resulted cumulative trauma disorder that from the MSDs in past 12-month represented. This finding of the risk level evaluated by REBA found that most of farmers had medium to very high (6–15 scores) risk levels on land preparation, sowing of seed and fertilizer, rice transplanting, pesticide spraying, and harvesting processes. Same as the previous studied among Indonesian farmers showed that farmers had REBA at 6 scores on planting, 8 scores on grass cutting for land clearing, and 10 scores on manual plow processes [13], excepted giving fertilizer and harvesting processes. A matrix combining the risk levels of MSDs over the past 12 months with the REBA levels showed that among farmers, 38.1% of moderate-high-very high risks. When evaluating the risk associated with ergonomic work postures, it was found that the risks predominantly ranged from moderate to very high levels. Similar to prior studies that revealed the moderate health risk was at least the high level of ergonomics risk and mild discomfort [7]. Farmers experiencing moderate and severe levels of any MSDs should undergo further investigation and implementation measures. This approach can serve as a valuable tool for predicting trends in MSDs for surveillance purposes. Therefore, the study revealed that the application of the SNQ survey combined with REBA assessment technique to assess the ergonomic risk level in farmers. This approach has the potential to enhance risk surveillance interventions and recommend ergonomic farming practices.

5 Conclusion

This study found the high prevalence of MSDs in the lower back, knee, shoulders, and neck in the past 12 months. A matrix combining the risk levels of MSDs over the past 12 months with the REBA risk levels among farmers was moderate-high-very high. Hence, this risk matrix could serve as a predictive model for surveillance programs regarding risk implications. The study suggests implementing ergonomics training programs among high-risk groups to prevent MSDs among farmers.

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Risk of Musculoskeletal Disorders in Workers of Micro and Small-Sized Enterprises in Chile: A Look to Labor Precariousness from Ergonomics

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Abstract. An exploratory, descriptive, cross-sectional study was conducted in 15 small companies located in the city of Copiapó, Chile. 119 workers (58 women and 61 men) participated in the study. The ergonomic analysis was carried out during the working day, through open observation of the work processes. To identify and assess the risk of musculoskeletal disorders (WRMSD), instruments according to Chilean standards were used, in addition to a survey to assess the perception of work-related musculoskeletal symptoms and the NASA-TLX mental workload index. The study was approved by an ethics committee and informed consent was obtained from participants. Descriptive analyses of WRMSD symptom data stratified by gender were performed. Student's t-tests and chi-squared tests were used to assess significant differences at the 99% and 95% confidence levels. This study contributes to the visibility of the need to implement ergonomics in micro and small enterprises in Chile, reflecting, as part of this panorama, the issue of the precariousness of employment and the challenges it poses for ergonomics. The precarious-ness of work today goes beyond jobs that do not have a formal employment relationship. The conditions that favor the precariousness of work are reproduced in the forms of remuneration, in the territory and in the contexts that are far from the control of the state in terms of working conditions, which increases the risks of WRMSD.

Keywords: micro and small-sized enterprises · occupational musculoskeletal disorders · precarious employment · systemic approach · ergonomics

1 Introduction

Work-related musculoskeletal disorders (WRMSD) are a significant global health issue affecting about one-third of the world's population, leading to chronic disability, increased absenteeism, and reduced productivity [1]. In Chile, WRMSD is workers'

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second most common cause of illness, representing approximately 35% of all occupational pathologies in the Atacama region [2]. Micro and small-sized enterprises (MSSEs) are vital to Chile's economy, employing nearly half of the private sector workforce and comprising the majority of formal sector companies. However, MSSEs face challenges implementing effective Occupational Safety and Health (OSH) measures, including WRMSD prevention [3]. Chilean regulations have introduced standards for upper extremity WRMSD and Manual Handling of Loads (MHL) aimed at improving workplace safety. Both standards have adopted the model of ISO standards 11.228-1; 11.228-2; 11.228-3 and with the recommendations raised by the technical report ISO-TR 12.295-2014 [4]. Despite these efforts, there is limited evidence on the effectiveness of interventions in MSSEs, indicating a need for greater focus on addressing rather than mitigating these health issues [3]. This article aims to study WRMSD symptoms in MSSEs in Copiapó, Chile, exploring their occupational exposures and ergonomic conditions to propose improvements.

2 Methods

A descriptive cross-sectional study with an ergonomic approach was conducted in 15 MSSEs in Copiapó, Chile, from January to December 2023. The study aimed to assess and characterize work-related musculoskeletal disorder (WRMSD) risks among employees. Phase 1 involved an ergonomic diagnosis and characterization of occupational exposures to WRMSD risks. Phase 2 included communicating findings to workers and employers to initiate dialogue for implementing improvements based on study recommendations. The ergonomic analysis observed workers during their shifts, with open observations and recordings of work processes analyzed by two ergonomists. WRMSD risks were evaluated using Chilean technical standards. Surveys using a Body Scheme assessed musculoskeletal symptoms [5], while the NASA-TLX Index measured mental work-load. Surveys were conducted face-to-face with tablets and SurveyMonkey® for data recording efficiency. Descriptive analyses by sex, Student's t-tests, and Chi-square tests were performed using SPSS version 27 to identify significant differences and relationships between variables. Ethical approval and voluntary con-sent were obtained from all participants.

3 Methods

Sample distribution by sex and industry: Men are in fruit and vegetable sales (22.9%), bakery and pastry (22.9%), mini-markets (13.1%), metal-mechanic industry (14.6%), and bottled water processing (8.2%). Women are in mini-markets (46.6%), bakery and pastry (24.1%), delicatessen industry (17.2%), pharmacy (6.9%), and fishmongery (3.5%). Table 1 shows musculoskeletal symptom perceptions by sex; mean age was 34.8 years (±10). 68.1% reported musculoskeletal pain in the past week, with no significant gender differences.

Table 1. Perception of musculoskeletal symptoms according to sex.

Sex	Male (Mean ± SD)		Female (Mean ± SD)	Total (Mean ± SD)	p-value
Age	34,1 ± 10.5		35,5 ± 9,6	34,8 ± 10	0,47
Pain during the last 7 days	**Male N (%)**		**Female N (%)**	**Total N (%)**	**p-value**
	NO	24 (39,3)	14 (24,1)	38 (31,9)	0,56
	YES	37 (60,7)	44 (75,9)	81 (68,1)	0,56
Sites of Pain	**Male N (%)**		**Female N (%)**	**Total N (%)**	**p-value**
Neck	NO	51(83,6)	31(53,4)	82(68,9)	0,00**
	YES	10 (16,4)	27 (46,6)	37 (31,1)	0,00**
Shoulders	NO	39 (63,9)	24 (41,4)	63 (52,9)	0,01**
	YES	22 (36,1)	34 (58,6)	56 (47,1)	0,01**
Elbows/Arm	NO	40 (65,6)	32 (55,2)	72 (60,5)	0,16
	YES	21 (34,4)	26 (44,8)	47 (39,5)	0,16
Hands/Wrists	NO	41 (67,2)	28 (48,3)	69 (58,0)	0,02*
	YES	20 (32,8)	30 (51,7)	50 (42,0)	0,02*
Dorsal Spine	NO	49 (80,3)	53 (91,4)	102 (85,7)	0,07
	YES	12 (19,7)	5 (8,6)	17 (14,3)	0,07
Lumbar Spine	NO	29 (47,5)	42 (72,4)	71 (59,7)	0,05*
	YES	32 (52,5)	16 (27,6)	48 (40,3)	0,05*
Hips, thigh	NO	61 (100)	48 (82,8)	109 (91,6)	0,00**
	YES	0 (0,0)	10 (17,2)	10 (8,4)	0,00**
Knees, leg	NO	59 (96,7)	55 (94,8)	114 (95,8)	0,47
	YES	2 (3,3)	3 (5,2)	5 (4,2)	0,47
Ankles, feet	NO	59 (96,7)	47 (81,0)	106 (89,1)	0,06
	YES	2 (3,3)	11 (19,0)	13 (10,9)	0,06
Pain affects daily living activities	NO	26 (42,6)	13 (22,4)	39 (32,8)	0,01**
	YES	35 (57,4)	45 (77,6)	80 (67,2)	0,01**
Work activities related to pain	NO	19 (31,1)	14 (24,1)	33 (27,7)	0,26
	YES	42 (68,9)	44 (75,9)	86 (72,3)	0,26
Improvements desired	NO	22 (36,1)	26 (44,8)	48 (40,3)	0,21
	YES	39 (63,9)	32 (55,2)	71 (59,7)	0,21

NOTE: Standard deviation (SD); * p = 0.05 ** p = 0.01

Table 2 shows the risk factors identified in the job evaluations in the 15 participating companies and their relationship with the workers under study. It was found that Repetitive Work is present in 83.2% of the workers in the study, with no significant differences between men and women. Regarding the level of risk found by applying the ISO 11.228–3 Checklist, it was found that 70.6% of the workers were exposed to a high level of risk (red).

Table 2. Risk factors present in the workplaces according to sex.

Risk Factor		Male N (%)	Female N (%)	Total N (%)	p-value
Repetitive Work	NO	13 (21,3)	7 (12,1)	20 (16,8)	0,13
	YES	48 (78,7)	51 (87,9)	99 (83,2)	0,13
Checklist ISO 11.228–3	No risk	13 (21,3)	7 (12,1)	20 (16,8)	0,16
	Low	3 (4,9)	7 (12,1)	10 (8,4)	0,16
	Moderate	4 (6,6)	1 (1,7)	5 (4,2)	0,16
	High	41(67,2)	43 (74,1)	84 (70,6)	0,16
Manual Handling	NO	5 (8,2)	39 (67,2)	44 (37,0)	0,00**
	YES	56 (91,8)	19 (32,8)	75 (63,0)	0,00**
Mental Workload	Low	20 (32,8)	15 (25,9)	35 (29,4)	0,54
	Medium	25 (41,0)	23 (39,7)	48 (40,3)	0,54
	High	16 (26,2)	20 (34,5)	36 (30,3)	0,54

NOTE: ** p = 0.01

On the other hand, 63.0% of workers were exposed to MHL this risk factor affected 91.8% of men and 32.8% of women significantly. Mental workload was high for 30.3%, medium for 40.3% with no significant gender differences. Workers frequently suggested improvements such as machine renewal, load height in manual handling, floor conditions, and additional personnel in open-ended responses. Another crucial aspect to emphasize is the determinants of the work environment in MSSEs, particularly those related to the risks identified earlier. Table 3 highlights the most common factors influencing work activity within these contexts.

As determinants of labor activity, it is important to note the lack of formal work contracts in MSSEs, which affects 20% of the sample. Additionally, 40% of the workers was immigrants, with no significant difference between men and women. Many workers are employed on a daily wage basis, lacking social security bene-fits and facing intensified work demands due to incentive-based pay systems. This situation often extends across generations within family-run enterprises. Figure 1 illustrates typical work activities observed among MSSE workers in the study.

Table 3. Most common determinants of work activity in MSSEs.

Category Determinants	Macro Determinants	Micro Determinants
The conditions offered by the workplace	Employment conditions: No contract, pay only for the day, incentives for more work in the same day, no social security. When there is a contract, wages are at the minimum wage, no overtime pay Work organization: Teamwork of 3–9 people, in normal working hours, manual work Organization of training: There is no training for the job. It is learned by working. There is no training in the MHL or prevention of repetitive work	Work rhythm: Very intense work periods, with scarce personnel for the MHLs and repetitive work. There is no established pause High variability: Customers are variable and so are working conditions, especially in delivery, car cleaning and customer service
	Physical environment: Very cold or hot, most companies do not have air conditioning and have facilities with poor thermal insulation. In the case of men, it is more frequent to work outdoors. Poor lighting conditions in most cases	Work spaces: No maintenance or renovation of furniture, counter heights do not take into account the anthropometry of the users (especially women). Narrow aisles for customer traffic and MHLs
	Technical devices: The machines are not maintained, and when they fail, work is delayed, or the workers themselves intervene to make them work (risk of accidents and injuries)	Technical devices: Lack of tools, old machines (e.g. bakeries and glassworks) is common

(*continued*)

Table 3. (*continued*)

Category Determinants	Macro Determinants	Micro Determinants
The social environment	Hierarchical relationships: Authoritarian in many cases, asymmetric due to lack of contract or irregular migrant status Culture: OSH climate is poor, oriented to solve day-to-day issues, without foresight to manage OSH risks. Migrant workers are less recognized in their work. Women's work is devalued	Relations with clients and users: variable contexts, cordial relationships, in some cases demanding
Tasks and demands	Task: Shortened time and production requirements. No task definition structures, usually improvised organization	Procedure: Not described, except for sanitary standards in food processing (e.g., charcuterie, bakery, pastry shops, and bottled water processing)

Source: Authors' own elaboration, adapted from St-Vincent et al., 2011

Fig. 1. Images of work carried out by workers of some of MSSEs participating in the study.

4 Discussion

The study highlights several dimensions of precariousness identified in MSSEs that align with the model of the seven securities proposed by postwar social democracy, emphasizing issues such as labor market security, employment stability, workplace safety, and protection against accidents and illness [6]. Ergonomic interventions are crucial in these enterprises, yet occupational risk insurers often overlook them due to the companies' small size [3]. This neglect contributes to a significant prevalence of musculoskeletal disorders (MSDs) and high mental workloads among workers, exacerbated by inadequate workplace conditions and practices such as piece-rate pay and informal employment arrangements [7]. The study underscores challenges in engaging workers in ergonomic improvements, particularly in informal work settings where contractual insecurity prevails. De-spite limitations, including a small sample from a single city, the study underscores the importance of addressing these challenges through tailored ergonomics and occupational safety and health (OSH) policies.

5 Conclusions

Today's labor precariousness extends beyond formal ties, affecting remuneration, geographic contexts, and working conditions lacking state supervision. In Chile, preventing WRMSDs in MSSEs is inadequate, and urgent ergonomic interventions are needed. Challenges include informal work and MSSEs' limited visibility to preventive services, perpetuating precarious conditions, and increasing WRMSD risks. Systemic analyses are crucial to understanding work intensification and conditions accurately. Public health and ergonomics must address vulnerabilities by gender, enterprise size, migration status, and location, posing poli-cy challenges.

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Product (I)

Quantifying AR/VR/XR Headset Comfort: Forehead Pressure as a Predictive Long-Wear Comfort Metric

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Abstract. Ensuring comfort for an AR/VR/XR head and face worn product is a time consuming challenge when relying on user comfort testing only. This study researches the relationship between pressure levels in the forehead region and subjective comfort ratings during long-term wear. By applying known loads to the forehead and coupling detailed load, material characterization, and empirical device fit with structural Finite Element Analysis (FEA) models, the forehead pressure distribution could be calculated per user. When these pressure distributions are mapped to comfort experiences of users, identification of pressure comfort thresholds for the forehead becomes possible. Participants wore a custom headset that could apply a set, known force to the forehead, for 4 h. Two force loads, 3.5 N and 8 N, were evaluated. Several pressure metrics such as average, peak, areas, and gradients were included in the assessment. Clear distinction between forehead comfort pass and fail was identified for average pressure and pressure gradient between 60–65th percentile values.

Keywords: Virtual reality · Augmented Reality · Mixed Reality · Wearable · Headset · Comfort · Forehead pressure · Wearable fit · Pressure Simulation

1 Introduction

Researchers defined pressure Discomfort Threshold (PDT) as the minimum amount of pressure generated by applying a force, which can cause discomfort to an individual [1]. Pressure sensitivity maps, developed from pressure threshold data, can be used as references for designing products with enhanced user comfort [1].

In order to measure PDT, researchers applied increasing force to specific measurement sites using a pressure gauge (probe ranging 2-10mm dia.) [2, 3, 5]. The participant is instructed to notify the researcher when the pressure becomes uncomfortable. The researcher then releases the pressure applied and reads off the pressure as the PDT. The measurements are taken in random order and the PDT is the average of the two/three measurements per site. Several studies reported higher PDT's for males than females [2, 4, 5]. No significant correlation between age, BMI, and pressure threshold for discomfort and pain were reported [2, 6].

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The pressure sensitivity on the head, neck and face have been mapped for adults [2, 3]. The landmarks on the top of the head showed higher values for pressure thresholds for discomfort, suggesting that this region is less pressure-sensitive. The landmarks in the forehead and temporal region have similar pressure threshold values with a medium level of sensitivity [2, 7, 8]. The landmarks in the facial and nasal region have comparatively lower values for pressure threshold, suggesting higher pressure sensitivity in this region [2, 3]. In order to assess wear comfort of wearable products, several researchers use Likert type comfort scales [9–12]. Likert scales that range from 4-point anchored, and 5-point to 10-point with anchored boundaries are typically used.

2 Materials and Method

2.1 Participants

Thirty participants (15 males, 15 females) were recruited to represent African American, Asian, and Caucasian demographics. Participants were selected from a pre-existing panel with available head anthropometric data, including traditional measurements and 3D head scans. Screening ensured no history of facial injury or surgery.

2.2 Wearable Force-Application Headset

The P.O.W.D.E.R.Horn device (Fig. 1) is a wearable device custom-built for the purposes of this study to apply consistent loads to a user's forehead over a 4-h period, focusing on stability, accurate force application, and real-time adjustments.

The device wrapped around a user's head and contained a 9mm foam forehead pad (1a). The device was secured to the head by tightening the back straps (2d) with a locking adjustment wheel (3c). Through internal trails, the foam's thickness and density were tuned to enable forehead comfort variance within an applied force range (3.5 N and 8 N) while maintaining device stability and avoiding foam hard-stacking and compressive head pressure. The device load was carried on the top of the head by adjustable straps (2c). A large back foam pad (3d) supported the device in the rear, balanced the weight ensuring a device COM closer to the head COM and ensured improved stability.

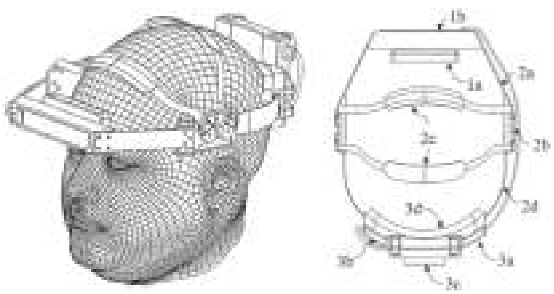

Fig. 1. P.O.W.D.E.R.Horn (Pressure Optimization Wearable Direct Electrical Readout)

To measure the force applied, the forehead pad foam connected to an aluminum bar load cell with a 5kg load capacity (inside the front housing, 1b). This load cell, was calibrated to ±1 g-force, and employed four strain gauges to enable highly accurate and repeatable readings (±0.05% Full Scale combined error). The load cell signal was communicated in real time to the study proctor via Wi-Fi (microcontroller, 3b).

During this test, load consistency over the 4-h wear duration varied by ±5%. Contributing factors to force variation included device slippage, vibration due to human motion, and material creep (hardware, foam, and skin). The proctor monitored the applied load every 15 min for the first hour and every 30 min thereafter, and adjusted tightness if required to maintain loads within the study target range (±0.5 N).

2.3 Experimental Design and Study Flow

Participants attended two sessions on separate days, during which one of two forces was applied to the forehead for a total of 4-h. The two forces included in the study were 3.5 N and 8 N, with the session order per participant randomized. The P.O.W.D.E.R.Horn device was fitted so that the bottom of the forehead pad was lined up with the Glabella landmark and the back of the device fitted over the most posterior point of the head. Activities completed during the wear time included being head scanned, watching a movie, completing a paper based activity (Sudoku or word search) and playing a video game. The participants' subjective comfort was elicited through proctored questions about comfort perception overall as well as specifically in the forehead region, at 30-min time intervals. The comfort responses were provided on a 5-point anchored Likert scale. The study protocol was reviewed and approved by an external ethics review board (Western Institutional Review Board).

2.4 Data Validation

The "Pressure Profile Systems" (PPS) Tactile Head (Fig. 2) was used to validate accuracy of the Finite Element Analysis simulation. The PPS Tactile head wraps a 50th percentile male head with 15 pressure sensors that utilize capacitance technology and the PPS Chameleon Software to display applied loads.

Fig. 2. PPS Tactile Head with Labeled Sensors

To verify the simulation pressure predictions, the P.O.W.D.E.R.Horn device was donned onto the Tactile Head and tightened to 3 different loads. At each load, the pressure information was saved and a 3D scan of the tactile head was taken to inform device placement within the simulation. Within the FEA tool (ANSYS Mechanical), the 3D CAD and mechanical properties of the Tactile Head was obtained from the Tactile Head supplier and was used to create a Finite Element Model (FEM). Similarly, a FEM was created for the P.O.W.D.E.R.Horn device, and P.O.W.D.E.R.Horn was aligned to the Tactile Head in the donned position as captured by 3D scanning.

In addition, model compression testing was conducted on the P.O.W.D.E.R.Horn forehead foam. "puck" and "uniform" compression tests were performed to fully capture the open cell foam's shear stiffness and compression curves. Good correlation was achieved with the majority of error occurring near the solid height of the foam, which was not approached during testing. The FEA verification simulations were performed and the simulated pressure values were compared to the Tactile Head pressure readouts. A strong correlation was observed between simulated and measured pressure values, with the most significant differences observed at the edges of the contacted regions.

2.5 Process Implementation for Pressure Simulation

In preparation for the structural FEA, the forehead pad CAD was aligned for each participant in the empirical fit location as worn during the comfort data collection. The Fit scan (collected during the data collection) was firstly aligned to the P.O.W.D.E.R.Horn front and forehead pad CAD, and secondly the base Anthropometry head scan was aligned to the Fit scan. All alignments were completed in Polyworks Inspector™ through least squares alignment of points selected on the face and forehead pad CAD.

When simulating the pressures applied to actual user heads, a similar process was used as described in Sect. 2.4 with the 3D base Anthropometry head scans being swapped out for what was previously the tactile head. Figure 3 shows examples of simulated pressure distributions on different heads. Pressure metrics calculated from these simulations was used as input to the statistical analysis to investigate prediction of user comfort.

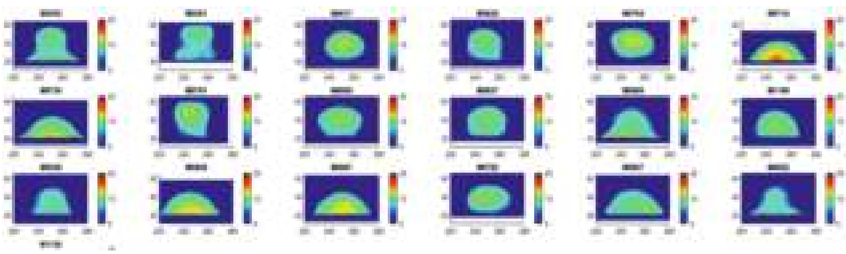

Fig. 3. Examples of calculated pressure distributions on difference user heads

2.6 Statistical Analysis

An analysis of variance (one-way within-subjects ANOVA) was performed on the Forehead comfort results to investigate if the differences in comfort per force condition were perceivable (statistically significant). A Stepwise Discriminant analysis was performed with independent variables including Pave, peak pressures representing the 10th through 90th percentile values (in 10 percent intervals), and pressure gradients (between 5th to 10th percentile pressure values for each 10 percent from 10 to 90 percentile values) to determine which variables are good discriminators of comfort acceptance. Stepwise discriminant analysis was performed using Wilks' lambda method. Data normality was tested by means of the Kolmogorov-Smirnov test. The Mann-Whitney-U-test and Wilcoxon rank sum tests were used to test significant of differences between pressure metrics for forehead comfort pass/fail at time points t = 60 min, 90 min, 120 min, 180 min and 240 min. Statistical significance was considered at $p < 0.05$. Pressure boundary between pass/fail was derived through visual comparison between distribution of comfort ranges and considering percentage comfort pass rates. All statistical analysis was performed using IBM SPSS (IBM SPSS, version 29.0.0.0, IBM Corporation, NY, USA).

3 Results and Discussion

Forehead comfort scores per time point illustrated that forehead comfort degraded over time, especially for the high force condition, but stabilized from t = 60 min onwards.

No clear discriminators were highlighted through the stepwise discriminant analysis, with some time points showing no discriminators, and others showing different discriminators. Pave, ave_pt, med_pt and q50 in addition to pressure gradients between q50–q55, q55–q60, q60–q65 and q65–q70 were seen to be statistically significantly different between comfort pass and fail groups at most time points after t = 60 min.

Pave was selected as comfort predictor. The distribution of values for average pressure is plotted for the pass (right) and fail (left) groups (see Fig. 4).

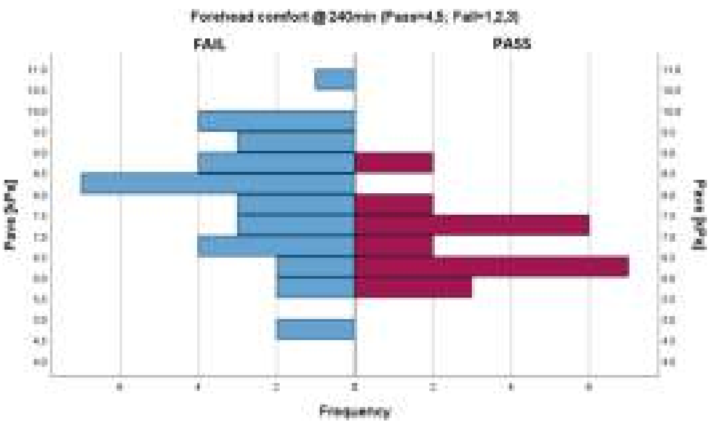

Fig. 4. The Pave (kPa) distribution for forehead comfort pass/fail at time point t = 240 min

Shah and Luximon [2] found the PDT to range between 229.1 to 271 N on the forehead region (SD 110.3 to 135.8 respectively). Since a circular disc with 3 mm diameter was used to apply the force, the force applied was translated to average pressure by dividing the force by the area of the disc (32.4 to 38.3 kPa on the forehead region (SD 15.6 to 19.2 kPa respectively)). Smulders et al. [3] found the PDT values in the forehead region to have a mean of 144.1 kPa (standard deviation 69.4 kPa). The findings of this study indicated acceptable comfort in the forehead region at 4-h of wear for a mean average pressure of 6.9 kPa and standard deviation of 0.9 kPa. The average pressure values at which comfort was deemed acceptable in this study were substantially lower than reported PDT values [2, 3]. Potential reasons for differences in acceptable average pressure levels could include the large differences in contact area, material types and pressure application durations. For the purpose of understanding long-wear wearable comfort, the PDT values might not be useful as a comfort pressure limit for simulation.

4 Conclusion

This study showed substantial average pressure differences in the forehead region between mean PDT values and mean average pressure values deemed comfortable when users wore a head mounted wearable product for 4 h. These results raise the question of how applicable PDT values are for implementation towards head and face wearable product design.

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Identification of Hand Grasps Through the Analysis of Touch Point Distribution

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Abstract. Amidst the growing research on hand grasping interaction with products, understanding and accurately identifying grasps remain challenging. Previous methods, such as vision-based grasp posture analysis, electromyography, and data gloves with inertial, magnetic, and bending sensors, faced challenges including limited grasp comprehension, visibility constraints during identification, low accuracy, and lack of real-time identification. Conversely, tactile-based methodologies appear to offer a promising solution for grasp understanding and identification. This study aimed to estimate touch point distribution on fingers and palm across 33 hand grasps, utilizing a wearable tactile glove. Moreover, an algorithm-based methodology was developed for identifying hand grasps and determining their grasp similarity index. The findings displayed distinct touch point distributions for each grasp, with the palmar grasp exhibiting the highest touch point counts of 215 out of 240. Furthermore, the proposed methodology exhibited high accuracy in real-time hand grasp identification, with the grasp similarity index serving as an additional tool to validate accuracy. In conclusion, the ability to estimate touch point distribution and identify hand grasps holds significant potential for enhancing our understanding of hand-product interaction, with wide-ranging applications in product design, ergonomics, rehabilitation, prosthetics, robotics, and haptic devices.

Keywords: Hand Product Interaction · Touch Point Distribution · Tactile Glove · Hand Grasp Identification

1 Introduction

Humans engage in a multitude of daily activities and perform grasping interactions, which involve holding products using fingers and palm [1]. Humans employ a wide range of hand grasps to hold products, with the type of grasp varying from task to task and product to product. Understanding these grasps is important as it ensures secure and comfortable product handling, facilitates successful and efficient task completion, and promotes user safety. Furthermore, the study of grasping interaction informs the design of robotic hands, prosthetic limbs, rehabilitation tools, and assistive technology devices, thereby enhancing their functionality and improving the quality of life for individuals with impaired hand function.

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However, despite technological advancements, the study of grasping interaction remains constrained by the limited availability and capabilities of measurement techniques. Currently, researchers analyze hand movement and predict grasps through various measurement techniques, including computer vision-based techniques [2], muscle activity measurement [3], data gloves with inertial, magnetic, and bending sensors [4], motion capture techniques [5], and participant observations [6].

While the aforementioned measurement techniques offer valuable insights, they also present various challenges. For instance, computer vision-based and motion-capture techniques may encounter visibility constraints during grasp posture analysis [7]. Electromyography is prone to low accuracy in hand grasp identification [8], and participant observation may suffer from subjectivity bias. Additionally, many of these measurement techniques provide limited detailed information about grasping interactions with products, primarily focusing on gesture recognition without considering interaction with the product itself [9]. Moreover, the majority of them lack the ability to support real-time grasp identification [9]. There is a need for a measurement technique capable of addressing the aforementioned challenges and offering a more promising alternative for the in-depth study of grasping interactions with products, especially for the accurate identification of hand grasps during product interaction. Literature suggests that tactile-based methods could be a viable option to overcome these challenges [10].

In this study, the feasibility of tactile-based methods for understanding grasping interactions was explored. The study extracted tactile signatures of 33 hand grasps during product interaction, and an algorithm was devised to identify these grasps based on touch point distribution across the fingers and palm.

2 Methods

2.1 Wearable System

A wearable glove embedded with 240 tactile sensors on the fingers and palm was developed using a resistive-based technique, as shown in Fig. 1. The tactile glove is made functional with Arduino technology, while data acquisition and visualization are achieved through Python programming. The tactile glove monitors the touch point distribution on the fingers and palm during tactile interactions with products.

2.2 Participant

The tactile glove was developed based on specific anthropometric dimensions, necessitating a case study. A healthy, right-handed, 30-year-old male from the Indian demographic was selected as the participant. The tactile glove was designed with hand length, palm length, and palm width measurements of 180 mm, 103 mm, and 81 mm, respectively [11].

Fig. 1. Wearable Tactile Glove

2.3 Hand Grasps and Products

The GRASP taxonomy [12] was used to assess the tactile signatures of 33 hand grasps. These grasps were performed using specific products in the study [12], most of which were everyday items.

2.4 Task Description

The tactile glove was placed on the participant's hand, and the types of grasps [12] to be achieved were displayed sequentially on a screen. The participant was instructed to hold each specific product using the designated grasp for 10 s, applying the pressure typically used in everyday situations. Additionally, the participant was advised to avoid any further manipulation of the product once the grasp was established.

2.5 Data Acquisition

The wearable glove captures tactile interactions with the product at a rate of 15 frames per second, recording binary data indicating touch or no touch. Data from 150 frames is aggregated for each of the 240 tactile points, with interactions exceeding 50% considered as touched, following the Majority Rule Method [13]. Subsequently, the tactile data for each grasp is recorded, creating a grasp taxonomy dataset, and visualized as scatter hand maps using Matplotlib, as shown in Fig. 2.

Fig. 2. Scatter hand map of touch point distribution on fingers and palm for various hand grasps.

Fig. 2. (*continued*)

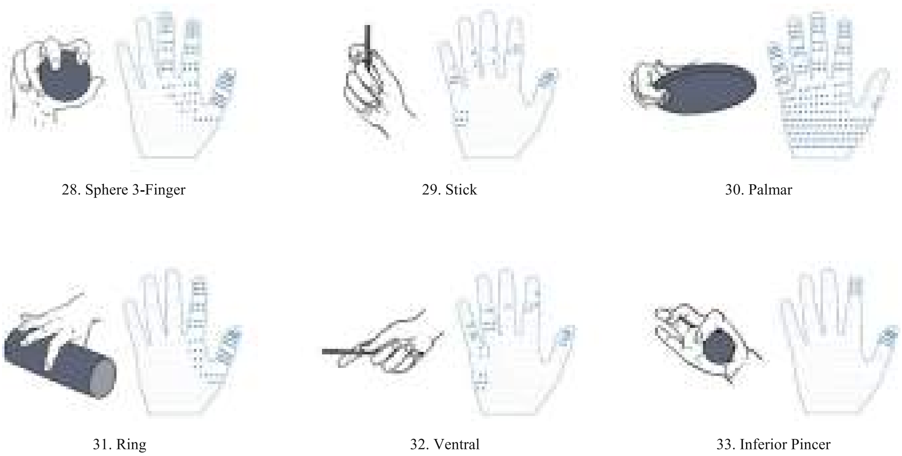

Fig. 2. (*continued*)

2.6 Identification of Hand Grasps

An algorithm-based methodology was devised for identifying hand grasps using the concept of Hamming distance (HD), which is defined as the number of points at which the tactile data differ. The participant was instructed to hold certain products with unidentified grasps, and the tactile data, comprising 240 points, was recorded for each grasp across 5 trials. The tactile data of each unidentified grasp was matched with the previously recorded grasp taxonomy dataset, and the Hamming distance was calculated. The grasp from the GRASP taxonomy [12] with the lowest Hamming distance was recognized as the closest match to the unidentified grasp.

Furthermore, to determine the degree of similarity between the unidentified grasp and the grasp from the GRASP taxonomy [12], the grasp similarity index was proposed and calculated using the Hamming distance, mathematically represented as:

$$\text{Grasp Similarity Index (GSI)} = (240 - \text{HD})/240 \tag{1}$$

A GSI value of 1 indicates perfect similarity, whereas a GSI value of 0 indicates no similarity between the two grasps.

3 Results and Discussion

The scatter hand maps displayed distinct touch point distributions for each of the 33 grasps examined, providing a reliable method for hand grasp identification. Further examination of the scatter hand maps revealed that 16 grasps had touch points exclusively on the fingers, while 16 had touch points on both the fingers and palm. Notably, one grasp, the adduction grasp, lacked any touch points on the palmar side of the hand. This differentiation enables clear identification and classification of grasps into finger-based and finger-and-palm-based categories. Moreover, the palmar grasp exhibited the highest touch point counts, with 215 touch points out of 240. The number of touch points on the tactile glove directly corresponds to the area of touch, indicating the level of hand-product engagement. Furthermore, the hand grasp identification using the algorithm-based methodology demonstrated high real-time accuracy across five trials, with GSI values of 0.87 for precision sphere, 0.78 for medium wrap, 0.90 for inferior pincer, 0.91 for palmar pinch, and 0.84 for ring grasp.

4 Limitations and Future Work

The placement of tactile sensors on the cloth glove can affect the touch perception and flexion of the fingers and palm to some extent. Moreover, the wearable glove has limitations in capturing tactile data from the lateral side of the hand, being restricted to collecting tactile data solely from the palmar side. Furthermore, the current research is conducted with one participant. Future work involves expanding the study to include multiple participants to better understand the variability in grasping behavior across different individuals.

5 Conclusion

The current research suggests that tactile-based methods offer a viable approach for understanding and identifying grasps during product interaction. The proposed tactile-based method has the advantage of being objective in nature, providing real-time grasp identification, and being effective in environments where vision is constrained. Additionally, touch point distribution helps identify grasps with larger touch areas during product grasping, leading to more effective hand-product engagement, a better hold, and reduced discomfort [14]. This insight informs designers to create products that encourage larger touch areas during grasping interaction. Further, the research holds significant potential for applications in product design, ergonomics, rehabilitation, prosthetics, robotics, and haptic devices.

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Surface Pressure Sensitivity of the Auricle and Periauricular Areas for Ergonomic Design Purposes

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Abstract. There has been a lack of detailed studies focusing on measuring pressure thresholds in the auricle and periauricular areas. This study aimed to investigate surface pressure sensitivity (SPS) in 320 healthy Chinese adults (aged 20–59), measuring Pressure Pain Threshold (PPT). Significant differences of PPTs observed between age groups and genders. PPT values varied across different measurement points and areas, showing correlations with age, height, weight, and BMI changes. Additionally, certain characteristics such as the ear lobe extension and external ear protrusion were associated with lower SPS in the measurement areas. The results and findings of this study pertain to the Chinese population and give an understanding of age-related trends, bilateral differences, and gender influences on SPS for the development of ear-related wearables.

Keywords: auricle and periauricular shin · surface pressure sensitivity · ergonomic design

1 Introduction

During the interaction with ear-related products, the mechanical pressure per unit area on the skin contact surface is one of the direct causes of human comfort issues [1, 2]. As the skin indentation increases, the user's perception of the maximum pressure per unit area generally follows " slight discomfort – pain (extreme discomfort)" [3].

Pressure pain threshold (PPT), with its characteristics of intuitive and visual expression, is often used to assess cutaneous mechanical pressure sensitivity [4, 5]. Lots of studies have shown that long-term mechanical pressure on the skin surface induces mechanical hyperalgesia, meaning the pressure value that causes mechanical pain decreases

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with increasing time load [6, 7]. Therefore, for the same product, users with a history of mechanical hyperalgesia may experience worse comfort than normal users.

The measurement of pressure thresholds has been widely applied in product design [8]. Despite this, there has been a lack of detailed studies focusing on measuring pressure thresholds in the auricle and periauricular areas. This study aimed to investigate surface pressure sensitivity (SPS) in healthy Chinese adults, measuring PPT. It sought to analyze age-related trends, bilateral differences, and gender influences on SPS for the development of ear-related wearables.

2 Methods

This study was conducted between 2016 and 2023 (from April to June each year). A total of 320 healthy Chinese participants (160 females, 160 males) with no history of headache or neck pain were recruited by online, campus and social networks for this study. All participants (age from 20 to 59) were categorized into four age groups: 20 s, 30 s, 40 s and 50 s. The study was approved by the Ethics Committee of Northwestern Polytechnic University (No. 201502024, No. 202002024); written informed consent was obtained from all subjects.

Totally 23 measurement points of each ear were determined by the anatomical position interacting with the ear-related wearables (i.e., in-ear and over-ear wearables) [9, 10]. The 23 measurement points were divided into three subareas based on their locations and cutaneous innervation [1, 7, 11] (Fig. 1): anterior area (AnA, points m1–m5), auricular area (AA, points a1–a11) and posterior area (PA, points lg1–lg7). PDT (i.e., little discomfort, and moderate discomfort) and PPT were measured for both ears of each subject.

According to Fan et al. [7], the average length and width (Mean ± Standard Deviation) of the Chinese auricle were 66.13 ± 5.86 mm and 35.75 ± 3.54 mm. On average, the differences of size between the earmuffs and Chinese auricles in length and width were both close to one-third of the auricular length. Hence, the method to determine the measurement grid for the ear was (Fig. 1b): (1) determining the ear boundary-box based on the auricular length (d) and auricular width (w) for positioning the on-ear measurement points (a1–a11); (2) creating the measurement boundary-box around the ear boundary-box based on the one-sixth auricular length ($d/6$) for positioning the around-ear measurement points (m1–m5, lg1–lg7).

The assessment of SPS for each participant was completed in two non-consecutive days. The head and ears of the participants were scanned using EinScan-Pro + Handheld HD Scanner (SHINING 3D Inc., China) in their first day. The concha impressions of each participant were casted using ABR impression materials (SOUNDLINK, Inc., China) and scanned [12, 13]. The auricle model of each participant was merged with the concha model using RapidForm XOR3 (INUS Technology, Inc., Korea). The coordinates of the measurement points were determined for the participants using the 3D scans for the PPT assessment and the generation of topographical pressure pain sensitivity maps.

The 46 PPT measurements of both ears were completed over one session lasting about 2.5 h for each participant. The room temperature was 23 ± 2 °C, the relative humidity was between 40% and 50%. Participants were assessed individually and required to sit at

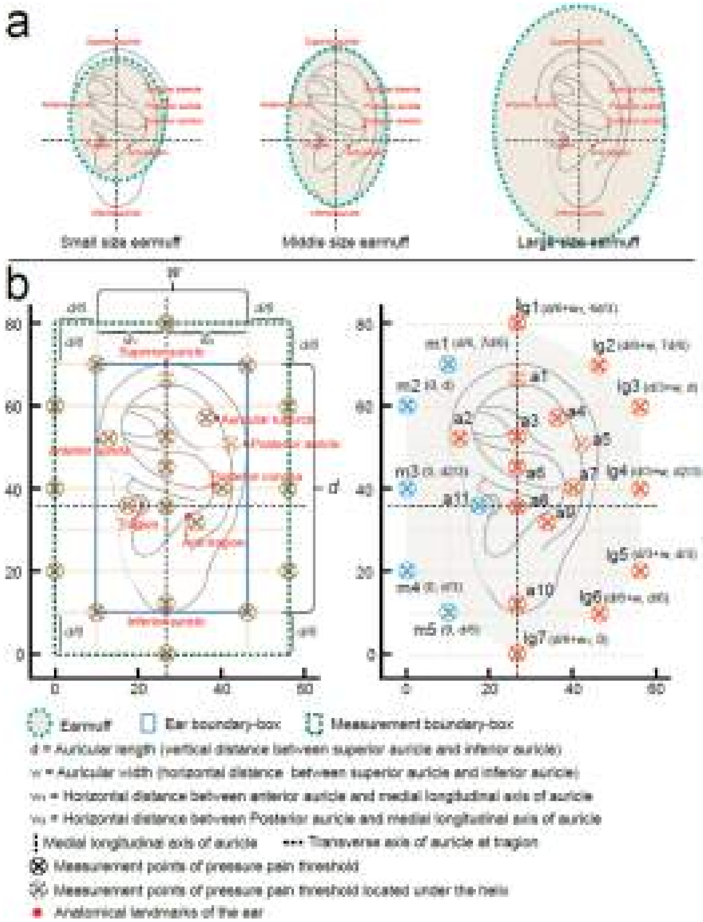

Fig. 1. Pressure pain threshold (PPT) measurements used in this study for the ear: (a) anatomical locations of human ear for wearable device interaction;(b) PPT measurements.

least 15 min to relax and get familiar with the assessment procedure. The measurement points were marked on the auricle and head using adhesive white dots (diameter: 1mm). A hand-held pressure algometer with a 0.5 cm^2 round rubber tipped plunger (Somedic AB, Sweden; Type II) was used for the ear PPT measurements. The algometer was pressed against the skin of the ear in a perpendicular angle at a constant slope of 30 kPa/s to simulate the interaction between ear and wearables. The participants held a response button to lock the display of the algometer when their perception of the stimulus changed from pressure to pain.

All PPT recordings were done by the same researcher. In order to prevent spatial and temporal summation of pain, the recording order of measurement points was randomized between left- and right-side ears and by starting randomly at one subarea of the measurement points, of which every two recordings were separated at least by one minute. Each point was recorded three times and with a 10 min interval in between. The final value of each point was obtained by calculating the average value of three recordings with a coefficient of variance (CV) < 0.2. For points' CV ≥ 0.2, a fourth recording was made to reduce the intra-individual variation and incorporated to calculate the final value.

Statistical analysis was conducted at $\alpha = 0.05$ with Matlab R2018a (MathWorks, Inc., USA), and $p < 0.05$ was considered statistically significant. The results are presented as Mean and Standard Deviation (SD). A normal distribution of the data was verified by means of the Kolmogorov–Smirnov test. The intra-rater reliability of each measurement points was determined using intra-class correlation coefficient ($ICC_{2,1}$ for absolute agreement), standard error of measurement (SEM) and minimum detectable change (MDC). A mixed-effect analysis of covariance (ANCOVA) was conducted to detect differences in measurement values using the measurement points and sides as intra-subject variables, age group as a between-subject variable, and gender as a covariate. An independent-samples t-test was investigated to examine the sex-related differences in the measurements. A Paired-samples t-test was investigated to examine the bilateral differences in the measurements. The interpolation was performed using an inverse distance weighted interpolation with Franke and Nielson weightings to obtain the topographical pressure pain distribution.

3 Results

Topographical pressure sensitivity maps of the ear were generated using the averaged values of each point. All maps were generated using 60mm × 36mm (auricular length × auricular width) as the standard ear size which is determined as the closest integer to the mean value of all subjects (60.40 mm × 35.59 mm, Fig. 2).

The results of ANCOVA revealed significant differences in PPTs between points ($F = 74.48, p < 0.001$) and subject groups ($F = 12.764, p < 0.001$), but not for sides ($F = 0.458, p = 0.498$). No significant Subject Group × Side × Point ($F = 0.115, p = 0.734$) interaction was observed. The significant effect of gender ($F = 117.350$, $p < 0.001$) on the PPTs was found.

The minimum PPT value was observed at point a9 (134.64 ± 29.68 kPa) of a female subject. The PPT values of measurement points and areas in the 20s were significantly lower than those in other age groups ($p < .001$). There were no significant differences in PPTs for a1 to a11, m1 to m5, lg3, lg5, AA, and AnA between the 30 s, 40 s, and 50 s. However, PPTs for lg1, lg2, lg4, lg6, and PA showed a significant increase in the 40s group and a significant decrease in the 50s group, with no significant difference between the 30 s and 50 s. There were no significant bilateral differences in PPTs between ears of the subjects ($p > .05$). Significant gender differences were achieved ($p < .05$ Fig. 2) with excluding the effects of height and weight.

4 Discussion

Based on Fig. 2, the PPT values near the upper rear (lg2 and lg3) and anterior upper (m1) regions close to the temporal bone were lower. The lower PPT values in these areas may be due to the participants' hair acting as a pressure buffer. The pressure-buffering

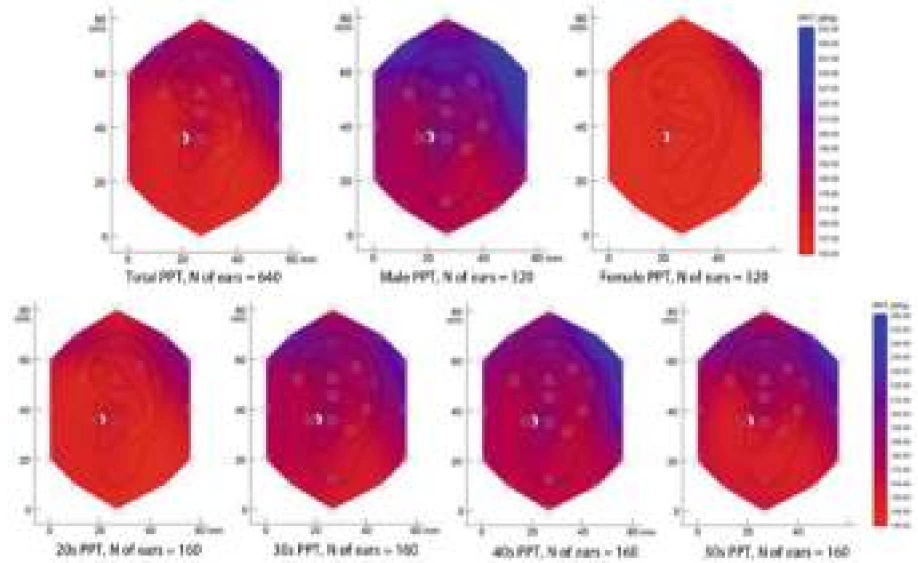

Fig. 2. Topographical pressure sensitivity maps of Pressure pain threshold (PPT) measurements for this study.

effect of hair is more pronounced in studies comparing head-to-face PPT. However, the area just above the ear (lg1) is also covered with hair, but compared to lg2, lg3, lg4, and m1, its PPT value is higher.

Regarding the muscles at the measurement points, m1 is located at the anterior auricular muscle, lg1 is located at the superior auricular muscle, and lg2 and lg3 are located at the occipitofrontalis and posterior auricular muscles, respectively. These three muscle tissues belong to the superficial layer of the head-face muscle group. In terms of the deep arrangement of the head-face muscle group, these three points are all located at the temporal muscle, with lg1 being closer to the transition zone between the belly and tendon of the temporal muscle. The differences in pain feedback between the anterior auricular muscle, occipitofrontalis muscle, and posterior auricular muscle are currently unclear. Based on the Topographical pressure sensitivity maps (Fig. 2), some basic suggestions for applications could be useful: (1) It is recommended to design the contact areas or stability reinforcement structures of large ear cushions to interact with the skin on the temporal bone around the ear, the skin of the mastoid, the tragus, and the concha. (2) For other areas, reduce or avoid designing skin interaction interfaces. For ear cups or medium-sized ear cushions, it is recommended to design the contact areas or stability reinforcement structures to interact with the skin of the concha and the upper edge of the helix. (3) For small ear cushions, it is recommended to design the contact areas or stability reinforcement structures to interact only with the skin of the concha.

Further research is needed before the application of the results of the current study to users under age 20 and over 60 years old due to the dearth of subjects under that age category.

5 Conclusion

Significant differences in PPTs observed between age groups and genders. PPT values varied across different measurement points and areas, showing correlations with age, height, weight, and BMI changes. Additionally, certain characteristics such as the ear lobe extension and external ear protrusion were associated with lower SPS in the measurement areas. The findings suggest potential implications for designing ear-related wearables and provide references for future design of auricle-related wearable devices.

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Factors Affecting the Form Design of Miniature Model Players: A Case Study on Warhammer Wargames

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Abstract. The Warhammer series is a series of miniature wargames designed and manufactured by the British tabletop game manufacturer. It usually uses miniature resin or plastic models as game components and pays attention to the details and proportions of the models. There are also several clubs in Taiwan, and their members often achieve a high degree of customization in the process of assembling and painting miniatures so that the shapes of the miniatures can be personalized. This kind of culture emphasizes the independent creation of individuals or communities. This study aims to explore the factors affecting the form design of miniature models. The study's methodology was based on in-depth interviews and qualitative analyses of the visual representations of their creative outputs. The results of the analysis show that the shapes of the miniature models are highly correlated with the contextual narratives and characterizations of the models.

Keywords: Miniature model · Wargames · Forms · Expression

1 Introduction

The miniature wargames originated from the renowned franchises "Warhammer Fantasy" and "Warhammer 40K," both developed by the British game manufacturer Games Workshop, and collectively referred to as the "Warhammer game." The core of the Warhammer game lies in its meticulously crafted and diverse range of miniature models, which consumers assemble and paint. Beyond engagement in battles, he process of assembling, painting, and amassing these models imbues individuals with a profound sense of fulfillment and achievement.

The diverse array of models and customizable gear and accessories available within the Warhammer series not only offers players opportunities for imaginative expression but also fosters heightened engagement in creative pursuits within the Warhammer gaming community, particularly amidst the proliferation of accessible production technologies and collaborative development trends within online community platforms. This phenomenon has sparked the interest of researchers in this industry.

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Nevertheless, research on miniature models in Taiwan has been relatively lacking, with firsthand sources of information such as gaming regulations, assembly techniques, and narrative backgrounds for games like "Warhammer Fantasy" and "Warhammer 40K" originating predominantly from the UK and being primarily available in foreign languages. In September 2020, "Warhammer 40K" underwent its 9th edition major rule update, accompanied by the inaugural release of a Chinese-language translation. The Greater Taipei area alone hosts at least three Warhammer game clubs. Non-official tournaments organized from time to time by various establishments draw substantial participation and generate considerable interest.

This study primarily investigated the expressive forms of Warhammer game club members' miniature models and comprehend the inherent artistic value of miniature model creation, focusing on the forms of expression in modeling. The industry stakeholders are expected to obtain a more profound understanding of consumer needs. Furthermore, this study aims to provide a reference for future research exploring alternative forms of expression and techniques in miniature model creation.

2 Literature Review

2.1 Miniature Model of Warhammer Wargames

This study investigates the Warhammer series by Games Workshop. Established in the 1980s, Games Workshop has become the world's largest producer of miniature wargames, with 2023 sales of £470.8 million [6] and over 526 stores worldwide [7].

The Warhammer series draws inspiration from traditional Western literature and is divided into two main systems: (1) "Warhammer Fantasy" features races such as humans, elves, dwarfs, and demons, engaging in conflicts and alliances driven by their purposes, survival, and honor. It incorporates elements from J.R.R. Tolkien's "The Lord of the Rings," while its gameplay mechanics are influenced by "Dungeons & Dragons." (2) Warhammer 40K, a darker spin-off introduced in 1987, involves factions like humans, demons, and aliens in mutual combat and competition. It references Christian classics and historical elements, including European medieval Christianity and the Roman Empire.

Heljakka and Harviainen [5] describe "Worldbuilding" as the creation of a comprehensive fictional world, including geography, history, flora and fauna, races, and technologies, by designers before crafting narratives. Carter, Gibbs, and Harrop [1] surveyed players preparing for Warhammer 40K tournaments and identified four key aspects in game design: (1) Competitiveness: Fairness is crucial in Warhammer, a competitive game. Players aim to ensure enjoyment for both sides, not just victory. (2) Costs: Playing Warhammer is expensive, with armies at tournaments like Arcanacon in Melbourne costing between $600 and $1000. (3) Visual Appeal: Customized models reflect DIY and maker culture, with players personalizing and coordinating the aesthetic of their miniatures to enhance immersion. (4) Narrative: Players create background stories for their armies, aligning with the Warhammer universe detailed in rulebooks, novels, comics, and other media.

2.2 Forms of Expression in Miniature Models

The expression of art involves two aspects: inner form (expression) and outer form (form). Expression refers to the sensuous and spiritual state the artist conveys, while form translates these inner ideals into tangible images and objects. According to Hegel [4], art's content embodies the absolute idea (inner form), realized through various physical forms (outer form).

In the Warhammer series, the expressive form is seen as "scale models" within sculpture [3]. Miniature modeling originates from visual imagery, forming the model's visual representation [8]. These models replicate real-world prototypes, with various factors considered in humanoid modeling. Humanoid models have a robust torso reflecting human body structure, designed for battlefield postures and styles. The torso and limbs include weaponry and armor to denote strategic positioning, aiding player identification during gameplay. Warhammer Fantasy and Warhammer 40K are known for expansive worldbuilding, often centered around the struggle between good and evil.

3 Research Method

This study primarily employs content analysis as the main research method and was conducted in four steps: (1) Exploring the developmental history of Warhammer game miniature models, defining miniature models, and reviewing relevant theoretical frameworks of expression. (2) Creating tools for content analysis. (3) Conducting interviews with Warhammer game players and documenting their creative outcomes concerning expressive forms. (4) Content analysis on the expressive forms of creative outcomes.

The research entailed interviewing and documenting six members of local Warhammer game clubs in Taiwan. Criteria included aged 20 or above and recommended by club operators and community members for active engagement in miniature model creation activities. There were 5 males and 1 female; 4 players had over 10 years of experience in Warhammer wargames, 1 player with 5–10 years of experience, and 1 player with less 2-year experience. Upon obtaining consent from the interviewees, the miniature model creations they presented during the interview sessions were utilized as samples for the analysis of model expression.

An online one-on-one interview format was adopted, with interviews lasting approximately 30 min to one hour. Interviews were recorded, and interviewees were encouraged to were requested to provide several detailed photographs of their creative works of their miniature model creations in advance for explanation and presentation during the interview. The central theme of the interviews was the expressive forms of miniature model creation under the maker model. Factors such as the background setting of model characters, which could influence the expressive forms of miniature models, were discussed within the scope of modeling aspects. This study chose interviewee 04's miniature model creations serve as an example, employing the Warhammer game miniature model expression analysis table designed for this study (Table 1).

Table 1. Interviewee 04's Creative Work

Work Name: Chaos Dwarf (Serial No.: interviewee 04-01)	
 Official model	**Original Official Setting:** The design of the Chaos Dwarf exhibits distinctive traits such as protruding fangs, gray skin, and bloodred eyes, as well as severe mutations that may even result in beastly forms. They are characterized by greed and brutality, dedicating themselves to technological advancement and warfare, often resorting to pillaging and enslaving any foreign races they may encounter. Bull Centaurs combine features of bulls and human forms. They boast superior strength, arrogance, and agility compared to ordinary Chaos Dwarfs.
 Interviewee's model	**Interviewee's Creative Concept:** This piece's creative concept aligns with the original official setting of Chaos Dwarfs in the Warhammer Fantasy universe. Since the official appearance of Bull Centaurs has not provided any color recommendations, the interviewee based his choice of color scheme on the context in which Chaos Dwarfs live: a life away from civilization, relying on plundering and enslaving others for survival.
Character Imagery	Key Modeling Features
Cruelty, plundering, greed, enslavement	Lower body of animal (bull), Large beast horns on the skull, Protruding lower jaw, Prominent fangs, Asymmetrical handed axe and shield
Strong, agile	Running posture, Bare upper body, Muscular, Limited body covered in armor

4 Results

The researcher compiled a total of 12 miniature model creations provided by the six interviewees. Through the amalgamation of official original settings and the interviewees' creative concepts, the researcher identified several character imagery keywords symbolizing the narrative of these miniature models. All models were categorized into three types: Order, Neutral, and Chaos, based on the character imagery.

Regarding the defense of the survival of the overall intelligent races, including humans, and the possession of rational values such as honesty, obedience to authority, and respect for tradition, characters are classified as "Order." Individuals deviating from this ethos are categorized as "Chaos," while those exhibiting traits from both sides are classified as "Neutral." Based on this method, there are a total of 6 works classified as "Order," 1 work classified as "Neutral," and 5 works classified as "Chaos."

The researcher employed style modeling as the primary category for content analysis, examining four aspects of significant stylistic differences observed with varying character positioning (Table 2): "Surface Features," "Armor Coverage," "Animal Features," and "Head Modeling." The researcher invited an expert in miniature model gaming and a professional in the field of 3D character design to validate the analysis results of this study. After the two aforementioned experts had conducted a thorough review, they agreed with the results of the analysis presented by the researcher.

(1) Surface Features

The surface features of a character play a significant role in defining their narrative function within the storyline [2]. In this study, miniature models representing heroic characters predominantly exhibit stable and smooth geometric shapes, such as squares or

Table 2. Statistical Data on the 12 Miniature Models

Item				
Character Category		Order	Neutral	Chaos
Surface Features	Smooth surface	3	0	0
	Both smooth and spiky surface	2	1	2
	Spiky surface	1	0	3
Armor Coverage	Fully Covered	6	0	1
	Partially Covered	0	1	3
	Not Covered	0	0	1
Animal Features	No beastly features	5	1	1
	With beastly features	1	0	4
Head Modeling	Round and smooth	4	0	0
	None of the above	2	1	2
	Beast horn	0	0	3

circles (Fig. 1), whereas villainous characters often showcase more aggressive features, such as triangles or spikes (Fig. 2). The researcher believes these features are seen as sharp and dangerous in human perception. Spikes on hazardous natural objects like poisonous thorns and jagged rocks evoke associations with violence, injury, and threat, leading to feelings of unease. Additionally, spikes and triangles symbolize power and might, highlighting the antagonist characters' authority and combat prowess. In cases where a character's positioning is neutral, their features may incorporate elements from both ends of the spectrum. The researcher observed similar phenomena regarding the "surface features of miniature models (Table 2).

Fig. 1. Smoother surface

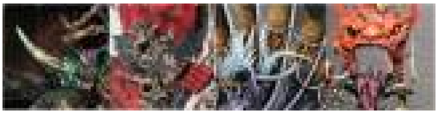

Fig. 2. Spikier surface

(2) Armor Coverage

The Warhammer characters primarily assume roles as active warriors on the battlefield, with their armor serving as their ultimate defense against harm. As indicated by statistical analysis (Table 2), miniature models affiliated with the Order faction tend to embody qualities such as rationality, wisdom, and vigilance. Consequently, they often feature comprehensive armor coverage, significantly augmenting their survivability in combat scenarios (Fig. 3). Conversely, miniature models aligned with the Chaos faction, some of which possess supernatural protections, tend to prioritize the depiction of muscular contours in their body sculpting, resulting in reduced armor coverage (Fig. 4); this reflects the chaotic and irrational persona associated with the Chaos faction.

(3) Animal Features

The researcher noted a significant correlation between the presence of beastly visual elements and characters aligned with Chaos. Drawing from the perspective of religious anthropology, the worship of animals often emerges from collective beliefs in primitive societies, certain animals are revered as ancestral figures, with their worship intended to imbue the community with strength and protection against external challenges. Moreover, the expulsion of primal (animalistic) traits from human nature has been projected onto specific animals. Consequently, characters aligned with Chaos frequently blend human and animal features in an attempt to evoke a sense of transcendence beyond conventional rationality and laws (Table 2 and Fig. 5).

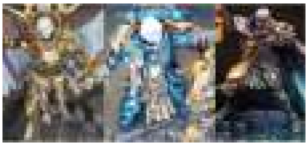

Fig. 3. Fully covered

Fig. 4. Partially covered

Fig. 5. Animal features

(4) Head Modeling

The researcher noticed that some of the miniature model work classified as representing Orders had decorative elements resembling a "halo" at the back of the head. The halo is often used in religious paintings and sculptures of protagonists to symbolize the holiness of characters in artistic works (Fig. 6). The researcher attributes this phenomenon to the dualistic worldview of good versus evil within the Warhammer series. Within the Order faction exists the concept of "good gods." Conversely, certain miniature model works classified as representing Chaos consistently feature sculpted animal horns on the head (Fig. 7), aligning with the previously observed occurrence of animal features commonly found in miniature models representing Chaos (Table 2).

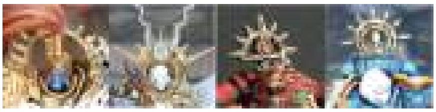

Fig. 6. Head modeling of the Order faction

Fig. 7. Head sculpture of the Chaos faction

5 Conclusion and Limitation

This study has identified the following correlations between the modeling and character imagery of Warhammer game miniature models: (1) A correlation exists between the surface area of armor coverage on the models and their faction alignment. (2) Chaos faction models commonly display angular or triangular line patterns on their bodies and armor, while Order faction models tend to feature square or smooth shapes. (3)

Warhammer models frequently incorporate religious visual elements into their head or body designs. The study's focus on analyzing photographs of respondents' miniature model works limited the ability to fully explain the creative ecosystem of players or the impact of narrative backgrounds on their creations. Factors such as community involvement, and the relationship between age, gender, and creativity were not fully explored. Addressing these issues could significantly contribute to the growth and expansion of the miniature model market.

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Challenges and Future Trends of EEG: Application of the Human-Centred Design Approach in the Paediatric Field

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Abstract. Recent advances in EEG technology have addressed some crucial challenges, focusing on developing more advanced monitoring devices. However, finding a balance between comfort, aesthetics, recording efficiency and adaptability to different contexts, such as home and paediatric settings, remains an open challenge. It is known that children can be sensitive to uncomfortable or invasive devices; therefore, the article examines innovation scenarios in paediatric neurophysiology. The research at Meyer Children's Hospital in Florence proposes an entirely new vision of the EEG monitoring device to ensure a more user-friendly and familiar system for children. Thanks to the application of Human-Centred Design and User Experience methodologies, it was possible to analyse the current critical issues and define the requirements of Cosmos+. This new system was developed to improve the experience of young patients, reduce discomfort and promote personalised monitoring even at home, representing a new frontier in paediatric neurophysiology.

Keywords: Paediatric neurophysiology · EEG wearable technologies · Health Design · Usability · Human-Centred Design

1 Introduction

Modern neurophysiological techniques have significantly enhanced understanding cortical dysfunctions in neurological diseases. In paediatrics, conditions like brain lesions, epilepsy, and stroke are prevalent and often lead to high mortality and disability rates [1]. Emerging neuro-monitoring technologies, particularly continuous and non-invasive electroencephalography (EEG), are essential in paediatric care for diagnosing and managing acute brain injuries and monitoring critically ill patients [2].

EEG is crucial in detecting brain activity anomalies and seizures [3] and assessing cognitive and affective processes despite methodological limitations such as muscle artefacts and the position of the reference electrodes. In paediatric emergency medicine, EEG and video-EEG are vital for identifying non-convulsive seizures [4], monitoring wakefulness and sleep, and detecting brain dysfunctions [5].

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However, using EEG in children faces challenges like usability and comfort, as traditional systems require conductive gel electrodes, limiting mobility and ease of use [6]. These recording systems require time-consuming activity and an unpleasant application that forces the patient to wash their hair to remove gel residues. Recent advancements have led to the creation of portable, wireless EEG devices [7, 8], yet balancing comfort, aesthetics, efficiency, and adaptability to different operational contexts remains challenging. Often, the healthcare sector prioritises technical and regulatory aspects over patient and healthcare personnel needs, leading to usability issues. Therefore, the University of Florence and Meyer Children's Hospital initiated a multidisciplinary research project to improve paediatric EEG monitoring. The project aimed to optimise the system and enhance the experience for patients and medical staff by developing a new wearable EEG device suitable for both hospital and home use. Specific goals included analysing human-device interaction in paediatric EEG monitoring, identifying workflow issues, evaluating current EEG devices' effectiveness and usability, and defining requirements for a new device.

2 Methods

The research, conducted at the Meyer Children's Hospital in Florence, used theoretical and methodological tools specific to Ergonomics for Design [9], specifically those of Human-Centred Design (HCD) [9] and User experience [10], to analyse the human-medical device interaction. These tools allow complexity management by keeping the human factor central and preventing incorrect uses. Furthermore, by including information collected in the contexts of life and work, they allow the definition of effective design solutions.The study, developed over several phases, involved some field investigations and the involvement of various figures who use EEG devices in the paediatric field (doctors, healthcare workers, neurophysiopathology technicians, and biomedical engineers). It focused on their needs and expectations, as well as the skills and points of view of the professionals involved in the programming and design of this product/service. The research precisely followed the following operational phases:

Phase 1: Literature analysis and benchmarking.

Phase 2: Evaluation of current EEG systems.

Phase 3: Data analysis.

Phase 4: Development of design concepts and intervention scenarios.

2.1 Literature Analysis and Benchmarking

In the initial phase of the study, a literature review was conducted to establish a scientific foundation. The search for relevant articles was performed on platforms like Google Scholar, PubMed, and ResearchGate using specific keywords related to "EEG devices", "wearable technology", "paediatric neurophysiology", and the "emotional impact of EEG". It helped identify significant national and international research contributions. Concurrently, a benchmarking analysis was performed to examine various EEG devices on the market, focusing on their functionality, technology, morphology, and application areas [11]. The findings were summarized into sheets to aid further research phases.

2.2 Evaluation of Current EEG Systems

Thanks to the application of HCD methodologies involving healthcare workers and patients (User Trials), the subsequent phase evaluated the brain electrical activity monitoring service and the instrumentation used in the ward, explicitly analysing current EEG devices and their usability. To this end, were conducted:

- *Direct observations* [12]: Users were observed before, during, and after monitoring, documenting every action of patients (6–14 years old), parents, and healthcare personnel to gather information for redesigning the device.
- *Semi-structured interviews* [13]: Experts and professionals provided insights into activities, highlighting issues, needs, and details of user-product/service interaction.
- *Questionnaires* [13]: Neurophysiopathology technicians, neurologists, and paediatric epileptologists at Meyer Hospital and other public and private hospitals nationally and internationally shared their satisfaction and opinions via a 5-point Likert scale and open questions, yielding significant statistical data.
- *Personas, Scenarios and Task Analysis* [9]: These tools helped analyse and design the new device by representing ward activities, operational phases of EEG monitoring, and identifying interaction problems.
- *User journey maps* [14]: These tools visualised users' actions, feelings, and perceptions during interaction with the product/service, identifying weaknesses and opportunities for enhancing the user experience.

2.3 Data Analysis

The data collected in the previous phase were crucial for identifying critical issues in the EEG monitoring workflow and outlining new requirements and innovation scenarios. The main challenge was determining the correct requirements to address these problems [15]. Data from interviews, questionnaires, and direct observations were analysed and synthesized into maps and diagrams to highlight critical areas and system requirements. Additionally, graphs showing user response percentages were created to facilitate understanding of the questionnaire data.

2.4 Development of Design Concepts and Intervention Scenarios.

In the final phase of this research, new design solutions were formulated and developed with a strong focus on usability and emotional impact. Utilising design-orienting scenarios was crucial in generating innovative visions and proposals and prioritising user needs. This approach enabled the team to articulate a strategic vision to create a new, user-friendly wearable EEG monitoring system. Given the extensive scope of the research, only the most significant results are highlighted below.

3 Results

3.1 Evaluation and Analysis of Critical Issues

The investigation phase data were crucial in identifying issues and defining requirements for a new EEG monitoring device. Problems with current devices in the neurophysiology ward include their bulkiness, excessive cables connecting the patient, and discomfort, especially during sleep monitoring. The cap and gel-based electrodes are unpleasant and leave patients feeling wet, causing anxiety and fear. In addition to the general discomfort declared by patients and their families, difficulties emerged relating to its use by healthcare professionals; in particular, they declared difficulties relating to the correct positioning of the electrodes on the scalp due to the absence of feedback from the device. These challenges have paved the way for developing the EEG Cosmos+ device, a potential game-changer in paediatric EEG monitoring. The main results of this innovative device are reported below.

3.2 Design Solutions

The *Cosmos+* device was designed to diagnose and monitor brain activity anomalies in paediatric patients, such as epileptic seizures and sleep states. It aimed to provide long-term monitoring outside the hospital, making the technology more accessible, comfortable, and emotionally acceptable. Key design aspects include *ease of use*, *versatility*, and *modularity*. Equipped with three modules that can be positioned on different scalp areas according to the international 10–20 system, Cosmos+ allows for accurate analysis and recording of electrical activity. It also offers improved comfort and familiarity for young patients and more accessible use for healthcare personnel (see Fig. 1). The *modularity* and *versatility* of Cosmos+ specifically allow the monitoring of different areas of the scalp according to the user's needs and medical directives. Equipped with dry electrodes, the devices can monitor various brain regions:

- Device 1, positioned on points FP1 and FP2 of the international 10–20 system, monitors the activity of the frontal lobe, which is involved in higher cognitive functions such as executive control and emotion regulation.
- Device 2, placed on the O1 and O2 points, monitors the occipital lobe, responsible for vision and visual processing.
- Devices 1 and 2, through elastic bands positioned on points F7, F8, T3, T4, T5, T6, favour monitoring the temporal lobe, involved in functions such as memory, hearing, language and facial recognition.
- Device 3, on points F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, allows monitoring of the parietal lobe, which processes sensory information, spatial perception and attention.

The system employs adjustable elastic bands and dry electrodes for comfort, eliminating the need for conductive gel and reducing movement artefacts. It wirelessly transmits electrical pulses to an amplifier, which sends the data to a computer for EEG trace viewing. The amplifier provides luminous feedback to indicate correct or incorrect electrode positioning. Cosmos+ is *user-friendly, portable and supports telemedicine*, allowing home monitoring and real-time result transmission to specialists via an app. It could optimise specialist workflows, reduce patient wait times and ward overcrowding, and prevent errors. Designed with soft lines and pleasant colours, it is less invasive and more comfortable for young patients. Using *medical-grade materials* ensures excellent sterilisation, lightness, comfort, and adaptability.

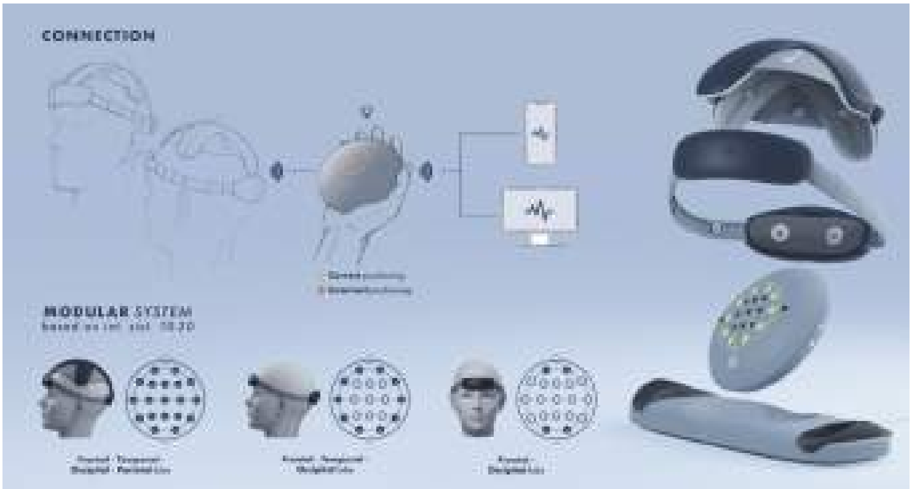

Fig. 1. The Cosmos+ system, the innovative EEG device for more user-friendly and familiar monitoring in the ward and at home.

4 Discussions and Conclusions

The Cosmos + concept introduces innovative scenarios in neurophysiology, offering a renewed vision of EEG monitoring devices with a focus on usability and morphology. The results presented in this article highlight the advantages of applying Ergonomics for Design and Human-Centred Design methodologies in designing healthcare solutions. The new device's proposal aims to advance the development of wearable technologies and guarantee a more user-friendly and familiar monitoring brain activity system for the end user. Its features, such as a modular system, luminous feedback, dry electrodes, and connectivity to apps and external devices, offer versatile monitoring solutions in hospitals and at home.

Cosmos+ represents a new frontier of homecare EEG. This type of technology has the potential to revolutionise the way neurological and psychiatric disorders are managed, allowing: (i) more frequent and continuous monitoring compared to traditional hospital or clinic visits; (ii) greater comfort and convenience for patients; (iii) cost reduction by avoiding hospital admissions; (iv) personalisation of treatment; (v) facilitated access to diagnostics and treatment from home. This last aspect could represent a significant step forward in neurophysiology. The proposed system has potential applications in clinical, research, and monitoring fields both in the ward and at home, contributing to neuroscience and brain understanding. Despite its potential benefits, several challenges must be addressed. These include ensuring the accuracy and reliability of collected data using dry electrodes, safeguarding sensitive patient information with robust privacy protections, and ensuring affordability across all demographic segments. Practical user training and strategies to maintain long-term user engagement are also essential. Future developments involve prototyping, further enhancements, and exploring gamification strategies, particularly in paediatric hospital settings, to enhance user interaction and engagement.

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Experiment on Form-Morphing Handles for Anthropometric Shapes and Reduced Contact Pressure in Load-Transfer Use Cases

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Abstract. Different hand anthropometry and load transfer use cases require specific handle forms for maximum usability with minimal contact pressure in the hand-handle interface. This work's form-morphing handle adapts to these factors by varying stiffness of its granulate-filled, flexible shell aiming at the use context of walking aids. The 3 x 6 study compares the adaptive handle to a size-personalized and a use case-optimized handle for load transfer tasks. Contact pressure is compared via rmANOVA, showing significantly lower pressure for the adaptive handle. 3D-scan form analysis provides design suggestions for enhanced ergonomics in adaptive hand-handle interfaces of hand-held products and tools.

Keywords: Adaptive handle · usability analysis · experiment · load transfer · contact pressure

1 Introduction to Load Transfer Handle Evaluation

Manual load transfer via handles applies in use cases ranging from power tools and mobility aids for the elderly to steering interfaces for vehicles. For ideal ergonomics the handle form must fit individual users' anthropometry as well as the transferred loads within its intended use cases. For varying users and varying loads, the handle form must therefore adapt itself to the changing conditions [1].

Approaches to evaluating handle forms and their effects on usability consider maximum transferrable loads, subjective ratings or contact pressure distribution in the hand-handle interface. Contact pressure is measured with sensors on the handle in realistic use cases with power tools [2] or steering wheels [3] to compare it to the respective output loads, e.g., power tool acceleration or steering wheel torque. Previous studies [4, 5] also utilize more abstract test stands for varying handle orientations and manual arm strength measurements. Nicholas et al. (2012) identify task-specific contact pressure distribution by varying push and pull load transfers normal to a cylindrical handle attached to a force gauge. They use a Tekscan pressure sensor on the handle surface [6]. Handle designs are similarly analyzed: Harih and Dolšak (2014) compare cylindrical handles and counter-shapes to an individual hand's power grip anthropometry by subjective ratings. They use

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a force gauge to control a constant 50 N normal load output [7]. Kong and Lowe (2005) evaluate handle diameters by maximum grip force and hand-handle contact pressure comparison, measured by pressure sensors attached to the hand [8]. Hokari et al. (2019) attach Tekscan Grip System 4256E force sensitive resistor pressure sensors to a glove and compare differently shaped handles to identify pressure patterns without measuring the output load [9]. However, Kadefors et al. (1993) propose considering output loads when evaluating hand-handle interfaces by contact pressure [10]. This is consistent with the common definition of *efficiency* when evaluating usability [11]. Thus, this work focuses on the relation of transferred load (output) and contact pressure (input) when comparing handle forms.

2 Methods and Experiment Design

Based on the initial hypothesis that handle forms need to adapt to users and tasks [1], the following study hypotheses are examined: (1) Mean contact pressure between the hand and the adaptive handle is lower than with the personalized and optimized handle respectively for different load transfer tasks. (2) The ideal handle form, resulting in lower contact pressure, differs by task.

A 3 x 6 within-subject experiment [14] is conducted with n = 35 subjects and informed consent. The sample contains 13 female, 22 male subjects aged 22 to 73, with a hand length of $160 \leq l \leq 210$ mm and a hand width of $67 \leq w \leq 97$ mm. The factor *handle* has three levels, see Fig. 1a. First, a personalized handle in three sizes following [12] is assigned according to hand length and hand width percentile [13]. The subjects chose the handle size themselves if the assignment based on hand size is ambiguous. Second, an optimized handle for the use case of walking aids/ rollators is examined. It is designed specifically for support and push tasks with a thenar support. Third, the adaptive handle, with a form-morphing surface and variable diameter, as described by [16], is used. Its cylindrical base form adapts to hand anthropometry under pressure and is switched rigid by extracting air from its granulate-filled shell within < 1 s, allowing for load transfer. The handles' dimensions (D, d, l) and form morphing range (Δr) are specified in Table 1. The six levels of the factor *task* are derived from real-life use cases of using a rollator as a mobility-aid [15]. Each task is characterized by a dominant load as shown in Fig. 1b. A constant load level of F = 30 N or M = 5 Nm ensures comparability of individual contact pressure measurements for equal outputs as well as all subjects being physically able [17] to transfer the load.

Anthropometric measurements of the hands are taken manually and with a computer vision system [18] locating joints and measuring hand, palm, and finger lengths and widths. The test stand height is adapted to the subject's body height for equal hand-arm positioning. Figure 2 shows the test stand design and components. Contact pressure is measured with a force-resistive sensor (Tekscan Grip System 4256E) fixated on a thin cotton glove, ensuring exact sensor cell placement on the palm, thumb, and phalanxes [14] for differently sized hands. The transferred load is controlled via a 6-axis force sensor (ME K6D80). The subjects perform the tasks with isometric load transfer while maintaining consistent hand-arm positioning (straight wrist, 135° elbow angle to grip the handle horizontally). The subjects are instructed to comfortably grip the handle

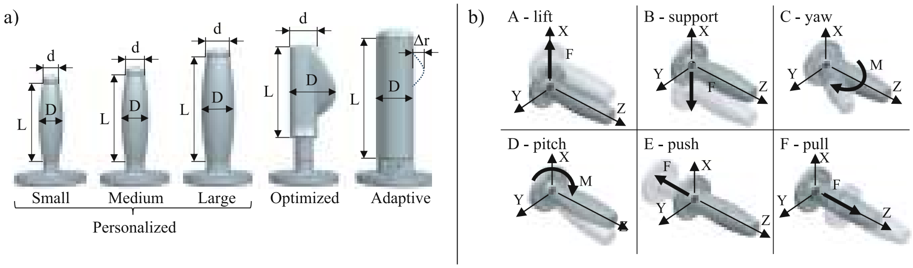

Fig. 1. Independent variables: handles with dimensions (a), tasks with load direction (b).

Table 1. Handle dimension specification for the three sizes [12] of the personalized handle as well as the optimized and adaptive handle.

Handle	Personalized			Optimized	Adaptive	
Dimension	Small	Medium	Large			
D [mm]	28	32	38	53		44
d [mm]	18	22	28	32	Δr [mm]	±10
L [mm]	90	100	120	108		125

with a right hand, five-finger power grip and transfer the loads individually in a randomized order. Sensor measurements are taken during 10 s of constant load transfer within a 2 min cycle time per handle and task. The form-morphing handle is adapted to each hand and task prior to measurement, its shape is 3D-scanned using an Artec 3D Space Spider scanner afterwards.

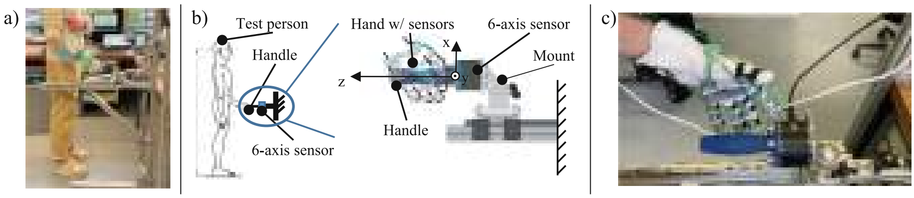

Fig. 2. Test stand design with size appropriate hand-arm positioning (a), schematic diagram with components (b), and detailed view of a hand with pressure sensor [14].

3 Contact Pressure and Adaptive Handle Form Results

The mean contact pressure by handle and task sensor data is mapped on the respective hand zones in Fig. 3a. Areas of high contact pressure peaks are shown in darker color and vary by task. They indicate the main load transfer locations in the hand-handle interface. Overall, these pressure peaks are less prevalent in the adaptive handle's pressure maps and most distinct for the personalized handles.

Differences in mean contact pressure are tested using repeated measurement analysis of variance (rmANOVA). Since the test for sphericity is significant (Mauchly-W(2) = .942, $p = .002$) a Huyn-Feldt correction is applied. The following rmANOVA ($F(1.954, 398.542) = 344.372$, $p < .001$, $\eta_p^2 = .682$, $n = 35$) and Bonferroni corrected pairwise comparison show significant differences in the mean contact pressure between the three handles for all six tasks, see Fig. 3b. The effect is strong ($f = 1.464$). Therefore, hypothesis 1 is accepted.

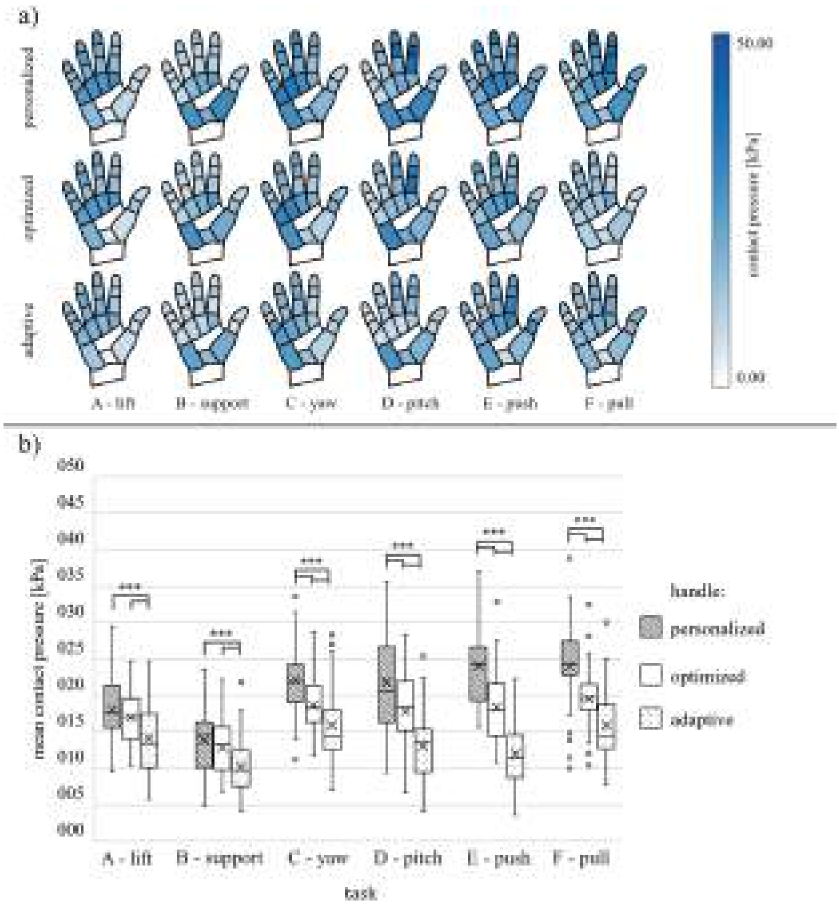

Fig. 3. Mean contact pressure by handle and tasks within sensor zones on the hand surface (a); significant differences in contact pressure by handle and task (b).

The point clouds of the 3D-scanned handle forms are analyzed using CloudCompare 2.12.4 and MATLAB R2023b software. The individual (user- and task-specific) handle forms are averaged by task as shown in Fig. 4. Thumb and finger indentations as well as thenar and wrist contact zones are visualized in a side view in Fig. 4a. Finger indentations spread along the length of the handle with a local radius $r = 16 \pm 3.5$ mm (surface to length axis z). Figure 4c shows the top view of the thumb indentations (handle radius r = 18 ± 5 mm), metacarpophalangeal joint contact zone (r = 20 ± 2.5 mm), and thenar support protrusion (r = 24 ± 4 mm). This protrusion differs between tasks in its tangential position (x) along the z-axis, as depicted in the cross section Fig. 4b. Generally, the adaptive handle form allows for maximum normal load transfer, e.g. large finger indentations for task A, flat top side for task B. Especially for the tasks E and F it provides a large normal load transfer interface between the finger and palm side of the handle. Based on these results, hypothesis 2 is accepted at present. The smoother anthropometric shape is exemplarily compared to the optimized handle in Fig. 4d.

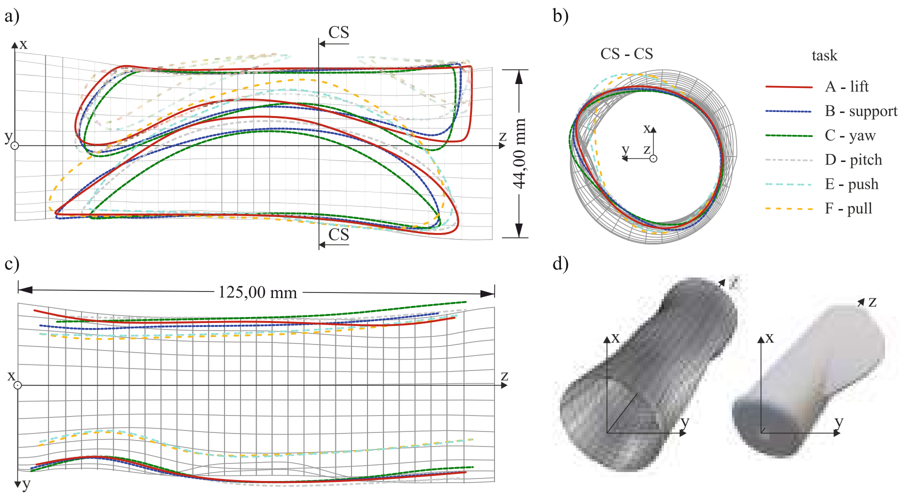

Fig. 4. Mean adaptive handle form by task with thumb and finger zones side-view (a); wrist support in cross section (b); thumb indentation, wrist support, and palm radius in top view (c); comparison of the adaptive handle for task A – lift and the optimized handle (d).

4 Discussion, Conclusion, and Product Design Outlook

Although isometric tasks offer controlled conditions, their abstraction from real-world scenarios limits applicability [19]. Still, the results of this study can be transferred to further applications since contact pressure distribution fits the load transfers of occupational use cases and expected patterns from [6]. The average contact pressure is generally low for all three handles. However, the adaptive handle results in significantly lower contact pressure for each of the six examined tasks. So, comfort improvements for higher load tasks could be further investigated regarding hypothesis 1.

Despite generating a database of hand anthropometry and corresponding adaptive handle forms, the study design would benefit from repeated measurements of hand positioning during load transfer analogue to [9] and repeated 3D scans for each task. With this, task- and user-specific handle forms can be further analyzed (cf. Hypothesis 2).

Mean differences in task-specific handle forms are small but promising to improve load transfer in real-life applications especially by adapting the thenar and wrist support area's position to maximize normal load transfer in the hand-handle interface. Considering the initially mentioned use cases, the results can be applied to product design, where handle position is often determined by the product's structure, like vehicle steering interfaces or hand-held tools. Positioning the contact zones from Fig. 4 according to the main loads, designing for adaptivity of the zones and smoothing of the handle form is recommended. Thus, employing either a form-morphing adaptive handle or transferring results to static handle designs can improve contact pressure distribution.

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ERGOGRIP: Redefining Experience Through Ergonomically Designed Multifunctional Digital Pen

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Abstract. Ergonomics plays a crucial role in both professional and academic settings, with the primary goal of enhancing user comfort and precision in consumer products. One such product that exemplifies this principle is the ergonomic pen, designed to alleviate wrist strain and prevent discomfort. By incorporating features like Ergogrip, these pens not only address ergonomic issues but also prioritize user well-being and productivity. It is essential to recognize that prolonged use of traditional pens can contribute to musculoskeletal disorders, making ergonomic pens indispensable tools for maintaining user health. In order to gain insight into consumer needs regarding digital pens, a comprehensive survey involving 400 participants aged 18–50 in Metro Manila was conducted alongside detailed interviews. The findings underscored consumers' emphasis on usability, durability, design aesthetics, as well as pricing when considering a digital pen purchase. Through its diverse functions and specifications focused on providing comfort while bolstering productivity, Ergogrip emerges as an ideal solution for users seeking ergonomic and efficient writing tools.

Keywords: Ergonomics · Digital Pen · Multifunction · Musculoskeletal Disorders · Productivity

1 Introduction

Digital pens represent a convergence of traditional writing tools and modern digital technology, enhancing productivity through efficient and organized digital note-taking and drawing [1]. They offer significant advantages in various fields, including education, graphic design, art, animation, online teaching, and healthcare such as facilitate interactive learning, allowing students to annotate directly on digital documents, enabling precise control and creativity, and streamline processes by allowing for the efficient input and management of electronic health records and patient data.

The evolution of digital pens is driven by the need for more advanced and user-friendly products. As technology progresses, so does the functionality of digital pens, incorporating features like pressure sensitivity, tilt recognition, and wireless connectivity. The study of digital pens is crucial to keep pace with these advancements and fully leverage their benefits in various professional and academic settings.

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In a study conducted by Microsoft, Riche et al. [2] explored the everyday use of analog pens to enhance digital experiences. The study examined the evolving perspectives on the use of analog versus digital pens across different scenarios and activities. Insights were gathered from heavy analog pen users with diverse backgrounds and occupations, and these were compared to those of digital pen users.

This research aims to develop a multifunctional digital pen that combines writing, drawing, and advanced technological capabilities based on user opinions and preferences. This study seeks to create a digital pen that not only meets current demands but also anticipates future trends in digital writing technology. The goal is to provide a tool that seamlessly integrates into various workflows, offering ergonomic design, enhanced functionality, and user-friendly features that cater to a wide range of applications.

2 Related Literature and Studies

The study of digital pens intersects various fields, including ergonomics, healthcare, and education. As Sánchez-Margallo et al. [3] emphasize, the ergonomic design is critical not only in surgical instruments but also in tools like digital pens to ensure user comfort and efficiency. Boyle and Joyce [4] illustrate the significant role of smart pens in aiding students, particularly those with learning difficulties, in taking quality notes. This aligns with the broader narrative within ergonomics, where users seek comfort and efficiency while adapting to technological advancements.

2.1 Ergonomic Challenges and Innovation

Prolonged hand usage can lead to musculoskeletal disorders (MSDs), a concern noted by Dennerlein [5]. Occupational MSDs are prevalent among healthcare workers due to the nature of their work, which often involves repetitive hand movements and extended use of hand tools. The ergonomic struggle is not limited to healthcare; it affects any profession involving extensive use of hand-operated tools, including digital pens.

The handle design of laparoscopic instruments is crucial to both surgical performance and the surgeon's ergonomics. This principle of ergonomic design extends to digital pens, which must facilitate "flexibility in use" to accommodate a wide range of users. The study of Sancibrian et al. [6] indicates that hand tools should match certain design characteristics to overcome barriers such as age, gender, laterality, and psychomotor abilities. The onset of pain and long-term use of poorly designed hand tools can result in conditions like finger numbness and paresthesia. Ensuring a consistent tool design that reduces grip forces and pressures is critical for preventing health problems associated with prolonged exposure to high forces and pressures in the hand area.

2.2 Digital Notetaking

Modern learning and teaching practices increasingly involve the use of information and communications technologies (ICT) along with complementary tools. Patty and Garland [7] highlighted smart pens as contemporary technological devices that significantly help students with learning difficulties improve the quality of their notes. These smart pens facilitate effective note-taking by integrating digital technology with traditional writing, thus supporting students in modern educational environments. This integration is particularly beneficial in enhancing the learning experiences of students with disabilities, enabling them to participate more fully in educational activities.

2.3 Multifunctionality and User Preferences

The multifunctionality of digital pens, which combines writing, drawing, and advanced technological capabilities, is essential to meet diverse user needs. A multifunctional design not only enhances usability but also increases the appeal of digital pens across various professional and personal applications. User preferences, as highlighted in several studies, point towards the need for durable, user-friendly, and aesthetically pleasing designs [8]. Understanding these preferences is crucial for developing digital pens that are not only technologically advanced but also ergonomically sound and user-centric.

3 Methods

This research study utilized a mixed-method approach, incorporating both qualitative and quantitative research designs. The primary aim was to explore how digital trends and transformations affect individual users and to understand the relationship between technological advancements, customer experience improvements, cost reduction, and sustained competitive advantage. By collecting and analyzing both qualitative and quantitative data, the study sought to gain a comprehensive understanding of significant factors influencing user preferences and behaviors regarding digital pens.

The research focused on discovering users' attitudes and preferences toward using digital pens as daily tools. The study aimed to identify potential factors influencing consumer preferences for the Ergogrip digital pen, considering aspects such as retail pricing, durability, design, branding, and initial functionalities. To gather in-depth insights, the researchers conducted interviews with 14 randomly selected respondents about their everyday use of digital pens.

Considering the population of tablet users in Metro Manila and a 0.05 margin of error using Slovin's formula, the researchers identified 400 participants for data collection. The data gathering process involved a structured survey deployed through Microsoft forms and social media websites. The first section explained the primary purpose of the study and how the research would contribute to the understanding of digital pen usage. The following section contained questions about demographics, essential for assessing the target audience for the Ergogrip digital pen. Subsequent sections focused on traditional and digital pen usage, collecting data on the types of pens respondents used and their experiences with them. Further sections aimed to evaluate the satisfaction and reliability of current digital pens on the market and willingness to try and purchase different brands. Another section assessed how much respondents were willing to pay for a digital pen, providing valuable insights into pricing strategies for the Ergogrip. The survey also explored consumer store preferences, buying behavior, and potential marketing and advertising strategies for the Ergogrip. Finally, the last section analyzed the critical factors influencing the purchase decisions of digital pen users, including their attitudes, interests, and opinions.

By using this data collection approach, the researchers aimed to gather detailed and actionable insights into the preferences and behaviors of digital pen users. This information was crucial for designing a product that meets user needs and expectations, ensuring the success of the Ergogrip digital pen in the market.

4 Results and Discussion

The survey results provided valuable insights into the demographic and behavioral preferences of digital pen users. The majority of respondents, 89.5% (358 responses), were aged 18–24 years, indicating a clear preference for digital pens among younger users. This age group likely finds the pen design appealing or comfortable, potentially due to extensive note-taking or academic writing tasks.

Employment status data revealed that 88.5% (354 responses) of the respondents were students. Thus, students are the primary market for digital pens, utilizing them for notetaking, assignments, and other academic activities. Regarding the type of pen used, 42% (186 responses) of the respondents reported using both traditional and digital pens. This indicates a blend of preferences, with many users finding value in both types of writing tools. The willingness to try a different brand was evident, with 34% (136 responses) being extremely likely to try a different brand. This suggests that there is an openness to exploring new options in the digital pen market, providing opportunities for new entrants like the Ergogrip digital pen. Price sensitivity was another critical factor, with 86.5% (345 responses) willing to spend between 100–2000 pesos on a digital pen. This price range provides a benchmark for setting competitive pricing strategies for the Ergogrip pen. The importance of digital pen functions was rated as “Very Important” by 62.3% of the respondents. This highlights the need for digital pens to offer robust functionalities that meet the diverse needs of users, such as writing, drawing, and integration with modern technology.

The data indicates a strong preference for comfortable and functional digital pens among the 18–24 age group. This demographic is highly engaged with extensive note-taking and academic writing tasks, which necessitate comfortable and reliable writing tools. The high satisfaction levels suggest that current digital pen offerings meet or exceed user expectations, providing a positive writing or drawing experience. Furthermore, the willingness of respondents to purchase another digital pen or try a different brand indicates a dynamic and expanding market.

The innovative design of the Ergogrip digital pen should consider not only economic factors but also long-term health benefits. Emphasizing ergonomic improvements can enhance user comfort and reduce the risk of musculoskeletal issues associated with prolonged use. By addressing these needs, the Ergogrip pen can provide a competitive edge in the market, appealing to users who prioritize both functionality and health benefits in their writing tools.

These results underscore the importance of ergonomic design and functional capabilities in digital pens. The insights gained from this study will guide the development of the Ergogrip digital pen, ensuring it meets the expectations and preferences of its target audience. By focusing on user comfort, innovative features, and competitive pricing, the Ergogrip digital pen can successfully capture a significant share of the market.

5 Conclusion

The Ergogrip project aimed to design and develop an ergonomically superior multifunctional digital pen that addresses the physical discomfort associated with traditional writing tools while integrating advanced technological capabilities to enhance user productivity and well-being.

The research focused on the ergonomic challenges faced by users, particularly within the 18–24 age demographic, and the need for a digital pen that combines comfort, functionality, and aesthetic appeal. A significant finding was that a vast majority of users (89.5%) within the target age group frequently engage in activities such as note-taking and academic writing, which necessitate the use of comfortable and efficient writing tools. This demographic also demonstrated a high willingness to try new brands and emphasized the importance of digital pen functions, with 62.3% rating these functions as "Very Important".

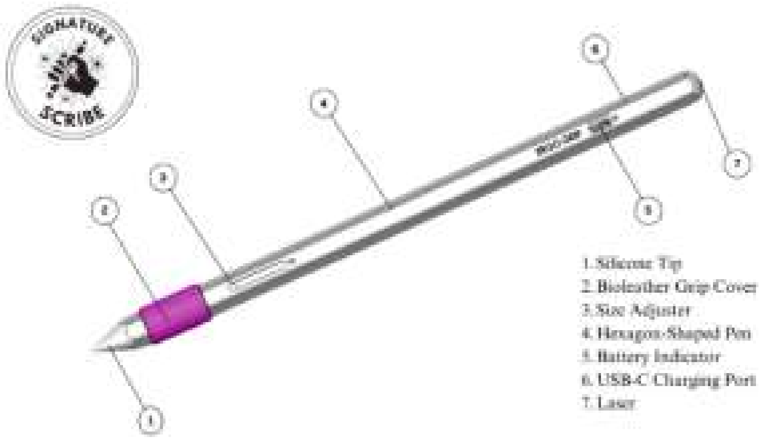

Fig. 1. Concept design of Ergogrip

Ergogrip, as shown in Fig. 1, is an ergonomically designed digital pen, crafted for durability and customized to embody traditional pen aesthetics. It connects to any touchscreen device via Bluetooth or USB Type-C. Featuring an adjustable silicone pen tip on one end and a presentation laser on the other, it caters to diverse user needs. A microbial bioleather grip cover retracts automatically, enhancing ergonomic support, complemented by a hexagonal body for a comfortable grip. This bioleather offers a significantly reduced carbon footprint and human toxicity levels [9]. Ergogrip includes a battery indicator to prevent mid-use surprises of low power and an eraser activation button for continuous functionality.

The Ergogrip digital pen was conceptualized to meet these needs by offering an ergonomic design that minimizes wrist strain and promotes comfort during prolonged use. By reducing the risk of musculoskeletal disorders, Ergogrip aims to provide a sustainable and health-conscious solution for users. The focus on ergonomic design not only addresses immediate user comfort but also contributes to long-term well-being, making Ergogrip a competitive choice in the digital pen market. Future recommendations for the Ergogrip project include broadening the demographic scope of the study to include a more diverse range of users, incorporating additional technological features such as built-in speakers or microphones, and conducting longitudinal studies to assess the long-term health impacts of the ergonomic design. Engaging with users through focus groups and collaborating with ergonomics and human-computer interaction experts can further refine the design and functionality of the Ergogrip digital pen.

In conclusion, the Ergogrip project successfully identified and addressed key user needs and preferences, resulting in a digital pen that prioritizes ergonomic excellence and multifunctionality. By continuing to innovate and adapt based on user feedback and technological advancements, Ergogrip has the potential to set a new standard in the digital pen industry, offering a product that not only enhances productivity but also promotes user health and comfort. Lastly, broadening the scope including diverse type of users will further strengthen the study's contribution to the field of Ergonomics.

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Enhancing Recycling Behavior Through Plastic Take-Out Container Design: The Moderating Role of Attitudes and Past Behaviors

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Abstract. In an era defined by the intersection of convenience, health consciousness, and environmental awareness, the proliferation of takeout and delivery services has reached unprecedented heights in the food industry. This surge, driven by the allure of fresh, healthy meals and the omnipresence of third-party delivery platforms, presents a double-edged sword: while offering lucrative opportunities for plastic take-out container manufacturers, it exacerbates the environmental burden of single-use plastics. Recycling emerges as a potential solution, promising to mitigate environmental impact by repurposing plastic containers. However, the pervasive issue of food residue contamination undermines the marketability of recycled plastic. This study explores how product design influences recycling behavior, moderated by consumer-related characteristics. Employing a mixed-method approach, we found that certain container attributes, such as single compartments and octagonal shapes, foster better recycling behavior. Consumer attitudes and past behaviors significantly moderate these effects, highlighting the importance of targeted interventions. Addressing challenges of contamination and recyclability uncertainty calls for collaborative efforts across the food supply chain. By offering actionable insights, this research seeks to catalyze a sustainable shift in the food industry towards harmonizing convenience with environmental consciousness.

Keywords: Plastic take-out containers · Recycling behavior · Container attributes · Attitude · Environmental sustainability

1 Background of the Study

In an era where the convergence of convenience, health consciousness, and environmental awareness shapes consumer behavior, the proliferation of takeout and delivery services in the food industry has surged to unprecedented heights. This surge, driven by the allure of fresh, healthy, and readily available meals coupled with the ubiquity of third-party delivery platforms, presents a double-edged sword. While it offers a lucrative opportunity for plastic take-out container manufacturers, it also exacerbates the environmental burden posed by single-use plastics (Filho, 2019). Recycling emerges as a potential panacea, promising to mitigate the environmental impact by repurposing

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plastic take-out containers into new products. Yet, amidst this promise lies a significant challenge: the pervasive issue of food residue contamination, which undermines the marketability of recycled plastic (Ishimura, 2022).

Exploring the nexus between product design and consumer behavior, extant literature suggests that recycling efforts can be catalyzed and facilitated by two key dimensions: the intrinsic attributes of the product and the characteristics of the individuals interacting with it. Research by Madria et al. (2021) underscores the pivotal role of product design, demonstrating that features such as compartmentalization and overall shape can serve as triggers for recycling behavior. However, the efficacy of such triggers is contingent upon consumer-related characteristics, as posited by Jekria and Daud (2016) and Park and Ha (2014). This assertion suggests that attitudes and past behaviors act as moderators, influencing the extent to which individuals engage in recycling practices.

Delving deeper into the interplay between product attributes and consumer behavior, this study aims to elucidate how product design shapes recycling behavior, moderated by consumer-related characteristics. By drawing on insights from behavioral theories, the research endeavors to design interventions tailored to target the determinants of recycling behavior. As underscored by Michie and Prestwich (2010), understanding the nuances of consumer behavior is paramount for devising effective interventions aimed at promoting sustainable practices. Through a nuanced exploration of these determinants, this study seeks to unravel the complexity of recycling behavior and pave the way for more sustainable practices in the food industry.

In essence, this research endeavors to bridge the gap between plastic take-out container attributes and consumer recycling behavior. By shedding light on the potential of product design as an intervention to enhance recycling behavior, it aims to catalyze a paradigm shift towards more sustainable practices in the food industry. Through a multidisciplinary approach that synthesizes insights from environmental science, psychology, and design, this study strives to offer actionable recommendations for stakeholders across the food supply chain, fostering a more sustainable future for all.

2 Conceptual Framework

2.1 Plastic Take-Out Container Attributes

The literature review highlights key insights from studies by Klaiman et al. (2017), Langley et al. (2011), and Wikström et al. (2016), informing the selection of attributes for plastic take-out containers in this study. Klaiman et al. (2017) underscored the challenge of cleaning food packaging before recycling, suggesting that containers with curved edges may facilitate easier cleaning compared to angular ones. This observation led to the hypothesis that containers with curved edges would be more conducive to recycling. Additionally, Klaiman et al. (2017) identified that single-compartment containers might be easier to clean and empty, addressing concerns about the effort required for recycling. Langley et al. (2011) highlighted consumer aversion to touching food residues during recycling, proposing that altering container shapes to allow lids to function as scrapers could mitigate this “ick” factor. Furthermore, Langley et al. (2011) noted that uncertainty about recycling procedures hindered recycling behavior, suggesting that clear information on recycling guidelines could promote better recycling practices. These findings collectively underscore the importance of packaging attributes and communication in enhancing consumer recycling behavior.

2.2 Consumer-Related Factors

Attitudes and past behaviors moderate the influence of certain attributes on recycling behavior. Research indicates that individuals with positive attitudes towards recycling, driven by an appreciation of its benefits, find recycling convenient (Klaiman et al., 2016, 2017). Thus, attributes aimed at facilitating recycling may have minimal impact on them. However, some individuals, despite positive attitudes, avoid recycling due to perceived difficulties (Bendak & Attili, 2017).

Furthermore, those with a history of consistent recycling are more receptive to recycling interventions, possessing the adaptability needed for behavioral adjustments (Heidbreder et al., 2019). Conversely, individuals without recycling experience resist habit change, even if they express willingness to participate. Hence, interventions promoting recycling may be more effective among individuals with prior recycling experience.

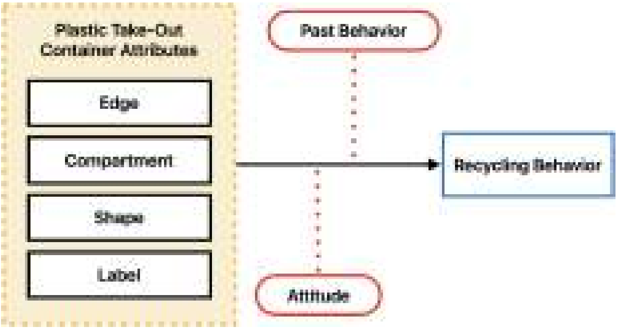

Fig. 1. Conceptual Framework

The complete conceptual framework, illustrated in Fig. 1, delineates the dynamics of recycling behavior concerning plastic take-out containers. Building upon the initial work of Madria et al. (2021), here, recycling behavior serves as the dependent variable, indicating consumers' actions regarding the disposal of their plastic take-out containers when recycling bins are available. These are moderated by consumer attitude and past recycling behavior. To enhance proper recycling practices among consumers, it is imperative to mitigate attributes associated with negative recycling behavior while accentuating those conducive to improving recycling behavior through thoughtful design considerations.

3 Methodology

To achieve the study objectives, a mixed-method approach was employed, combining quantitative and qualitative methodologies for data collection and analysis. Given the focus on recycling behavior, the primary experiment aimed to simulate consumers' take-out experiences, emphasizing realistic disposal actions. Before conducting the main experiment, a screening experiment was carried out to assess the suitability of plastic take-out container models. Criteria included the detectability of differences between model configurations and relevance to recycling behavior and perceived control.

The main experiment incorporated selected attributes (edge, compartment, shape) across varying levels to create eight container models. Recycling behavior was measured based on proper recycling, improper sorting, and improper recycling/sorting, with perceived behavioral control assessed through validated questionnaires. To maintain participant focus, the experiment was presented as a food evaluation task to avoid bias from observation awareness.

Convenience sampling via social media and personal invitations recruited 100 participants, with 74 datasets analyzed post-experiment. Structural equation modeling (SEM) was employed for data analysis, allowing assessment of latent variables and causal relationships. The analysis followed a two-stage methodology: measurement model evaluation through exploratory and confirmatory factor analyses, followed by hypothesis testing using explanatory modeling, as recommended in SEM literature (Fig. 2).

(a) (b) (c)

Fig. 2. Sample of plastic containers for the experiment: (a) angular, double, octagonal, with normal setup, (b) curved, single, rectangular, with explicit direction, angular, double, rectangular, with explicit direction

4 Results and Discussion

The investigation into the effect of container attributes on recycling behavior yielded results consistent with the findings of Madria et al. (2021), thus underscoring the robustness of the model. Specifically, the analysis revealed that the impact of edge design on recycling behavior was inconclusive, while the influence of compartment design proved significant. Notably, single-compartment containers were found to foster better recycling behavior. Additionally, regarding container shape, octagonal containers exhibited superior recycling behavior (Table 1).

Expanding upon this examination, the model suggests that utilizing plastic take-out container attributes as an intervention to enhance recycling behavior is more efficacious among consumers harboring favorable attitudes towards recycling. Notably, attitude emerged as a significant moderator ($p = 0.0193$), indicating its pivotal role in shaping the relationship between plastic take-out container attributes and recycling behavior. This finding aligns with previous scholarship positing that positive attitudes towards recycling

Table 1. Global moderation effect significance

Factors	P-value	Conclusion
Past Behavior	0.0344	Accept
Attitude	0.0193	Accept

are conducive to recycling intention. However, it is important to note that a favorable attitude does not invariably translate into positive recycling behavior, highlighting the potential for product attributes to bridge the gap between attitude and behavior.

Conversely, employing plastic take-out container attributes as an intervention to bolster recycling behavior is particularly effective among individuals with a history of frequent recycling. The analysis revealed that past behavior significantly moderates the effect of plastic take-out container attributes on recycling behavior ($p = 0.0344$), indicating that the attributes are most impactful among those who possess prior experience with waste sorting. Notably, participants with a habit of proper waste segregation demonstrated a higher propensity to adopt desired recycling behaviors during the experiment. Conversely, individuals who seldom engage in waste sorting expressed distinct concerns, such as aversion to obstacles like dirty trash bins or uncertainty about waste materials.

Participants who habitually engage in waste sorting often attributed their behavior to early exposure to proper waste segregation practices, suggesting that such habits facilitate adherence to desired behaviors. However, challenges persist, particularly concerning products that present uncertainty regarding their recyclability, such as contaminated plastic take-out containers. Conversely, participants who infrequently or never engage in waste sorting expressed disparate concerns, including disinclination triggered by perceived obstacles or a lack of consideration for recycling during waste disposal.

5 Conclusion and Recommendation

In the current landscape of the food industry, the study sheds light on the pivotal role of plastic take-out container attributes in shaping consumer recycling behavior. Through a mixed-method approach, we discerned that single-compartment containers and octagonal shapes facilitate improved recycling behaviors, echoing previous research findings. Notably, consumer attitudes and past behaviors emerged as critical moderators, indicating that interventions leveraging container attributes are most effective among those with positive recycling attitudes and prior sorting experience. However, challenges persist, particularly regarding container contamination and recyclability uncertainty. Addressing these challenges requires collaborative efforts across the supply chain to enhance consumer awareness and streamline recycling processes. Ultimately, by offering actionable insights, this study aims to catalyze a sustainable shift in the food industry, harmonizing convenience with environmental consciousness for a brighter future.

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Comparison of Actual Diver Thermal Comfort with Measured Properties of Neoprene

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Abstract. The body core temperature must be maintained within a narrow range in all types of environments, and neoprene insulating capacity is usually used to minimize heat loss in the water. The thickness of the neoprene sheet is highly correlated to the thermal resistance of neoprene and can be precisely measured. However the physiological response of the diver will depend on several factors besides the thickness of the neoprene wetsuit: water temperature, current, body movement, body size, body fat, and fit of the neoprene suit. Previous experiments included measured differences in diver's body temperature with ingestible capsules and skin temperature patches, as well as measurement of heat loss of a human diver and thermal mannequin. This paper compares the thermal resistance of nine different commercially available neoprene measured with a hot plate device, and the heat loss of a person immersed in water with the same nine neoprene suits measured with a thermal camera. The relationship between the obtained measurements is described by suitable statistical models.

Keywords: Thermal comfort · scuba diving · neoprene · thermal image · thermal resistance

1 Introduction

Divers, surfers, and others in various water sports wear a wetsuit. Wetsuits must be soft, elastic, have tensile strength, and tear and wear resistance to protect divers from hurt. The material must have strong thermal insulation properties. Neoprene foam contains all these characteristics. Often wetsuits are made by laminating neoprene and knitted materials. They are most often made in thicknesses of 3, 5, and 7 mm. Neoprene is filled with air bubbles that act as a heat insulator. The thicker the suit it retains heat better. If diving in warm waters (24–30 °C) a suit of only 1–2 mm will be enough, to protect from the sun's rays and marine organisms. If diving at warm temperatures (21–25 °C), a thicker suit of 3 mm is recommended. At lower temperatures (18–22 °C), a 5 mm suit is best. In cold waters (10–20 °C) a thick suit of 7 mm is suggested, and in very cold waters (up to 12 °C) it would be best to dive in a suit of 9–10 mm or a dry suit [1]. The body core temperature must be maintained within a narrow range. Individuals exposed to cold are unable to maintain steady temperature for extended periods of time

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despite vasoconstriction and shivering [2, 3]. Heat loss in cold water is more rapid than in cold air. A wet suit does not keep the body dry, water enters and is trapped between the body and suit. Body heat warms the trapped water, and neoprene minimizes further heat loss. The physiological response will depend on water temperature, current, body movement, body size and fat, and wetsuit. Persons of smaller stature more rapidly lose heat. Persons with lower muscle mass produce less metabolic heat through exercise and shivering. The thicker fat layer will provide more insulating capacity [2].

Several investigations were focused on human trials wearing wetsuits. Hall et al. investigated the thermal response of triathletes swimming in 14 °C cold water with and without wetsuits. Wearing a wetsuit slowed down the temperature drop and helped athletes maintain higher body temperatures, allowing them to rewarm on the bike [4]. The research by Ulsamer et al. aims to investigate the influence of wearing a wetsuit on swimming performance in open swimming. The results suggest that wearing a wetsuit had a positive effect on swimming speed for both women and men, but the benefit of using a wetsuit appeared to depend on the length of the race. Women appeared to benefit more from wearing a wetsuit than men in longer open swimming events [5]. Chapin et al. measured temperature in divers using use ingestible core temperature capsules and skin temperature patches. Thick neoprene wetsuits provided effective thermoprotection during a 6 h full submersion dive in 5 °C. There was high individual variability in metabolic rate. Variability in metabolic demands may be attributable to individual physiologic adjustments due to prior cold exposure patterns of divers [6]. Looney, D. P. et. al highlight the dangers of warm water diving expeditions and enhance understanding of human thermoregulatory limits. Physical performance degrades sharply at warmer temperature extremes [7].

Mak et al. dealt with the questions of whether the heat loss from a thermal mannequin is representative of the heat loss of a human under the same conditions, and whether the measured heat losses can be related to the drop in body temperature with appropriate models or correlations. The research compared two thermal mannequins immersed in water and two people wearing suits with three different levels of insulating foam. Differences between mannequins and humans (±12%), between human subjects (±13%), and between thermal mannequins (±6%) are comparable. The trend of the resistance as a function of the suit thickness was similar to the results of the measurement of the suit on the hot plate [8].

This paper aims to determine whether measurements of the thermal resistance of neoprene in laboratory conditions on a hot plate are representative of the heat loss of a person immersed in water with a protective neoprene suit and whether the measured heat loss of the person can be correlated to the laboratory measured thermal resistance with appropriate statistical models.

2 Materials and Methods

Nine different commercially available neoprene were prepared for the analysis to cover a wide interval of the tested characteristics (Table 1).

The thermal resistance was measured using the sweating-guarded hotplate (SGHP) produced by Measurement Technology Northwest. The SGHP simulates the transfer of heat from the skin, through the layers observed, to the environment. The thermal resistance of textile materials (Rct) is determined as described in ISO 11092 [9].

Infrared thermography was used to observe the changes in skin temperature after immersion in water wearing a wet suit. For the measurement is used thermal camera FLIR E5 produced by Flir Systems Inc. [10].

Fabric thickness was determined according to EN ISO 5084: 1996 as the distance between the plate and the circular presser-foot that exerts a specified pressure on the area of the textile. The measurements are carried out using the DM 2000 – Wolf produced by Wolf Messtechnik GmbH. The mass per unit area of the fabric was measured according to the ISO 3801 standard, method 5, where a sample size of 10 * 10 cm was cut and measured on a scale with an accuracy of ±0.001 g. For the measurement is the analytic scale ALJ 220–4 produced by Kern company. The morphology of the materials was visualized using a Dino-Lite Edge AM7915MZT digital microscope (manufactured by Dino-Lite).

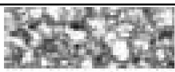
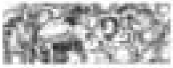
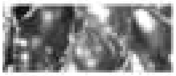
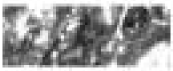
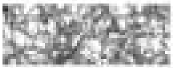
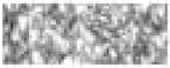
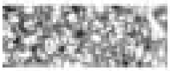
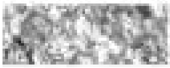
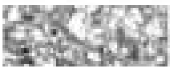
3 Results and Discussion

The microscopic images of the studied materials, mass per unit area, thickness, and thermal resistance are shown in Table 1. The structure of all neoprene sheets is similar, with uniform air bubbles. In the case of N3 and N4 air bubbles are bigger. The mass per unit area is within the limits of 843 g/m^2 to 1930 g/m^2. The thickness is between 3.96 mm and 8.94 mm.

The values of the thermal resistance are in the range from 0.0692 m^2KW^{-1} to 0.1551 m^2KW^{-1}. The used apparatus is highly precise and the coefficient of the variation of the repeated measurements is under 0.5%. The values of the measured thermal resistance are the highest for the sample N6 and the lowest for the sample N1. The sample N6 is the one with the highest thickness and with higher mass per unit area. As opposed, the material with the lowest Rct value (N1) is the one with the lowest thickness and mass per unit area. This result is expected because the thicker materials are supposed to give higher resistance to the transfer of heat from the body to the environment and thus are more capable of retaining the produced body heat. The differences in the thermal resistance of examined materials are significant. The value of the thermal resistance of material N6 is 2.2 times higher than the thermal resistance of material N1, and this property highly affects the thermal comfort of a person wearing neoprene material in a cold environment.

Table 2 presents the results of the measurement of skin temperature of 3 divers with the thermal camera after 10 min of immersion in the water wearing the above-described neoprene. The temperature of the water during immersion was relatively warm 24.4 °C. The thermogram of the body taken before immersion did show an average skin temperature of 35.2 °C. After immersion, uncovered skin had an average temperature of 25.2 °C, which is to some extent higher than the temperature of the water, and covered skin was 29.8 °C. In the previous research, three divers in wetsuits lost heat gradually; the skin temperature of a diver without a wetsuit dropped in 5 min from 36.1 °C to 24.8 °C, which was again slightly higher than the temperature of the water (23.6 °C) [11].

Table 1. Properties of neoprene sheets.

Samples	Image (200x magnification)	Mass per unit area [g/m^2]	Thickness [mm]	Thermal resistance [m^{2}KW^{-1}]
N1		843.3	3.96	0.0692
N2		1455.9	5.07	0.0783
N3		1228.3	4.42	0.0751
N4		1930.1	7.77	0.1331
N5		1075.5	5.69	0.1091
N6		1634.0	8.94	0.1551
N7		1329.8	5.84	0.1096
N8		1259.4	6.21	0.1239
N9		1286.9	5.66	0.1009

The measurement with a thermal camera provided the data of the skin temperature in the real environment on a real person. It is interesting whether measurements of the thermal resistance of neoprene on a hot plate are representative of the heat loss of a person immersed in water with a protective neoprene suit, and whether it is possible to correlate the measured skin temperature with the laboratory-measured thermal resistance using appropriate statistical models.

The difference between the warmest and coldest place on a person's skin during N1 and N2 measurements is significantly higher (3.1 °C) than the difference between the warmest and coldest place during N3 and N6 measurements (1.4 °C), which would significantly affect a person's feel of thermal comfort (Table 2). The combination of the fit of the suit and the individual metabolism of the person could be responsible for different results on the thermogram.

Table 2. Skin temperature after 10 min of immersion in water wearing neoprene.

Samples	Skin temp. Max, °C	Skin temp. Min, °C	Skin temp. Aver., °C
N1	31.1	28	29.7
N2	31.3	28.3	30.0
N3	30.0	28.6	29.4
N4	31.2	28.6	30.4
N5	30.1	28.4	29.6
N6	30.6	29.2	30.3
N7	29.9	28.2	29.6
N8	30.6	29.1	30.1
N9	29.7	28.0	29.4

The average skin temperature measured on a larger skin surface gives more reliable results. There is a high correlation between neoprene thickness and average skin temperature after immersion in water ($r = 0.7390$). Correspondingly, the correlation between thermal resistance of neoprene measured in laboratory conditions and average skin temperature after water immersion is fairly high ($r = 0.6619$). Still, both results indicates the influence of other factors, as fit of the suit and the individual metabolism of the person, on thermal comfort in real conditions.

The measured results also confirm that the correlation between neoprene thickness and heat resistance is extremely high ($r = 0.9635$), and thickness is better correlated than neoprene mass per unit area with heat resistance ($r = 0.6516$).

The visual comparison of the thermal resistance and average skin temperature in Fig. 1, also confirms the correlation of the laboratory-measured results of thermal resistance and average skin temperature of a person.

The measurements on a hot plate device and human are comparable, but differences should be expected because of suit fit and individual metabolism.

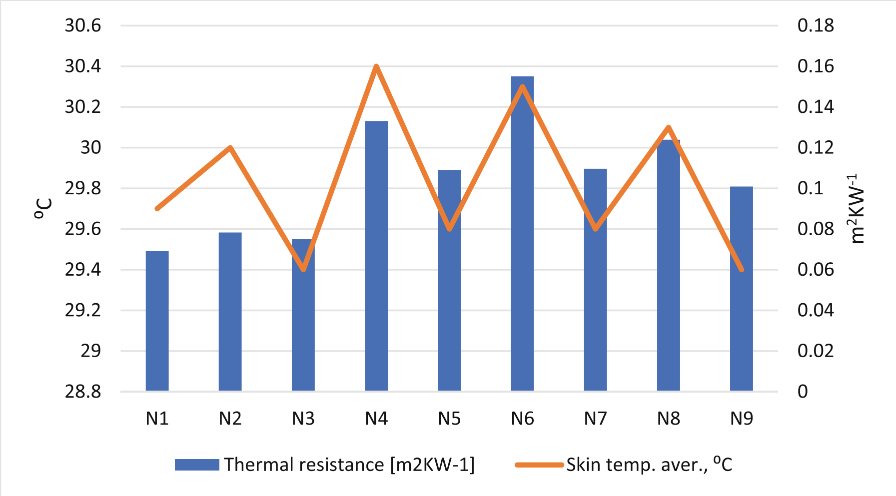


Fig. 1. Relationship between thermal resistance of neoprene and average skin temperature of thermogram.

4 Conclusion

This paper verifies that measurements of the thermal resistance of neoprene in laboratory conditions on a hot plate are representative of the heat loss of a person immersed in water with a protective neoprene suit.

The correlation between neoprene thickness and heat resistance measured on a hot-plate device is very high (r = 0.9635). The correlation between neoprene thickness and average skin temperature measured with the thermal camera after water immersion is fairly high (r = 0.7390).

The average skin temperature measured with a thermal camera provides authentic data of the skin temperature in the real environment on a real person and is fairly highly correlated with the heat resistance of neoprene measured in laboratory conditions (r = 0.6619).

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Consideration of Product Application Using PUI Guidelines: Focusing on Home Appliances

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Abstract. When developing home appliances, various ergonomic guidelines that conform to the physical user interface (PUI) design specifications are applied and used. However, developing products based on only the guidelines that conform to the design specifications of home appliances is difficult. This study was aimed at re-viewing various PUI guidelines for home appliance development and deriving design specifications by analyzing their usefulness. Among the controllers, which are representative PUI elements of home appliances, we focused on knobs, handles, and buttons and analyzed these ergonomic guidelines.

Guidelines that are widely used in various industries were selected to determine the suitability of their ergonomics. These guidelines mainly review military standards, nuclear design guidelines, and general guidelines.

For the knobs, shape, size, rotation direction, and rotational force are the main variables. Their size is determined mainly by considering design factors emphasizing safety. The direction of rotation at the time of use is considered. The category of buttons contains many guide items. However, the design and emotional aspects are not considered while designing their size and pressure.

The product PUI is still designed using design specifications mentioned in these guidelines. However, as most guidelines do consider identical items, they tend to be used as rough reference values or are inferred based on similar guidelines. In particular, the guidelines do not reflect aesthetics, design trends, or emotional needs of customers. This is because they were developed in fields directly related to safety and not electronics. We attempted to determine the usefulness and applicability of these guidelines in determining the detailed specifications of the product.

Keywords: PUI (Physical User Interface) · Guideline · Home appliance · Knob · Button

1 Introduction

Competition among companies is intensifying, and products are being developed with high quality, low cost, and differentiation to secure a competitive advantage in the market. Usability must be considered to provide customers with different experiences when developing new products. Usability includes various factors, such as the ease of operation, installation, simultaneous functionality, and portability [1].

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Toward customer satisfaction, we must focus not only on usability but also on emotional, cognitive, and physical acceptability [2]. In particular, with the growing interest in health and the shift toward an aging society, physical acceptability and convenience are being increasingly considered. Products that do not consider body characteristics can cause discomfort to customers by creating unsafe postures and repetitive movements. Therefore, for products with which many customers interact, such as home appliances, research on physical user interfaces (PUIs) that consider physical aspects is necessary. PUI refers to a traditional operating device that directly operates with the hands or feet while using a product, and customers have a significant impact on usability through their interaction with these devices.

Various ergonomic guidelines conforming to the PUI design specifications have been applied and used in the development of home appliances. However, developing products using only guidelines to adhere to their design specifications is difficult. Thus, we examined the limitations of these guidelines and determined a direction for developing guidelines suitable for home appliances. This study was aimed at determining whether ergonomic guidelines for PUI development in home appliances are appropriate for use and the limitations of these guidelines. To analyze these guidelines, we focused on knobs and buttons, which are representative PUI controllers used in home appliances.

2 Methodology

Guidelines used in the domestic industry include: 1) general standards, such as IEEE, IEC, ISO, and ANSI; 2) regulatory guidelines, such as KINS-G-001, OHSA, KOSHA, and the NRC's NUREG series; and 3) defense guidelines, such as DoD's MIL-STD series, which can be divided into academic guidelines, such as the ergonomic handbook [3, 4]. Among these, those related to ergonomics have been used to a limited extent in the field of public regulation. In addition, regulatory guidelines do not provide detailed standards, making them difficult to use in conformity reviews. In this study, guidelines widely used in various industries were selected to determine the suitability of the ergonomic guidelines. These guidelines mainly include military standards [5], nuclear energy design guidelines [6], and general guidelines typically used in ergonomics.

The PUI guidelines were categorized and reviewed according to four criteria: safety, aesthetics, usability, and affection. Safety refers to the provision of an appropriate size for use and ensuring no malfunctions. Aesthetics refer to whether the design shape is considered externally. Usability is convenient and intuitive in actual environments. Affection refers to whether emotional satisfaction is high according to the five senses.

3 Results

In the specifications for the knob, the shape, size, turning direction, and turning force are the main variables, and only the round shape is considered among various shapes in home appliances. The size is guided to be sufficiently large, rather than considering design elements, emphasizing safety aspects. Considering the user usage scenario, providing guidance on turning direction and angle is not possible. Additionally, the turning force tends to considerably large to consider the emotional aspects of home appliances.

For the buttons, shape, size, pressing force, and pressing depth were the main variables. Home appliances contain buttons of various shapes, such as round, oval, square, and straight; however, only the round shape is considered. The guide to the legend button covers the squares. In terms of size, the guidelines provide specific values for diameter, displacement, and separation; however, similar to the knob, they provide minimum and maximum values in terms of safety. Compared to knobs, various factors considering the form used are presented; however, the design and emotional factors are not considered.

Table 1. Guidelines evaluation for the PUI elements.

PUI elements	Safety	Aesthetic	Usability	Affection
Knob	Dimension (width, length, and separation) Force (Torque)	Circle type	Grasp type (fingertip, thumb and fin-ger, and palm)	None
Button	Dimension (diameter, displacement, and separation) Resistance	Circle type	Finger type (fingertip, thumb, and palm) Glove type (bare hand and gloved hand)	None

According to the data listed in Table 1, the design standards mentioned in the PUI guidelines barely consider the aesthetic aspects and affection needs of customers. This is because most guidelines consider safety and usability aspects first, and they are in safety and directly related fields, such as national defense, nuclear power, and worksites. However, in the PUI design of home appliances, design trends and principles are continuously changing, and product design is being implemented accordingly. In one of the recent design trends of "seamless," complex shapes are hidden as much as possible and simplified forms are shown. A good example is the gradual change from the bar-type handles of refrigerators and dishwashers in the past to pocket handles. Even a pocket handle can be considered sufficient in terms of safety. However, in many cases, considering the external sense of proportion and design, the free space is small (Fig. 1).

According to the guideline listed in Table 2, The design guide should provide the minimum and recommended sizes, and take into account various user behaviors and products.

Fig. 1. (Left) Bar handle, (Right) Pocket handle (source: Costco.com).

Table 2. Bar and pocket handle guideline for the PUI elements.

PUI elements	Safety	Aesthetic	Usability
			Grasp type (Hand and finger grip)
Bar and pocket Handle	Clearance : Min 25mm, Recommend 32mm Width : Min 65mm, Recommend 100mm Depth : Min 12.7mm, Recommend 32mm	Circle type, Ellipse type, Quadrangle type	

4 Discussion

In this study, PUI design guidelines were reviewed, and the need for improvement in deriving design specifications for home appliances was discussed. We examined the usefulness of the guidelines under various review criteria and identified meaningful differences among several traditional controllers.

Significant parts of product PUI design are derived from design specifications based on guidelines. However, as most guidelines do not include exactly the same items, these guidelines are used as approximate reference values or inferred based on guides for similar types of devices. In particular, the guidelines were developed in fields directly related to safety, rather than electronic products; therefore, they do not reflect aesthetics, design trends, or emotional customer needs. In future, developing guidelines suitable for electronic products, such as style guides and developments, in terms of accessibility will be necessary.

5 Conclusion

Ergonomic guidelines are used in many industrial fields for product safety and convenience. In this study, we determined the usability and application problems of these guidelines in determining detailed product specifications. If ergonomic guidelines suitable for home appliances are developed as suggested by the results of this study, they will be helpful in confirming the design specifications.

Although design elements are important for products, accessibility is also becoming an important factor. Research on the acceptable range of the human body for various customers, such as disabled and general users, is expected to expand gradually.

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Nose Shape Categorization and Its Impact on Design in Head Mounted Displays

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Abstract. This study evaluates how Martin and Saller's nasal index correlates to a more comprehensive exploration of nose shape variables using Principal component analysis (PCA) and nonparametric bivariate correlation analysis in the context of the design of head-mounted displays (HMDs).

A sample of 1736 individuals (468 Asian/Asian American, 378 Black, 741 White, 203 Other; 799 Female, 937 Male), aged 18 to 74, was analyzed. PCA identified five principal components (PCs) explaining approximately 83% of the variance in nasal shape. PC1 (27.941% variance) relates to the nasal width at the nose's inferior portion. PC2 (19.332%) involves the height and angle from the center of the nose to its most inferior point. PC3 (15.064%) describing the width at the central region of the nose. PC4 (73.374%) describing the nasal length. PC5 (10.108%) describes the angular shape of the fleshy portion of the nose.

Correlation analysis revealed a moderate positive relationship between the nasal index and PC1 (Spearman's $\rho = 0.537$); no statistically significant correlation with PC2; a weak negative correlation with PC3 (Spearman's $\rho = -0.178$); a moderately negative correlation with PC4 (Spearman's $\rho = -0.429$); and a weak to moderate negative correlation with PC5 (Spearman's $\rho = -0.312$). The study concludes that while the nasal index categorizes noses into broad groups, it lacks the comprehensiveness required for HMD design. The authors recommend a more nuanced approach, incorporating multiple anthropometric variables, to effectively design HMDs and reduce slippage. Future work will focus on integrating these findings into physical models for evaluating HMD prototypes.

Keywords: Nasal Index · Nose Shape Categorization · Head Mounted Displays · Anthropometric Inputs · Product Design

1 Introduction and Background

Extended reality head mounted displays (HMDs) are head worn devices that immerse users in virtual reality (VR), augmented reality (AR), or mixed reality environments by projecting digital content into users' field of view. AR devices, in particular, have been growing in popularity and their demand have proven to be an important solution in different work environments such as in the manufacturing and healthcare fields [1]. The product design of an HMD requires important research on human subjects through the implementation of anthropometric factors related to human comfort, device slippage and

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stability, and other elements analyzed under the discipline of human factors engineering to facilitate its design process, ensuring the development of a comfortable, wearable, and usable HMD. Historically, the nasal index has been used throughout literature and anthropometry to categorize human noses [2]. By researching individuals from different ethnic groups, ages, sex, and cultures, the nasal index serves as a parameter of classifying different nose types amongst humans that is ultimately determined by the ratio of the width (maximum horizontal distance measured at the widest part of the nose) to the height (vertical distance from the nasion to the subnasale) of the nose [3]. When designing an HMD, it is important to consider every potential user of that device. With these considerations in mind, Martin and Saller's nasal index seemingly provides a pathway towards human nose type classifications based on different demographics, such as race, ethnicity, culture, sex, and age. However, the nasal index only measures the nasal width and nasal height [4], but does not consider other potential nose measurements that could be insightful in relation to designing HMDs. The extensive anthropometric measurements and fit panels that can be done on human subjects regarding their nose shape and HMD design can include nasal root breadth, nose breadth, and nose protrusion to name a select few [5]. To design around noses in HMDs, research in anthropometry and human factors engineering beyond the nasal index should be conducted.

This study evaluated how Martin and Saller's nasal index correlated to a more comprehensive exploration of nose shape variables. PCA was used as a tool to understand which anthropometric variables create the largest variance when finding design cases in HMD design.

2 Methodology

Anthropometry was collected on a large sample of USA residents predominantly located in Florida, California, and Illinois. The sample consisted of n = 1736 (468 Asian/Asian American, 378 Black, 741 White, 203 Other; 799 Female, 937 Male), mean age 36 [18–74]. Participants signed informed consent documents before anatomical points were palpated and physically marked. The 19 anatomical points (See Fig. 1) were the glabella, sellion, rhinion, pronasale, zygofrontale (left and right), supra- and infra-orbitale (left and right), zygion (left and right), supramaxila (left and right), inframaxila (left and right), and menton.

Fig. 1. Anatomical Landmarks

Participants' demographic information was also collected, e.g. race and gender. Various anthropometric measurements were taken, e.g. nose width max, nose length, nose width at inframaxilla, nose width at rhinion, etc., and added to a database of participants. A 3D surface image was captured using a 3dMDTM head scanner [6], digitized in 3dMDTM Vultus [6], and their coordinate data was rotated and translated using MATLAB® [7] into the "Neutral Gaze Vector System" [8]. A "Neutral Gaze Vector System" is defined as a user-specified system, where the origin was defined as a point 3mm in front of the Pupils at the midpoint between the Right and Left Pupil, the x-axis runs through the Right and Left Pupil, the y-axis runs vertically upwards, and the z-axis runs in the anterior direction.

Martin and Saller's Nasal Index [4] was calculated using equation (1) below.

$$\text{Nasal\_Index} = \text{NasalWidth}/\text{NasalHeight} * 100 \tag{1}$$

PCA was performed on anthropometric variables relevant to HMD design as it relates to the nose. Subsequently, nonparametric bivariate correlation analysis was conducted to assess the relationship between the derived principal components and the nasal index.

3 Results and Discussion

3.1 Principal Component Analysis

There are many potential variables to consider. The variables that were selected can be found in Table 2. These variables were identified from a combination of the authors' prior experience in HMD design, anthropometry, and human factors engineering and by conducting preliminary factor analysis to identify variables with minimal contribution. Prior to conducting the PCA, confirmation of assumptions and the Kaiser-Meyer-Olkin and Bartlett's test was conducted. The results indicate the PCA is an appropriate statistical analysis for this data (Table 1).

Table 1. PCA Results.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.515	27.941	27.941	2.515	27.941	27.941	1.629	18.097	18.097
2	1.749	19.432	47.373	1.749	19.432	47.373	1.624	18.048	36.105
3	1.356	15.064	62.338	1.356	15.064	62.338	1.597	17.743	53.848
4	.993	11.037	73.374	.993	11.037	73.374	1.427	15.859	69.707
5	.919	10.109	83.483	.919	10.109	83.483	1.240	13.776	83.483
6	.467	5.189	88.672						
7	.397	4.409	93.079						
8	.346	3.841	96.920						
9	.277	3.080	100.000						

Extraction Method: Principal Component Analysis.

The PCA indicates that the five principal components are cumulatively responsible for 83.483% of the variance. It is important at this stage to understand the relationship

Table 2. Component matrix and rotated component matrix

Component Matrix[a]

	Component 1	2	3	4	5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Extraction Method: Principal Component Analysis.
a. 5 components extracted.

Rotated Component Matrix[a]

	Component 1	2	3	4	5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in [illegible] iterations.

being described within each of those four principal components utilizing the component matrix and the more useful rotated component matrix (Table 3).

The Varimax rotation was applied for the rotated component matrix. Each principal component can be found by finding the largest magnitude within each column. This yields PC1 describing the nasal width at the inferior portion of the nose comprised of nose width max and nose width inframaxilla; PC2 describing the height and angle from the center of the nose to its most inferior point comprised of the sellion to pronasale angle and the rhinion to pronasale angle; PC3 describing the width at the central region of the nose comprised of nose width at the sellion and nose width at the rhinion; PC4 describing nasal length comprised of nose length and the distance between the sellion and the rhinion; and PC5 describing the angular shape of fleshy portion of the nose comprised of only the angle made between the inframaxilla and rhinion.

4 Non-parametric Bivariate Correlation Analysis

The principal components are then extracted from the analysis as variables and the Martin & Saller categorization is recoded into numeric categories. A nonparametric correlation analysis using Spearman's ρ was conducted. This assumes that there is no specific distribution of the variables and does not require a linear relationship. This method is particularly robust to outliers and deviation from normality and thus was chosen as the authors are interested in measuring associations but not linear relationships found within the data.

From this analysis (Table 3, below), we see that PC1 has a statistically significant moderately positive correlation with the Martin & Saller categorization; PC2 has no statistically significant correlation; PC3 has a statistically significant but weak negative correlation; PC4 has a statistically significant moderately negative correlation; and PC5 has a statistically significant and weak to moderate negative correlation.

5 Conclusion and Recommendations

While the nasal index is widely used in literature, the authors believe that it is not sufficiently comprehensive to provide adequate information to HMD design. PC1 and PC2 provide a way to characterize the nose ridge and height into four primary categories,

Table 3. Correlation Matrix

Correlations

			[illegible]	REGR factor score 1 for analysis 1	REGR factor score 2 for analysis 1	REGR factor score 3 for analysis 1	REGR factor score 4 for analysis 1	REGR factor score 5 for analysis 1
Spearman's rho	[illegible]	Correlation Coefficient	1.000	.537**	[illegible]	[illegible]**	[illegible]*	[illegible]**
		Sig. (2-tailed)		<.001	[illegible]	<.001	<.001	<.001
		N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REGR factor score 1 for analysis 1	Correlation Coefficient	.537**	1.000	[illegible]	[illegible]	[illegible]	[illegible]
		Sig. (2-tailed)	<.001		[illegible]	[illegible]	[illegible]	[illegible]
		N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REGR factor score 2 for analysis 1	Correlation Coefficient	[illegible]	[illegible]	1.000	[illegible]	[illegible]	[illegible]
		Sig. (2-tailed)	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
		N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REGR factor score 3 for analysis 1	Correlation Coefficient	[illegible]**	[illegible]	[illegible]	1.000	[illegible]	[illegible]
		Sig. (2-tailed)	<.001	[illegible]	[illegible]		[illegible]	[illegible]
		N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REGR factor score 4 for analysis 1	Correlation Coefficient	[illegible]**	[illegible]	[illegible]	[illegible]	1.000	[illegible]
		Sig. (2-tailed)	<.001	[illegible]	[illegible]	[illegible]		[illegible]
		N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REGR factor score 5 for analysis 1	Correlation Coefficient	[illegible]**	[illegible]	[illegible]	[illegible]	[illegible]	1.000
		Sig. (2-tailed)	<.001	[illegible]	[illegible]	[illegible]	[illegible]	
		N	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

**. Correlation is significant at the 0.01 level (2-tailed).

namely 1) narrow long noses, 2) narrow short noses, 3) wide long noses, and 4) wide short noses. The nasal index also groups noses into these four broad categories. When looking at nose shapes used in HMD design, more information is needed to adequately define nose shapes, especially as it relates to slippage. A combination of nose width, height, and depth are a necessity, but additional factors like the angular shape of the nose between different anatomical points also plays a critical role.

This study highlighted the need for a comprehensive approach to anthropometric considerations in HMD design. While Martin and Saller's nasal index offers a valuable starting point, leveraging PCA can provide a more nuanced understanding of the anthropometric factors influencing design. Future work includes leveraging the findings from this analysis to incorporate relevant boundary cases of nose shapes into a physical model to evaluate slippage and comfort in HMD prototypes.

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Ergonomic Evaluation of Refrigerator Handle Design: The Influence of Hinge Position, Grip Orientation, and Handle Height

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Abstract. The study aimed to identify the ergonomic design of a compact refrigerator with single-side hinged door by evaluating three factors: hinge position, grip orientation, and handle height. Twenty participants evaluated perceived exertion on shoulder, elbow, and back, respectively, as well as comfort and acceptability. Based on the analysis with consideration of both right- and left-handed users, we recommend placing the handle on a right-hinged door at an approximate vertical distance of between 900 mm and 1110 mm from the floor, with a grip oriented either upward or downward. The research not only provides the ergonomic guideline to mitigate physical strain and enhance usability of a compact refrigerator, but also has implications for other home appliances with single-side hinged door.

Keywords: UX Design · Recessed Handle · Refrigerator

1 Introduction

Recently, there has been a world-wide increase in the number of single-person households [1–4], leading to distinct consumption patterns, particularly in the choice of small and efficient home appliances such as a compact refrigerator [5, 6]. This trend highlights the importance of researching ergonomic design, especially in the handle design of small-sized refrigerators, as handle design significantly influences purchasing decisions [7]. Additionally, this demonstrates the importance of door opening tasks and related design factors in ensuring usability and user satisfaction.

Various refrigerators feature different door designs; full-size models often have side-by-side dual swing doors, while compact versions typically have single-side hinged doors. These single-side hinged doors may cause discomfort depending on a user's dominant hand [8]. Door handles also come in two main types: bar type handles, known for their comfort and affordability [9, 10], and recessed handles, favored for their aesthetic appeal and safety [11]. Handle orientation can be vertical or horizontal, each offering different grip options, and the height of the handle from the floor can impact usability for individuals of varying heights. Despite these variations, few studies have evaluated the ergonomic aspects of refrigerator door handles. Previous study suggests that comfort and maximum voluntary force are not directly correlated with handle height, emphasizing the

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need for studies focused on low-force tasks to better understand usability and comfort in everyday products [12–14]. Evaluating both physical and psychological aspects of user experience can lead to improvements in ergonomic design, particularly for compact refrigerators with single-side hinged doors [15–19].

2 Material and Methods

2.1 Participants

A group of 20 right-handed participants with no history of musculoskeletal disorders were recruited. The age of the 20 participants ranged from 21 to 36 with a mean of 28.9 ± 4.3 years (29.4 ± 2.8 for the 10 males and 28.3 ± 5.5 for the 10 females). The participants also reported no pain in the past seven days prior to the experiment. All participants provided informed consent for a study protocol approved by the Institutional Review Board of Korea University.

2.2 Experimental Setup

Two wooden refrigerator mock-ups, one with a left-hinged door and the other with a right-hinged door (see Fig. 1), were used. Multiple neodymium magnets, illustrated as the grey area in Fig. 1, were placed to require approximately 30 N pulling force for the user to open the door, which is an average force to open a refrigerator door [20].

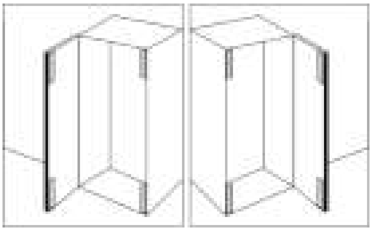

Fig. 1. Refrigerator mock-ups with left- (left) and right- (right) hinged door. The gray area indicates the location of the magnets.

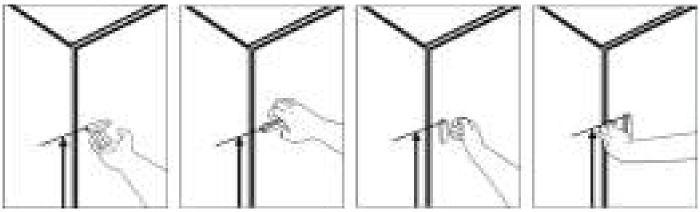

Fig. 2. Illustrative graphics of upward, downward, leftward, and rightward (from left, respectively) grips for a right-hinged door, each with a reference point for handle height measurement.

Furthermore, recessed handles were attached at 40, 50, 60, 70, 80, 90, or 100% of each participant's shoulder height in four different orientations, creating grips upward, downward, leftward, or rightward, respectively, as shown in Fig. 2. A reference point of a handle height was a contact point of a handle and dactylion II for upward, downward, and leftward grips and dactylion V for a rightward grip.

2.3 Procedure

After the instruction on the study was given, the total height (floor to vertex), shoulder height (floor to acromion/shoulder point), and elbow height (floor to inferior olecranon) of each participant were measured while standing barefoot. Participants were then asked to open a real refrigerator door with a right hand and rate their perceived exertion on their shoulder, elbow, and back, respectively using Borg Category Rating 10 (CR-10), which is widely used for grip tasks or repetitive multiple tasks [21–24]. The participants also rated their perceived comfort and acceptability of the refrigerator in a given condition, using a nine-point Likert Scale from one (very strongly uncomfortable/unacceptable) to nine (very strongly comfortable/acceptable) with six or above being considered as acceptable or comfortable [25–27].

Once the participants became comfortable with the subjective measurement scales, they completed the same door opening tasks using the refrigerator mock-ups, and rated their perceived exertions, comfort, and acceptability. A total of 56 ($2 \times 4 \times 7$) trials were completed, consisting of combinations of two hinge positions (left-hinged door and right-hinged door), four grip orientations (downward, upward, rightward, and leftward), and seven different handle heights (from 40% to 100%). Participants were given at least three minutes or more of break time after the 28th trial.

2.4 Data Analysis

A four-way mixed analysis of variance (ANOVA) with measures of hinge position, grip orientation, and handle height was conducted. Bonferroni comparisons were also performed to determine an optimal design of a refrigerator handle. A p value of $<.05$ indicated statistical significance. A statistical analysis was proceeded using SPSS Statistics Software Version 26 (SPSS Inc., Chicago, IL).

3 Results and Discussion

3.1 Effects of the Experimental Factors on Comfort and Acceptability

The participants reported the highest comfort and acceptability when using a handle positioned at near 70% and 80% of their shoulder heights (see Fig. 3). Based on the average elbow height of the 20 participants, which was $75.5 \pm 1.1\%$ of their shoulder heights. It can be inferred that the highest levels of comfort and acceptability were achieved when the handle was placed near to the participants' elbow heights.

The participants rated an upward grip positioned at between 60% and 90% as well as both downward and leftward grips positioned at between 60% to 100% as acceptable when using a right-hinged door. Furthermore, a downward grip was only perceived acceptable when it is positioned at either 70% or 100% on a right-hinged door.

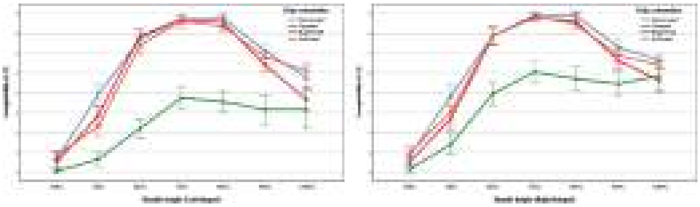

Fig. 3. Acceptability of handle height for left- (left) and right-hinged (right) doors, with different grip orientations.

3.2 Design Recommendations and Implications

By adapting a horizontal grip such as an upward or downward grip, a difference in comfort and acceptability for a left-handed user may not be as significant as using a vertical grip such as a leftward or rightward grip. However, a vertical grip still carries an advantage of having a wider coverage, which can bring the maximum comfort and acceptability regardless of different heights of users. Therefore, we suggest two different designs for a compact refrigerator based on our findings.

Firstly, a leftward grip is suggested with a right-hinged door, which can maximize acceptability for right-handed users. Then, the handle should be accessible at a vertical distance of between 903 mm (100% of 5th percentile female shoulder height) and 1235 mm (60% of 95th percentile male shoulder height) (see Fig. 4 left). In addition, we converted the upper bound, 1235mm, of the range for a hand to fit (see Fig. 4 right) by subtracting 95mm, which is the measurement of hand breadth (length from metacarpal V to metacarpal II) of 95th percentile Korean male [28].

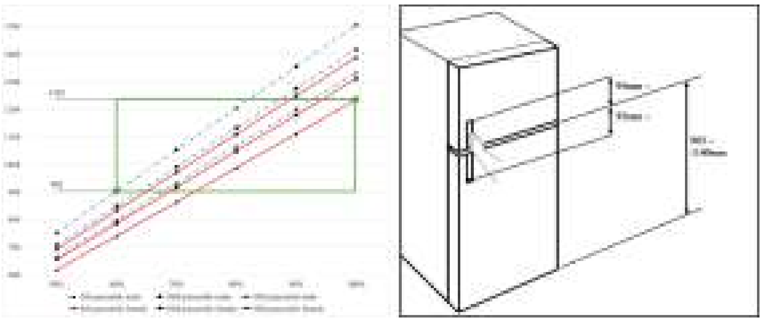

Fig. 4. A suggested handle height range of leftward grip (left) and an illustrative example of refrigerators with leftward grip (right).

A design with a leftward grip can provide the highest acceptability to right-handed users, but at the same time it is expected to provoke a low acceptability for left-handed users. Hence, a horizontal grip is suggested when designing for both right- and left-handed users because a small difference in acceptability is expected when using an upward or downward grip. We suggest placing either a downward or upward grip on a right-hinged door at a vertical distance between 903 mm (60% of 95th percentile male shoulder height) and 1112 mm (90% of 5th percentile female shoulder height) from a floor (see Fig. 5 left). Also, an upper bound may be extended to 1235mm (100% of 5th percentile female shoulder height) with a downward grip. With the design (see Fig. 5 middle and right), a refrigerator with single-side hinged door is expected to be acceptable for people from 5th percentile to 95th percentile.

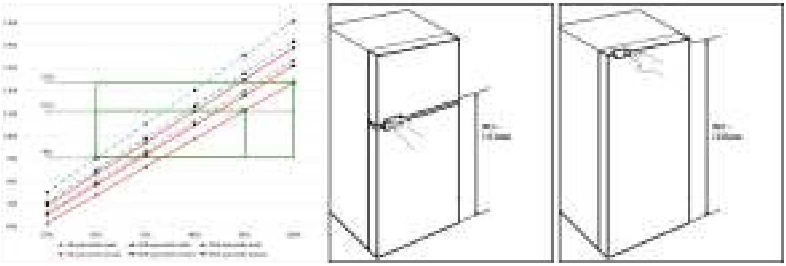

Fig. 5. Handle height with upper and lower comfortable bounds of horizontal (upward/downward) grip (left) and illustrative examples of refrigerators with upward (middle) and downward grips (right).

4 Conclusion

The purpose of this study was to evaluate the usability of a refrigerator door handle in terms of perceived exertion, comfort, and acceptability. Through an examination of the effects of hinge position, grip orientation and handle height on 20 participants, we suggested two different handle designs with either horizontal (downward/upward) or vertical (leftward) grip that take into account the ergonomic evaluation of hinge position, grip orientation, and handle height. Our study highlighted the importance of ergonomic design in the development of home appliances and the potential benefits it can bring for users in terms of comfort and acceptability.

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Resilience (I)

Resilience in Health Systems: Coping with Disasters or Handling Everyday Functioning?

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Abstract. Resilience is the capacity of a system to deal with change (resisting, adapting, or restructuring) or disturbances and continue to function in its present state. However, the level, type and timeframe of change or disturbances may vary from micro incidents up to major disasters, remaining vague in most healthcare systems approach for resilience. Aside from that, most healthcare resilience evaluating models still deal with components and structure, instead of actual system functioning. COVID-19 indicated the need to deeper understanding of the operating conditions of health systems under unpredictable and variable circumstances. This was, to a certain extent, due to the lack of effectiveness of some structure-based evaluation models in predicting the capacity of health systems to deal with the pandemic. In this paper we use recent literature coming from academia and health organizations to reflect upon the need for more research on the functioning of healthcare systems if we really want to deal, improve, and manage their resilience.

Keywords: Health Policies · Theory and Methods in Public Health · Resilience of Health Systems

1 Introduction

The Covid-19 pandemic focused the attention of both the scientific community and society on how science can support the functions and capabilities of health systems to respond to unexpected events. Publications on health system resilience have increased over the past decade, but have peaked since the pandemic. The topic of resilience or resilient performance puts pressure on the management models traditionally used to assess health system performance, as these models are typically based on the analysis of institutional capacity, e.g., structural characteristics such as beds, equipment, and workforce.

However, COVID-19 showed that institutional capacity is not sufficient (although necessary) for health systems to function adequately in scenarios of abrupt change or chronic stressors, and is therefore not a good predictor of how services adapt to unexpected events by maintaining their essential functions during the crisis, nor how they

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learn from this experience and transform positively as they recover from the shock [1]. Recently, the World Health Organization (WHO) described health system resilience as the ability of health institutions and stakeholders, including the population, to maintain their essential health functions when adversity strikes and to reorganize based on lessons learned [2]. Therefore, resilient health systems can achieve and maintain equity in population health and well-being and respond to public health emergencies. Fundamentally, resilience depends on how health systems behave in the face of adversity-that is, how their functions manage their institutional capacities. No matter how sophisticated the systems, they must be well managed to be resilient. This was probably the case in countries such as the United States and Brazil during the pandemic, which, despite their resourcefulness, experienced operational difficulties due to conflicting strategies at high levels of government [3]. To this end, new frameworks, indicators, metrics, and methods are needed to describe the preventive, adaptive, and absorptive capacities of health systems, considering aspects that guide the resilience of services.

It took a global health disaster to raise awareness of new evidence: having robust structures is necessary but not sufficient to ensure the development of resilience in a nationwide health system. The aim of this article is to highlight the need for progress on new concepts and analytical models on public health policy and the characteristics of health systems towards sustainable resilient performance. Note that the first paragraph of a section or subsection is not indented.

2 Methodology

A scoping review guided by the research question "In public health systems, what are the capabilities to promote resilience during major public health emergencies and disasters and those allocated to ensure regular and routine service delivery? From the research question, the aim is to identify the definitions to the term "resilience" in a health systems context and its application during major public health emergencies and disasters and in regular and daily health service delivery. The review will consider studies that examine the improvement of resilience during a health emergency or in regular and routine health service delivery. The aim is to clarify the concepts and uses of resilience and map the evidence on the topic. In addition, we seek to delineate the different dimensions of resilience that are emphasized in emergency contexts as opposed to routine daily contexts.

We listed several keywords and related synonyms and then built the corresponding search strings for three scientific databases: PubMed, BVS (Biblioteca Virtual de Saúde), Scopus and Web of Science. There are no restrictions on publication dates. The search criteria include studies from any country, written in English, Portuguese and Spanish, and available in full text. These databases were selected for their wide indexing coverage of health systems.

This review considered quantitative, qualitative and mixed methods studies published as peer-reviewed articles. Mixed methods studies were only included if data from the quantitative or qualitative component could be clearly extracted. There was no restriction on the year of publication, with the aim of providing a broad chronological examination of the topic. Theses, dissertations, reviews, opinion or news articles, unpublished studies, grey literature and papers focusing on private health systems were excluded. To ensure a comprehensive examination of the topic, no filters were applied regarding the quality of the articles or the impact factor of the journals.

3 Towards Novel Frameworks for Health Systems Resilience

Much research focuses on the functioning of health systems. Krug et al. [4] define a multidimensional framework of resilience as the ability to prepare for and recover from disasters and to absorb shocks while maintaining core health functions that meet the ongoing and acute care needs of affected communities. Neill et al. [5] examined everyday capabilities as a pathway to resilience during COVID-19 in 5 countries. They concluded that challenging emergency preparedness is the dominant framework for resilience and call for continued emphasis on strengthening health systems to respond to shocks. Haldane and Morgan [6] introduced the idea of transilience to address social vulnerabilities and structural inequalities in health systems. Haldane et al. [7] reviewed the COVID-19 responses of 28 countries. Based on primary health care practices, they describe a framework with 4 resilience elements for more effective country responses. Arcuri et al. [8] used the Functional Resonance Analysis Method (FRAM) to model the resilience of the mobile emergency care service riverine communities in the upper Amazon region before COVID-19, anticipating the resilience and fragility issues that would arise after the pandemic. In terms of system governance, the inadequate functioning of political and organizational arrangements compromised resilience in the face of the pandemic, even with the mobilization of robust structures and extraordinary resources.

Neves et al. [9] examined how Brazilian government agencies and stakeholders' Twitter communication created vulnerabilities that had to be addressed during the first wave of COVID-19 in Brazil. Similarly, Carvalho et al. [10] showed how conflicting political agendas led to a lack of cohesion between levels of government, jeopardizing essential health system capabilities to monitor, respond, anticipate, and learn, essential aspects of resilient performance. Chioro et al. [11] assert that political cycles that threaten the democratic rule of law directly affect the resilience of national universal health systems.

Supranational authorities such as the World Health Organization (WHO) and the World Bank [12, 13] have also addressed the resilience of health systems, using multidisciplinary frameworks, but still strongly based on institutional capacity and response to public health events of major importance. Resilience engineering has shown promising results, but its application focuses on the edge of complex systems, whereas public health relies on high-level interventions, especially policy making.

Innovative, evidence-based models and frameworks are needed to pursue optimal performance regardless of the presence of shocks, chronic crises, or minor disruptions. In general, projects, research, and models aim to create permanent spaces for building resilient capacities - from policymakers and managers to frontline service workers - to reconcile their perceptions and practices and develop more appropriate ways of dealing with expected and unexpected disturbances.

4 Perspectives for Research on Health Systems Resilience

The principles, concepts, and methods of resilience engineering (RE) [14] appear to be a new perspective in health systems research, as it allows the incorporation of resilience capabilities to monitor, anticipate, learn from experience, and respond to anticipated and unanticipated events.

The RE framework A more comprehensive notion of what resilient health systems should look like broadens the perspectives for research, management and planning of public policies based exclusively on scientific evidence. With the focus on improving the functioning of SUS organizations and services, the importance of incorporating resilience as an essential aspect, which must be constantly monitored and evaluated, becomes increasingly clear, especially in public and universal health systems.

A broader understanding of resilient health systems based on RE expands the viewpoints for research, management, and the development of public policies grounded solely in scientific evidence. Emphasizing the enhancement of the national and public health system organizations and services highlights the growing necessity to integrate resilience as a fundamental element that requires ongoing monitoring and evaluation [15].

Furthermore, assessing resilience is still a complex task. Given the established tradition of epidemiological research in supporting policymaking, it is crucial to create objective metrics for resilience in public health in the near future. When evaluating resilient performance, it is essential to focus on regular operations. However, relying solely on

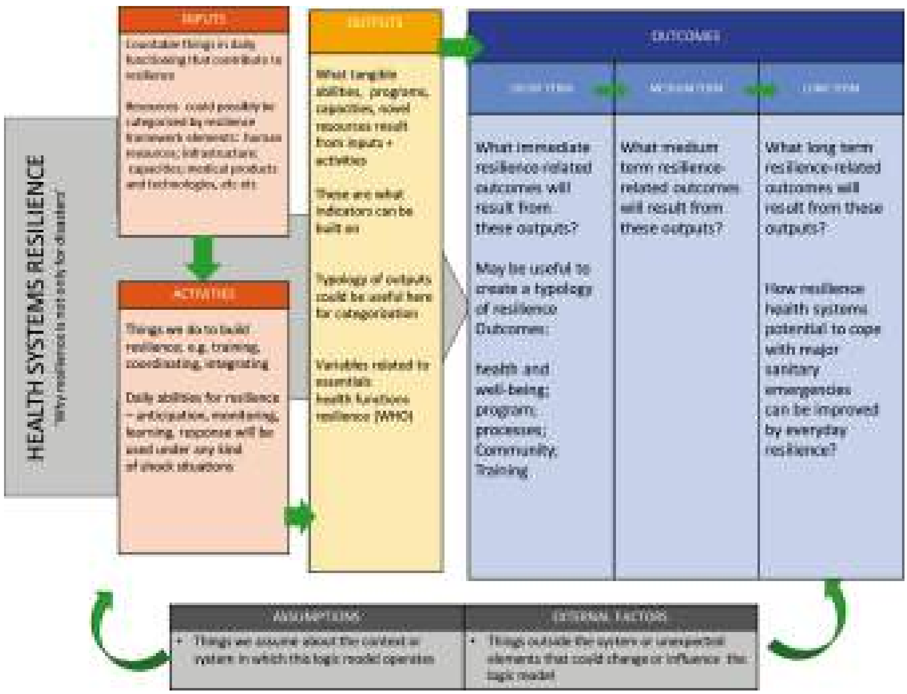

Fig. 1. A logical model for health systems resilience research.

indicators that reflect only past events, especially previous disasters, is not effective. Therefore, the logical framework for resilience research in public health systems, illustrated in Fig. 1, outlines various perspectives on the challenges and defining elements that signify not resilience itself, but rather the capacity for resilient performance.

5 Final Considerations

In 2024, the term "Health Systems Resilience" was added to the Health Sciences Descriptors (DeCS/MeSH), defined as "the ability of health systems to adapt and sustain themselves to effectively address sudden spikes in demand resulting from extraordinary events that impact population health, either directly or indirectly, while simultaneously ensuring the operation, safety, quality, and availability of services." The establishment of this definition marks a significant step toward a more relevant conceptualization that can transform the operational dynamics of health organizations. It emphasizes the ongoing development of capabilities to manage challenges not only from major health emergencies but also from any extraordinary events.

The cultivation of everyday resilience is what enables public health services to effectively withstand significant events like natural disasters, outbreaks, and epidemics. It's crucial for health authorities to recognize that resilience in public health extends beyond just responding to disasters. Efforts should be made to reduce the potential impact of such disasters on health whenever feasible, and when they do arise, they must be managed as a top priority. However, the environment in which health services operate is frequently unpredictable. Therefore, developing resilient public health systems necessitates a balanced focus on both routine occurrences and extraordinary events.

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Time Management for Reliability in Signal Station: Articulate Surveillance Task and Identification Sub-task

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Abstract. The sub-task of ship identification in the signal station is a key element of French maritime surveillance. However, its articulation with the other sub-tasks implies the deployment of time management strategies, responding to a logic of prioritization. This paper shows that lookouts organize and construct their time to meet identification objectives, without compromising watchfulness and vigilance. In this way, time management strategies contribute to the resilience of operators, and act as mainsprings to ensure the continuity and reliability of the service. (Research financially supported by the French Ministry of the Armed Forces – Defence Innovation Agency).

Keywords: Signal station · Surveillance · Time management · Reliability · Resilience

1 Introduction

The French Navy's signal stations are land-based units used for the surveillance of French waters. They adopt a shift-work organization, with lookouts taking turns on 4-h shifts, to ensure the continuity of a surveillance task with multiple stakes: military sovereignty of territorial waters, public-interest missions, and environmental protection. By keeping watch, detecting abnormal phenomena, and relaying information, in other words by being vigilant on both individual and organizational levels [1], signal stations lookouts play an active role in safeguarding human lives at sea.

The maritime environment can be defined by its complexity (it is variable, uncertain, dynamic) [2]. In this context, safety can no longer focus on the analysis of failures or malfunctions but must refocus on the risk management capabilities of the organization and on its operating characteristics, thus enabling it to be adapted to reality [3, 4]. The Resilience Engineering movement focuses on this "acting in safety", with operators prognosticating the occurrence of abnormal events, and negotiating with the variations encountered in the environment. This continuous process of preparing for surprise enables the unexpected to be managed through anticipation and support improvisation [5] when what has been planned proves to be insufficient or unsuitable, before, during or after the action [6]. Signal station lookouts thus require a high degree of resilience to achieve their surveillance objectives in a dynamic environment.

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2 Problem Statement and Objectives

The identification sub-task is a major determinant of the reliability of the signal stations' surveillance task. However, the dynamic characteristic of the situation, the diversity of tools used, and shift work all make it very complex. Under these conditions, tasks cannot be strictly regulated by sequential "if-then" procedures: the discretionary rules, which spell out only the (sub-)tasks purposes, then encourage and enhance the lookout's ability to regulate its activity and adapt [7]. In context, these individual regulations, while contributing to the resilience of the system, nevertheless may jeopardize the continuity of the activity over the shifts.

In the signal station where we conducted our study, which can attend several hundred ships a day, identifying and tracking all of maritime movements (departure from or arrival in port, fishing, anchoring, transit) is one of the main missions of the lookouts. This sub-task consists of filling a computer register listing precisely and exhaustively all observed movements by successive lookouts. It contributes to building and maintaining a Situation Awareness [8], a mental representation of the current situation that enables lookouts to understand it and anticipate its possible evolutions. However, the register, like any document supporting collective activity, requires that a minimum and homogeneous level of information be collected and understood, and that this process be continuously carried out by the various successive lookouts.

These factors lead us to pose three questions: What are the regulation strategies deployed by the lookouts during the surveillance task to fill in the movements register? What is the logic that these strategies follow? To what extent does it contribute to system resilience (and specifically to its anticipation and adaptation components)?

3 Methodology

3.1 Population

This paper is based on fieldwork carried out at a signal station on the French coastline of the English Channel. A team of eight lookouts (7 men and 1 woman, aged between 32 and 49, with 1 to 19 years' seniority, anonymized $L_{[seniority]}$) is assigned to the signal station. All team members agreed to participate. The lookouts rotate according to individual work rhythms, so that a team of three individuals (with ephemeral composition) is permanently at the signal station, carrying out the six shifts of the day (with one dayshift and one nightshift of 4 h per person).

3.2 Data Collection

Our approach is informed by the principles of activity-based ergonomics and makes situational work analysis a central tool in the comprehension process [9].

In April 2023, observations were conducted and consensually filmed for one dayshift of each lookout (i.e. 32 h). The chronological analysis of these surveillance situations enabled each film to be sequenced into different specific situations, each corresponding to a particular sub-task (prescribed or not) and staging the activity deployed to respond to it. We were able to identify the transition from one time to another as it is marked by a sudden discontinuity during action (e.g. a change in the tool used, a clear shift in attention allocation or a temporal break). We were thus able to create, for each shift, a library of 37 to 105 Characteristic Action Situations (CAS) [10]. They were classified according to a double-coding system distinguishing first between surveillance sub-tasks and then between the purposes pursued. For this paper, we only retained CAS about the identification subtask that distinguish four aims: recognition, filling in, monitoring, and actualization.

CAS, as contextualized mnemonic primers, are rich supports for understanding a work situation when conducting self-confrontation interviews [11]. By confronting lookouts with these traces of their own activity, this interview technique gives us privileged access to the logic and cognitive elements underlying observable behavior, enabling us to make an analysis of it and to grasp the determinants and reasoned foundations. An individual interview was conducted with each lookout, during their off-shift time and within a maximum of one week after the filmed shift.

These filmed and discussed data must therefore be contextualized at different levels to make sense from a resilience point of view: we thus collected and analyzed the 30 maritime movement registers of April (products of the identification activity) and had access to the prescription elements of the surveillance task.

3.3 Data Analysis

Filmed observations have been processed in the form of activity chronicles, enabling temporal logics and arrangements to emerge. The indicators chosen for each chronicle relate to the purposes pursued and actions carried out during the different CAS identified in the identification subtask (recognition, fill in, monitoring and actualization).

The processing of verbalization material took the form of a semantic content analysis [12] aimed at identifying the meaningful units of discourses to explain and contextualize variations in the chronicles.

For the registers, a descriptive quantitative analysis was carried out. We have extracted information on shipping flows (by type of ships, hours, and type of movement) and their relationship with tide times.

4 Results

4.1 Characterization of the Identification Sub-task

A Discontinuous Maritime Flow. By the systematic statistical analysis of the registers, we can observe that the maritime flow shows a peak in movements between 01:30 and 02:00 before the high tide (out of 47 rising tides), and between 00:45 and 01:45 after the high tide (out of 47 ebb tides). This uneven distribution of movement reflects an alternation between dense and weak times and corresponds to the opening and closing times of the port gates (about 01:45 before and after high tide). We therefore only consider shifts positioned in one of these two periods (4 shifts are excluded).

The Lookout's Activity. Let's take the case of L_{15} as an example (08:00–12:00 shift, April 4th, 2023). The prescription calls for very precise recording of the timing of movements (e.g. when entering or leaving port) and exhaustive identification in French waters. However, activity tends to deviate from these rules. We can observe that the surveillance task involves several sub-tasks (optical, auditory, and radar watch, maritime movements identification, data archiving and occupation activity during quiet times) in a non-sequential way (see Fig. 1). For identification times, we can identify two cases: i) when many movements occur simultaneously (e.g. just after port gates open or before they close, observed 6 times for the 4 shifts studied) and ii) with only one movement (quieter periods observed 46 times for the 4 shifts studied).

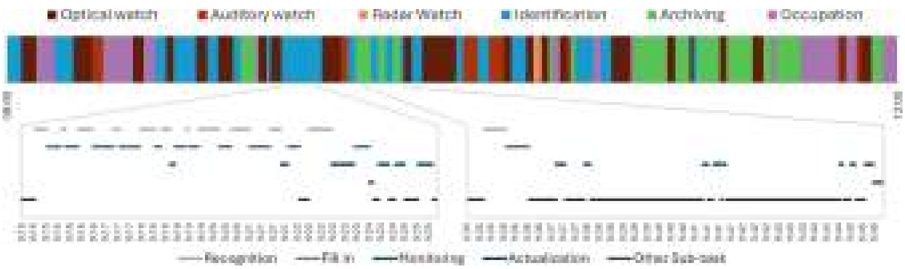

Fig. 1. Sub-tasks chronicle of L_{15} for one dayshift (08:00–12:00, on top) and zoom on two identification periods (identification during a rush after gates open on the left and identification of a lonely boat on the right) detailing purposes pursued.

For the rush time (port gates open at 09:15 that day), L_{15} alternates between recognition (by detecting distinctive signs or reading the registration number) and time spent filling in the register. Monitoring ships and actualizing the register are only retrieved once the flow decreases (from 09:22). During quieter periods, L_{15} spends more time on each boat, recognizing it, filling in its details in the register, and monitoring regularly (every 3min). He can thus engage himself in another sub-task (writing a report).

4.2 Regulatory Strategies Deployed

The two classes of situations presented for L_{15} are found in all the shifts filmed and lead to the deployment of similar regulation strategies between the eight lookouts.

Identify as Quickly as Possible. Ships are identified as quickly as possible according to the conditions of the situation (movement, weather, visibility, boat type, etc.). In Fig. 1 (on the right), the ship is registered at 09:36 but effectively at port at 09:45 (register actualized): "*I consider it more as an identification. It's not about getting into port; it's about getting it as soon as possible.*" (L_{15}). This logic may be seen for the other lookouts ("*I identify boats as soon as possible*", L_8; "*The sooner I've identified, the sooner I can increment the register*", L_7) and responds to a cautious posture ("W*e don't know what will happen next*", L_{15}).

Record What Matters. Some information is considered by the lookouts as being of a lower priority, especially in rush time: "W*e prefer to identify several boats rather than the exact time of a single one*" (L_{15}). Other lookouts adopt the same prioritization logic: "*It doesn't have a license number, so I move on to something else*" (L_8), "Y*ou may have a discrepancy between the register and the real time of return to port*" (L_7). Moreover, beyond movement within the port or within the signal station's area, the surveillance is aimed at updating the Situation Awareness: "*Keep an up-to-date knowledge of what's going on, not fill everything*" (L_{15}), "*I had two boats fishing. So, I'm not going to waste my time filling it in, I look just in case*" (L_{19}).

Group Identifications. The identification during rush time is a problem for the lookouts: "*You don't have time to get them all on your own*" (L_{15}). Several boats are then recognized, eventually noted on a draft sheet, and filled in the register. Using this strategy, lookouts identify boats faster than with a one-by-one method. This strategy is deployed by everyone in rush time ("*I take several at a time, which saves me time*", L_7; "*I identify a few that I write down on my draft sheet and then I write them all on the register*", L_8) and is even accentuated by the anticipation of the port's opening or closing time ("*I watched what time the gates opened, anticipating what was going to happen*", L_{19}; "*When the doors open, they always come in big bundles*", L_7).

4.3 Objective: Time Management

Using the strategies described above, lookouts build their time to: i) cope with event uncertainty and detect abnormal situations (that is, to direct their attention towards the phenomenon to understand it and anticipate its possible or probable evolutions): "*A boat that leaves the port at full speed and suddenly stops, I follow the thing, to be aware of it*" (L_8), "*Five people on a small boat, you can detect a situation that can quickly degenerate"* (L_{19}); ii) achieve other signal station missions: "*I take the opportunity to prepare the handover, take notes, sort things out*" (L_{15}), "*I'm writing up the report on the rescue operation, since it's quieter*" (L_8); or iii) implement strategies to maintain a high level of vigilance: "*[Preparing tea] also keeps you awake when it's quieter*" (L_{19}), "*[Reading] the newspaper keeps me busy and active*" (L_{15}).

5 Discussion and Conclusion

The strategies deployed during the surveillance task to identify maritime movements represent a compromise between achieving the aims of identification and maintaining the potential to react if there is a problem. This time management responds to a logic of prioritisation [13], implying the production of an incomplete register that nevertheless provides the essential information according to the lookouts. Concerning the ability to react to abnormal phenomenon, implementing these time management strategies supports the lookouts' vigilance capacity. In this way, lookouts can detect any early warning signs [14], the interpretation of which will enable them to anticipate such events and so ensure the efficiency of surveillance. It therefore seems appropriate to set up an organization that encourages the deployment of strategies in the service of vigilance, thereby increasing operators' resilience [1]. These improvisations could, however, constitute a limit to the continuity of the task, insofar as this register can serve as an intermediary object supporting the shift changeover. A detailed analysis of these times would be necessary to understand the issues involved in identifying and recording information. Furthermore, our analysis is only valid for the characteristics of the shifts studied (a day shift at this signal station during the month of April): another context probably requires the deployment of adjusted regulation strategies.

To conclude, the lookouts' time management strategies enable their identification aims to be achieved without compromising the other sub-tasks essential for reliability. The need for vigilance for example, essential to operator's resilience, requires a special time construction to manage watch time, identification time, and time dedicated to other sub-tasks. On the other hand, there may be consequences for the continuity of surveillance during the subsequent shifts or to manage any problems that may arise.

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Evaluation and Analysis of Disaster Response Exercise at a Large Hospital

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Abstract. Mass casualty incidents introduce significant challenges to healthcare systems. Although disaster training exercises are completed to enhance the response capabilities in hospitals, evaluating the effectiveness of these exercises is a challenging task that often requires subjective measures. This study aimed to develop a simulation model for the objective evaluation of disaster response performance in a large hospital setting. The model, refined through procedural modifications, accurately represents patient flow and task durations. Through a comparison of normative and descriptive scenarios, the gaps in disaster response performance were assessed, bottlenecks were identified, and improvements in preparedness were investigated. Furthermore, the results indicate that simulating normative scenarios provides optimal bed capacity and staff requirements, highlighting any areas for improvement to enhance the disaster response capabilities.

Keywords: Disaster Preparedness · Disaster Response Training · Mass Casualty Incidents · Hospital Resilience · Simulation

1 Introduction

Mass casualty incidents (MCIs) can result in multiple casualties and overwhelm the response capacity of associated healthcare providers. The cause of an MCI can be natural or manmade, and disaster preparedness and response capability must be evaluated to provide effective and resilient healthcare services accordingly. Healthcare providers utilize various methods for disaster training, including simulation exercises and disaster drills. Although the effectiveness of disaster response training has been studied, the reported evaluation measures are mostly subjective. Although self-report surveys report "lessons learned" after training, they fail to objectively evaluate the training [1]. Lecture-based studies have measured the change in knowledge with a test score to evaluate the disaster training [2, 3]; however, these studies could not demonstrate the hands-on performance of the hospital staff after training. Moreover, several studies have assessed the effectiveness of disaster response training tools but failed to report conclusive and objective evidence for the training evaluation [4, 5]. Standardized, objective, and quantitative measures for the evaluation of the performance and response capabilities of hospital staff are necessary to determine opportunities for improvement, bottlenecks, limitations, and resource requirements.

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The evaluation of disaster training helps determine the operational objectives, improve the disaster response capabilities, and assess the current level of preparedness. Although disaster response training is an important facet of disaster risk management, there is a lack of research focused on the evaluation of practical exercises in literature. Evaluating the effectiveness of the response in an exercise is only possible with computer simulation, as real-life flow of the normative scenario cannot be observed for analysis and comparison with the descriptive scenario. A simulation model previously developed for this purpose had several issues regarding task and patient flows during the exercise: Task orders and durations were not accurately defined, and the patient flow had procedural errors. Improving the simulation model to accurately represent the disaster response exercise could help enhance the disaster response capacity through an objective evaluation.

2 Objectives

This study aimed to develop an appropriate model for an objective and quantitative evaluation of the disaster response performance in hospitals. Specifically, the results of a disaster response exercise in a large hospital were analyzed, and bottlenecks, possible improvements in disaster preparedness, and the current level of response capacity were investigated. In addition, we aimed to improve a previous simulation model with a precise task duration model and compare the results of the normative and descriptive scenarios to evaluate the gaps in disaster response performance.

3 Methodology

This section introduces the hospital model, training data, simulation model, and the scenarios for the simulations (normative and descriptive), which were developed in the previous studies [6, 7]. The previous model had a generic approach to the task flow, where the process was not tailored for each patient. The task decisions and durations were not explicitly defined in the model, leading to less-than-ideal results. Using the conceptual model of the hospital with different areas, staff, tasks, and resources, a computer simulation model was realized in which the tasks each patient must go through, such as consultation, treatment, medical examination, transportation, and operation, have been redesigned so they can be customized for individual needs. The model was verified with the exercise results to accurately represent the exercise environment. The normative and descriptive scenarios were considered to evaluate the training results, the details of which are explained in Sect. 3.3.

3.1 Hospital Model

Triage. During an MCI, patients will arrive at a hospital's triage area to be sorted by priority based on their condition. The patients are then transferred to appropriate areas to receive consultation and/or treatment. In Japan, the triage system uses four color codes: red for patients with potentially life-threatening conditions, yellow for patients with non-life-threatening conditions and who require urgent treatment, green for patients with minor injuries, and black for patients who are already dead or unlikely to survive.

Consultation, Medical Exams, and Treatment. Patients receive consultation after their arrival in the color-coded areas. After a consultation in a color-coded area, the hospital staff may order an X-ray, CT scan, or blood test for the patients. When the X-ray and/or CT scans are completed, the patients are transferred back to their initially assigned areas for further treatment. Patients who do not need additional exams and those who completed all the necessary exams start receiving treatment.

Hospitalization, Operation, or Discharge. The hospital staff may decide to change the triage assessment at this time. In that case, the patients are transferred to their new areas to receive treatment. After the treatment in the color-coded areas, patients are either discharged from the hospital, transferred to general wards for further hospital stay, or transferred to an operation room for surgery. Figure 1 summarizes the hospital model.

3.2 Data

The data considered for the modeling and simulation in this study were obtained in a disaster response training at a disaster base hospital in Kanagawa Prefecture, Japan. These trainings took place in 2022, where the hospital staff included doctors, nurses, and transportation personnel, who participated in a 70 min-long disaster response training exercise. A task and patient flow plan were prepared before the exercise. The plan included patient arrival time, injury and treatment information, triage assignment, suggested treatment time, patient transportation duration, required tasks (X-ray, CT scan, blood test), and discharge/hospitalization decision. This plan is the basis of the normative scenario, which we used to evaluate the disaster response training results.

Forty-six patients arrived in the hospital during the exercise. As the training assumes an MCI, the patients arrived in large numbers in a short period, overwhelming the staff and resources. The staff was provided with basic information and vital signs of the patients to make triage and treatment decisions. Each patient's location throughout the exercise was recorded. From these records, we can determine the triage information, task decisions, and treatment and transportation decisions to establish the descriptive scenario.

3.3 Simulation Model

The computer simulation model included accurate task sequence and durations to replicate the exercise results (i.e., descriptive scenario), as well as observing the "what-if" scenario where the exercise follows the preplanned task and patient flow, i.e., the normative scenario. The simulation model improves the task process and durations, specifically for the consultation, treatment, and medical examination compared to the previous model [6, 7]. The class diagram is shown in Fig. 2. Exercise data were recorded in one-minute intervals. The normative scenario adopted 10 s intervals: Each simulation timestep t represents 10 s in real-life. Figures 3 and 4 show the patient load in each area throughout the exercise for the exercise records and descriptive scenario results. It is apparent that the simulation model could reproduce the training environment with minimal deviations. The deviations from the records in the descriptive scenario were caused by our assumptions in the scenario design.

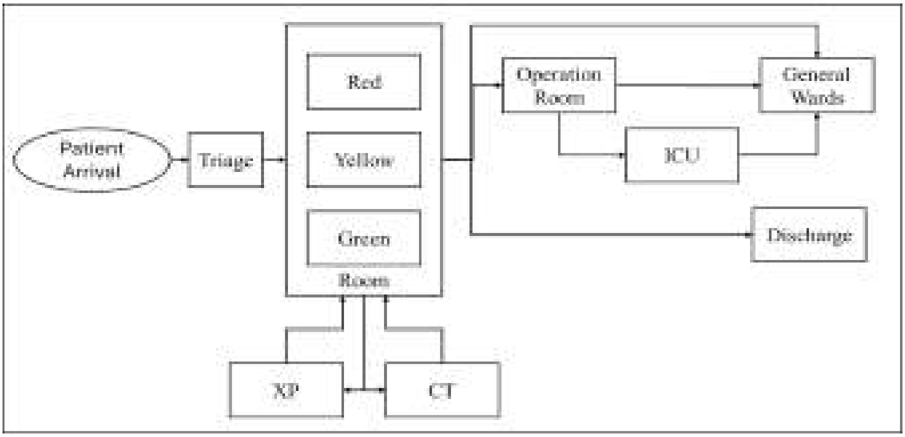

Fig. 1. Hospital model.

Fig. 2. Simplified class diagram of simulation model.

Scenarios. As stated earlier, the normative scenario was based on the preplanned task and patient flow. The exercise plan was created by exercise designers, and it described the suggested triage decision, treatment type and time, transportation time, tasks, and hospitalization decision. This plan, hence, the normative scenario, may be assumed as close to the optimal task and patient flow. The deviations in terms of decisions made and duration of a patient's stay facilitated evaluation of the training results. Regarding the descriptive scenario, the simulation replicated the disaster response training.

To evaluate the training results with the available information, we made a few assumptions. From the plan and exercise records, the patient arrival, triage time and duration, and task information were known; therefore, the input followed the respective data. Although the plan included suggested treatment times, the information was vague; therefore, the training results were used for both normative and descriptive scenarios. Meanwhile, the exercise records did not contain explicit information on the transportation duration, which tended to differ each time owing to the distances between different areas. Therefore, we used the normative transportation time for standardization. In summary, the descriptive scenario followed the exercise records precisely except for the transportation time. The differences between the triage and task decisions could be compared. The normative scenario used the treatment and consultation times from the exercise records.

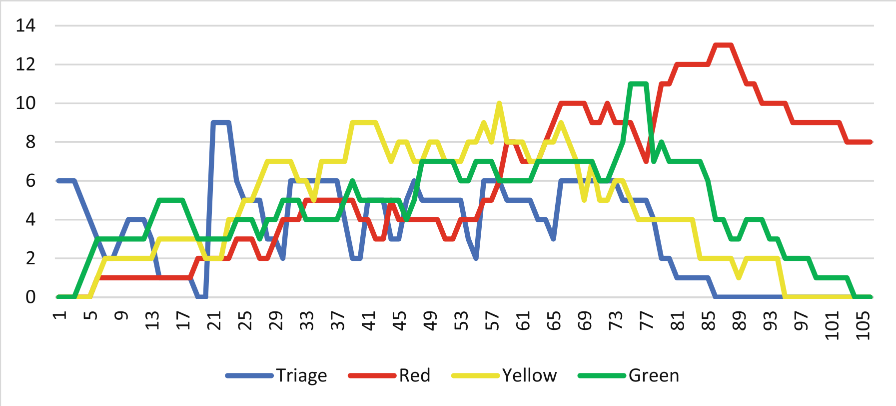

Fig. 3. The number of patients in each area in the exercise records.

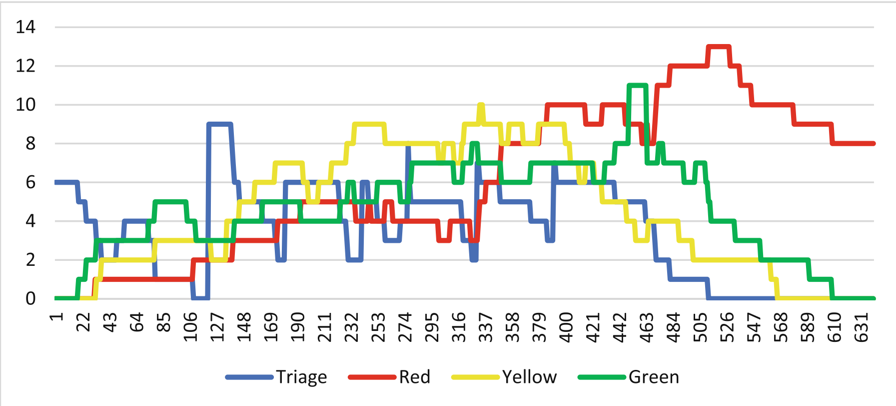

Fig. 4. The number of patients in each area in the descriptive scenario results.

4 Results

The simulation was performed for the normative and descriptive scenarios to evaluate the impact of the deviations from the normative scenario regarding triage decisions and durations. Information on the average and maximum bed occupancy indicated the areas of improvement and optimal capacity levels. From the first patient arrival to the last patient leaving the triage area, the mean number of patients in the triage area was 4.45 in the descriptive scenario, and 1.14 in the normative scenario. From the first patient arrival to the end of the exercise, the mean number of patients in the red, yellow, and green areas corresponded to 6.67, 5.24, and 5.49 for the descriptive scenario, and 6.25, 4.47, and 7.11 for the normative scenario. The maximum number of patients in the triage, red, yellow, and green areas at any time during the exercise was 9, 13, 10, and 11, respectively, for the descriptive scenario, and 6, 10, 9, and 14, respectively, for the normative scenario.

5 Discussion and Conclusions

The simulation model was improved with procedural modifications to achieve a more accurate representation of the disaster response exercise. Triage and task durations are explicitly and accurately specified in the model. Modifications in the resource allocation, such as staff and medical supplies, are necessary for a more detailed model. The model facilitates evaluation of the disaster response exercise as the results of the descriptive and normative scenarios can be compared. The simulation of the normative scenario demonstrated the optimal bed capacity and staff requirements in each area. The number of patients in the triage, red, and yellow areas were higher in the descriptive scenario, whereas the over triage of green patients during the exercise led to less patient load in the green area.

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A Proposal for a Leading Indicator to Diagnose the Level of "Productive Safety" Practices: An Empirical Study of Global Chemical Companies

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Abstract. In safety-critical industries, safety management based on the concept of "protective safety" has reduced accidents. However, in industrial fields where operations have become highly complex due to the development of science and technology and respect for human diversity, the limitations of safety management based on the concept of "protective safety" have been pointed out. In this study, we focus on safety management based on "productive safety" as another strategy for industries where traditional "protective safety" management has matured. "Productive safety" is a concept that shifts the focus of safety management to operators' successes and their sources. In this study, as a component of a safety management method based on this concept, we established a Productive Safety Leading Indicator (PSLI) to evaluate the status of "productive safety" practices in the workplace. To make PSLI, interview data were obtained from operators at Japan and USA plants of global chemical companies. PSLI consists of three axes which are diversity of adjustment actions, deep understanding, and logical understanding. PSLI enables the analysis of daily adjustment actions and their backgrounds and we found distinctive differences between Japanese and USA operators.

Keywords: Productive Safety · Leading Indicators · Chemical Plant Operations · Safety-II · Resilience-engineering

1 Introduction

In high-safety-critical industries, traditional safety management has adopted methods based on the concept of "protective safety." Typical methods of managing operations to "protect" against undesirable events, such as troubles, include creating and enforcing rules, evaluating sites by the number of cases where these rules fail, and adding measures to further multiply protections to prevent such failures. Over the past 50 years, the maturation of safety management worldwide and the reduction of accidents have undoubtedly been the results of safety management based on the concept of "protective safety."

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On the other hand, in industrial fields where operations have become highly complex due to advancements in science and technology and the respect for people's diversity, the limitations of safety management based on the concept of "protective safety" have also been pointed out. Specific problems include the difficulty of pre-determining rules in detail, the limited significance of evaluating the state of safety management based on the number of troubles which is already little, and the potential for measures that multiply protections to hinder the primary business purpose of production activities [1].

Therefore, this study proposes safety management based on "productive safety" as another strategy for industries where traditional "protective safety" has matured, and aims to establish safety management methods based on this concept. "Productive safety" is a concept that aims to prevent undesirable events, such as troubles, in advance and to sustain stable operations. It shifts the focus of safety management from operators' failures and their causes to operators' successes and their sources.

Hollnagel refers to "productive safety" in a passage explaining his concept of Safety-II [2]. Safety-II is a concept that anticipates the display of human resilience, two situations where this ability is expected to manifest are recovering from critical cases with large fluctuations and controlling small fluctuations in a steady state. This study focuses on the latter, targeting human resilience in the sense of actions and behaviors that stabilize regular operations to enhance both production and safety.

Although "productive safety" shifts the focus of safety management to operators' successes and their sources, understanding and evaluating the sources that create daily normal operations, which constitute operators' success, is far more difficult than analyzing failures and their causes. This difficulty is considered to be a factor that makes it challenging to embed the concept of "productive safety" into practical on-site safety management.

2 Objective

This study focuses on the voluntary "good adjustments" made by operators, both large and small, with the intention of avoiding troubles in advance and maintaining stable operations. Putting systematization of these adjustments as a starting point, we aim to develop a method for promoting safety management from the perspective of "productive safety." In the context of the PDCA cycle for safety management, which includes planning, implementation/training, evaluation, and improvement, this paper particularly reports on the establishment of leading indicators as an evalu-ation method from the perspective of "productive safety." Unlike lagging indicators that diagnose the site based on outcomes such as the number of troubles, these leading indicators diagnose the site based on the daily adjustment actions performed by operators to prevent troubles in advance.

3 Data Collection

In this study, we targeted a global chemical company and collected interview data from operators at plants in Japan and USA (10 operators in each country). The interviews involved one interviewer closely shadowing one operator throughout an entire shift (approximately 8 h) and asking about each voluntary adjustment action intended to maintain normal operations during work. The questions focused on the following four points: ① the content of the action (what they are doing), ② the reason for the action (why they are doing it), ③ the source of the action (the underlying experiences, learning, beliefs, etc.), and ④ what they would do in different situations.

Each operator was informed at the beginning that the purpose of the interview was not for auditing but to investigate the various actions and thoughts that support their daily work.

4 Analysis of Individuals

We conducted interviews with 20 operators, each lasting approximately 8 h, resulting in interview data that could be expressed in a total of 1,151 causally related sentences. To clarify the causal structure underlying the "good adjustments" each operator made to maintain normal operations—considering their intentions, knowledge, beliefs, experiences, and other factors—we applied DEMATEL (Decision Making Trial and Evaluation Laboratory), an advanced statistical method that represents the decision-making process hierarchically in graph form. As a result, for each operator, we were able to derive a tree-like model with actions at the top layer, followed by intentions, and further branching into experiences and beliefs. Figure 1 shows the analysis results for one operator.

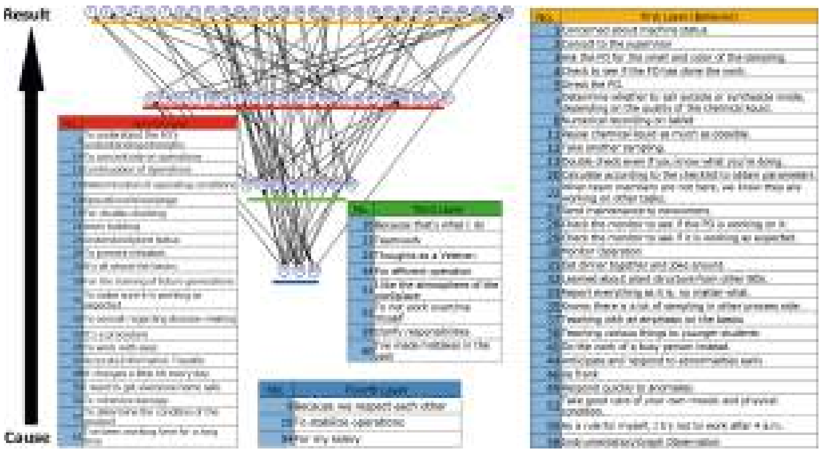

Fig. 1. DEMATEL model for a specific operator

5 Construction of Leading Indicator

The behaviors that appeared at the top layer of the DEMATEL model for each operator were classified based on their similarities using the KJ method, resulting in 64 categories as shown in Table 1.

Table 1. 64 behavior categories of "good adjustments".

Next, the intentions, experiences, beliefs, etc., linked to the behavior layer were classified into four levels based on their meaning. This classification used Degani & Wiener's 4P (Practice, Procedure, Policy, Philosophy) (Degani & Wiener, 1994)[3]. The Practice layer includes items such as "operation and equipment handling" and "instructions from colleagues," the Procedure layer includes items such as "rules" and "risk awareness," the Policy layer includes items such as "cooperative spirit" and "continuity of operations," and the Philosophy layer includes items such as "career advancement," "customer awareness," and "returning safely."

The above classification was applied to the DEMATEL model for each operator to quantify the implementation status of "good adjustments" from the following three perspectives. First, to what extent adjustment actions are taken to stabilize daily operations from a broad perspective. Second, to what extent these adjustment actions are based on deep thinking. Third, to what extent these adjustment actions are logically understood. The Productive Safety Leading Indicators(PSLI) were constructed based on these perspectives and were calculated through the following process.

Let the nodes at the top layer of the DEMATEL model for a certain operator be denoted as $first\ layer_i$, (i = 1, ..., n)), and the nodes of the DEMATEL model not in the top layer be denoted as $background_i$, $(i = n + 1, \ldots, m)$. In other words, the DEMATEL model is defined as follows.

$$G = \langle V, E \rangle$$
$$V = \{first\ layer_1, \ldots, first\ layer_n,\ background_{n+1},\ \ldots,\ background_m\}$$
$$E = \{(background_k, firstlayer_l),\ (background_{k+1}, background_k), \ldots\}$$

Since the $first\ layer_i$ nodes are linked to 64 behavior categories of "good adjustment", the following function is defined to take $first\ layer_i$ as input and output the linked behavior clusters.

$$f(first\ layer_i) = behavior_l, l = 1, \ldots, 64 \tag{1}$$

Since the $background_k$ nodes are linked to the 4Ps, the following function is defined.

$$g(background_k) = 4P\,place_a, a = 1,\ 2,\ 3,\ 4 \tag{2}$$

$$4P\,Place_1 = Practice, 4P\,Place_2 = Procedure, 4P\,Place_3 = Policy, 4P\,Place_4 = Philosophy$$

To quantitatively define the depth of the 4Ps, the following function is defined.

$$h(4P\,Place_a) = a \tag{3}$$

Let the set of nodes that can reach a certain node be denoted as $Can\,Reach(first\ layer_i)$. Let the set of $behavior_l$ for all i in all $first\ layer_i$ of a certain operator be denoted as $Behaviores$.

$$Behaviores = \{f(first\ layer_1) \cup f(first\ layer_2) \cup \cdots \cup f(first\ layer_n)\} \tag{4}$$

For $behavior_l$, define the set of $Can\,Reach\ to\ Behavior_{behavior_l}$.

$$Can\,Reach\ to\ Behavior_{behavior_l} = \{Can\,Reach(first\ layer_i) | behavior_l = f(firstlayer_i)\} \tag{5}$$

The implementation status of the operator's adjustment actions was evaluated based on three axes: "Variety of behavior Categories", "Depth of behavior" which measure the depth of understanding of behavior, and "Step thorough Each 4P" which measure the logical understanding of behavior. These three variables will be designated as the PSLI.

$$Variety\ of\ behavior\ Categories = \frac{|Behaviores|}{64} \tag{6}$$

$$Depth\ of\ behavior = \frac{1}{|Behaviores|}\sum\nolimits_{behavior_l \in Behaviores} \frac{\max\{h(g(background_i))|background_i \in (Can\ Reach\ to\ behavior_l)\}}{4} \tag{7}$$

$$Step\ Through\ Each\ 4P = \frac{1}{|Behaviores|}\sum\nolimits_{behavior_l \in Behaviores} \frac{|\{g(background_i)|background_i \in Can\ Reach\ to\ behavior_l\}|}{\max\{h(g(background_i))|background_i \in Can\ Reach\ to\ behavior_l\}} \tag{8}$$

By using K-means cluster analysis to PSLI, the operators were divided into three groups. The three types are shown in Fig. 2. The first type, Type A, performs adjustment actions based on logical and deep understanding. The second type, Type B, performs a diverse range of adjustment actions based on logical understanding. The third type, Type C, performs a diverse range of adjustment actions based on procedures. It was also found that the second type predominantly includes Japanese operators.

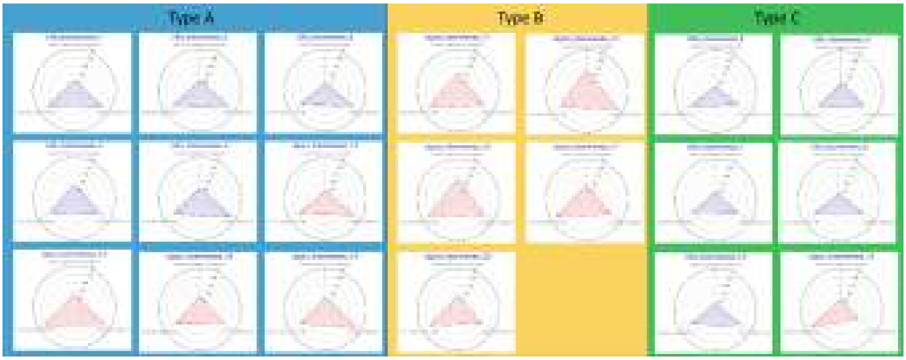

Fig. 2. Result of PSLI Clustering

By Japan and USA plants investigation, in addition to differences in the cultural backgrounds and legal systems underlying employment, the safety education and its methods implemented also differ. Therefore, these factors may potentially influence the implementation status of daily adjustment actions.

6 Conclusion

In this study, based on interview data obtained from operators at plants in Japan and the USA plants, this study developed a Productive Safety Leading Indicator (PSLI) as a concrete approach to translating "productive safety" into practical safety management. PSLI evaluates the daily adjustment activities performed by operators. Using this PSLI, we were able to identify characteristic differences between Japanese and American operators. In future research, we aim to apply this leading indicator to plants in other cultural and employment contexts, including those in Europe and Asia, to further examine its effectiveness and practicality as an evaluation method for promoting productive safety.

Predicting Future Situations Requiring Resilient Performance and Deriving Competencies to Strengthen in Preparation: An Analysis Based on the Aviation Safety Reporting System (ASRS)

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Abstract. In recent years, socio-technical systems, including aviation, require "resilience," the ability of people to maintain or improve their functioning by responding and adjusting flexibly to changing circumstances. To enhance resilience, focusing on daily successes (normal operations) and learning from them is necessary. However, it is not easy to learn from normal operations to understand the factors that led to why they succeeded.

Therefore, an attempt is being made to identify resilience competencies from near-miss incidents, considering them "successful cases in which flexible human behavior did not lead to accidents."

In this study, we propose a method for applying the resilience competencies identified in previous research to the practice of safety management. We predict the increase or decrease of situations where near-miss incidents occur, which are situations that require resilient performance. Furthermore, we propose a method for deriving the resilience competencies needed in those situations. This method is believed to enable focused training on specific resilience competencies in preparation for future situational changes.

Keywords: resilience engineering · natural language processing · aviation safety report

1 Introduction

In recent years, socio-technical systems, including aviation, require "resilience," the ability of people to maintain or improve their functioning by responding and adjusting flexibly to changing circumstances. To enhance resilience, it is necessary to focus on daily successes (normal operations) and learn from them [1]. However, it is not easy to learn from normal operations to understand the factors that led to why they succeeded.

The four abilities believed to be necessary for demonstrating resilience are anticipating, monitoring, responding, and learning [2]. Based on these abilities, efforts are being made to specifically understand the qualities required to exhibit resilience. In previous studies, behaviors observed in fields such as aviation and healthcare have been collected

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through interviews and other methods. These data are being analyzed to understand them in terms of the four abilities of resilience [3, 4].

One approach different from these prior studies for learning about normal operations, our project group has attempted to extract resilience from near-miss incidents. We regarded near-miss incidents as examples of success where accidents were avoided through flexible human action, and we considered that near-miss incidents include behaviors demonstrating resilience. Data collected and made public by the Aviation Safety Reporting System (ASRS) were utilized. These data were analyzed using natural language processing (NLP) to extract behaviors that demonstrated resilience. Then, the resilience competencies, which are the qualities necessary for resilient performance, were identified [5].

In this study, we propose a method to apply the resilience competencies identified in previous research [5] to the practice of safety management. This involves predicting the increase or decrease of situations where near-miss incidents will occur in the future, that is, situations where resilient performance are required, and deriving the necessary resilience competencies for those situations. This method enables the focused training of specific resilience competencies in preparation for future situational changes, which is expected to contribute to further enhancing aviation safety.

2 Methodology

2.1 Data

The ASRS is one of the world's largest voluntary reporting systems targeting the U.S. aviation industry. Many near-miss incidents are reported by people in various aviation-related professions. In 2023, the average number of reports per month was 8,841. These reports are analyzed by ASRS staff and made publicly available on their website [6].

We conducted our analysis using data downloaded from the ASRS website. Specifically, we focused on the near-miss reports written as free-text (Narratives) within the ASRS data. Additionally, considering the technical advancements in the aviation industry, we chose to analyze narratives from 2010 onwards.

2.2 Analysis Flow

In this analysis, we first used the method from previous research [5] to check each sentence in the ASRS narratives for the presence of resilience competencies. Next, we clustered the narratives to identify the characteristics of situations in which near-miss incidents occur. Then, we conducted time series analysis for each cluster to grasp the future trends of increase and decrease. Additionally, we derived the resilience competencies that are frequently exhibited (and should be strengthened) for each cluster. By combining these analyses, we identified the resilience competencies that should be strengthened for the future (see Fig. 1).

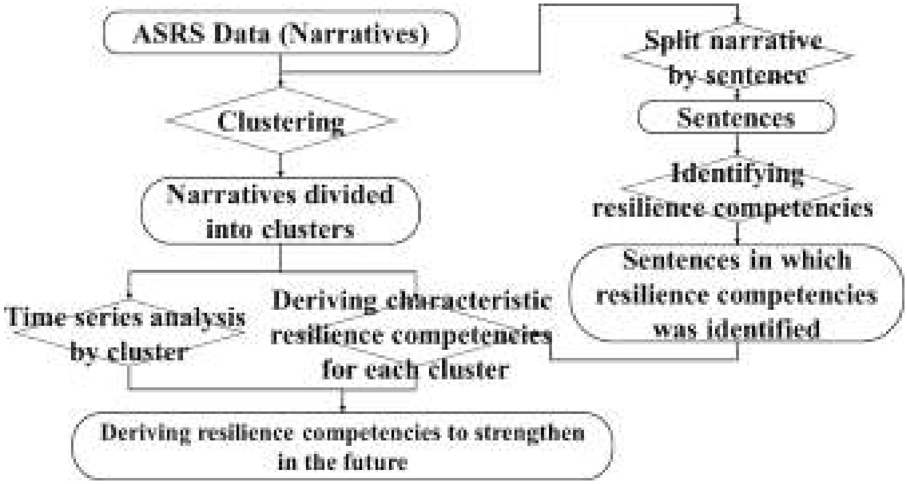

Fig. 1. Analysis Flow

2.3 Identifying Resilience Competencies Using ASRS Reports

Using the method from the previous study [5], we identified resilience competencies using ASRS data from the seven years between 2016 and 2022. First, we selected 6,878 sentences from the narratives in ASRS, ensuring no bias in the reporting year and the profession of the reporter. Next, we annotated whether the sentences included behaviors demonstrating resilience and whether they exhibited any of the four resilience abilities. Using these annotated sentences, we constructed a resilience extraction model and a resilience four abilities extraction model through NLP.

We then applied the models to 644,502 sentences, extracting sentences that demonstrated resilience and those that demonstrated each of the four abilities. Sentences extracted for each ability were clustered using the k-means method. By analyzing the frequent words in each cluster, we identified the specific actions through which each ability was demonstrated, thus identifying the resilience competencies.

2.4 Clustering of ASRS Reported Situations by BERTopic

To grasp the characteristics of situations where near-miss incidents occur, we performed clustering on 80,392 free-text narratives from the ASRS data spanning 13 years from 2010 to 2022. We used BERTopic for the clustering. In BERTopic, methods for embedding and clustering can be selected. For embedding, we chose the one of Sentence-BERT's pre-trained models, all-mpnet-base-v2 model, and for clustering, we used HDBSCAN. The minimum cluster size parameter for HDBSCAN was set to 402 (0.5% of the total number of narratives).

2.5 Prediction of Situations Likely to Increase Near-Miss Incidents in the Future

Time series analysis was conducted for each cluster obtained through the clustering in Sect. 2.4. This analysis predicted the future increase or decrease of near-miss incidents in the situations corresponding to each cluster. To account for seasonal variations, a SARIMA (seasonal autoregressive integrated moving average) model, which is one of the autoregressive models that considers seasonal cycles, was utilized. During model construction, the seasonal difference was set to s = 12, and for the other parameters (p, d, q; P, D, Q), combinations of (0, 1) were tested. The model with the lowest AIC (Akaike Information Criterion) was selected. Data from the 12 years between 2010 and 2021 were used as training data, and data from the year 2022 were used as test data.

2.6 Derivation of Resilience Competencies Demonstrated in Each Situation

To derive the resilience competencies that should be strengthened in situations where near-miss incidents occur, we analyzed the resilience competencies that are frequently exhibited and those that are disproportionately exhibited for each cluster.

First, the model created in Sect. 2.3 was applied to 13 years of data from 2010 to 2022 to identify the resilience competencies exhibited in each narrative. Then, from the narratives clustered in Sect. 2.4, we identified the resilience competencies exhibited in the narratives within each cluster.

To determine the resilience competencies frequently exhibited in each cluster, we identified those exhibited in more than 30% of the narratives in each cluster. We also identified the resilience competencies that were disproportionately exhibited in specific clusters. We compared the resilience competencies exhibited in each cluster with those exhibited overall. Using Fisher's exact test, we identified those that were significantly more frequent at a significance level of 5%.

These resilience competencies were considered the ones that should be strengthened in those specific situations.

3 Result and Discussion

As a result of identifying resilience competencies, we obtained a total of 31 resilience competencies (seven for anticipating, eleven for monitoring, seven for responding, and six for learning). Clustering the narratives resulted in 26 clusters, and the names of these clusters were determined based on frequent words for each cluster (see Table 1). From the time series analysis, we were able to construct models that captured both significant trends of increase or decrease and seasonal variations for each cluster. Additionally, it was possible to identify between 2 to 19 resilience competencies that were significantly prevalent in each cluster.

By combining the time series analysis for each cluster with the derivation of characteristic resilience competencies, we predict the resilience competencies that should be strengthened in the future.

For example, the Dangerous Goods Handling cluster has been increasing particularly since 2018, and it is expected to continue to increase gradually in the future (see Fig. 2). Table 2 shows the resilience competencies that are frequently exhibited in the Dangerous Goods Handling cluster, as identified in Sect. 2.6.

These resilience competencies are the ones frequently exhibited in the Goods Handling cluster, which is expected to increase in the future, and are considered the resilience competencies that should be prioritized for strengthening in preparation for the future.

Table 1. Cluster Names Obtained by BERTopic

Cluster names				
Descent Altitude	Taxing Procedures	Wake Turbulence	Airspace Control	Smoke Odor
Engine Failure	Cabin Safety	Traffic Pattern	Runway Excursion	Maintenance Equipment List
Pushback	Routing	Traffic Alert	Cabin Altitude	Dangerous Goods Handling
Flap Malfunction	Fuel Tank Imbalance	Landing Gear	Flight Instrument	Hydraulic system
Drone Flight Safety	Trim Control	Flight Scheduling	Takeoff	Helicopter Traffic
Auxiliary Power				

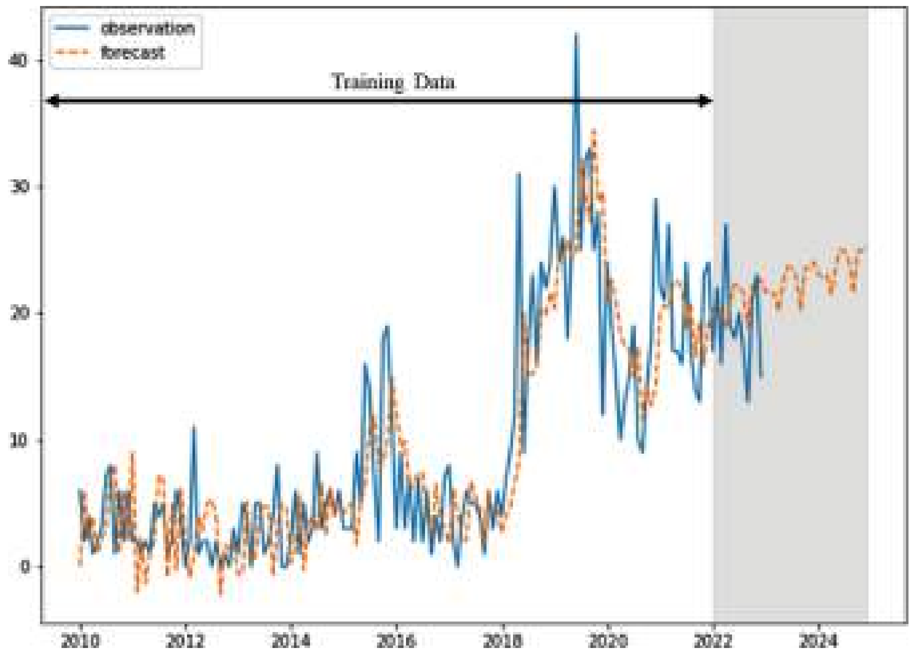

Fig. 2. Results of Time Series Analysis for the Dangerous Goods Handing Cluster

Table 2. Characteristic Resilience Competencies for the Dangerous Goods Handling Cluster

Resilience ability	Resilience Competencies
Anticipating	・Recognize situations as hazards ・Recognize delays and non-implementation as hazards ・Identify possible cases and how to respond to them
Monitoring	・Pay attention to internal conditions of self and others ・Confirms current information (out of control) ・Confirms that it is safe
Responding	・Share information with relevant agencies ・Collaborate with others
Learning	・Consider systems that need to be improved ・Examine underlying factors of the hazard ・Reflect on what happened and share learning with others

4 Conclusion

This study explored methods for applying the 31 resilience competencies identified in previous research [5] to the practice of safety management. We predicted increases or decreases in situations which near-miss incidents may occur in the future and derived the resilience competencies required in each situation. Through this analysis, we identified the resilience competencies that should be strengthened for the future.

By continuously utilizing the method proposed in this study, it is possible to derive, in preparation, the resilience competencies that should be trained according to changing circumstances. This contributes to preventing accidents by keeping critical situations from escalating into accidents and maintaining them as near-miss incidents.

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Standard Operating Procedures Design for Resilient Performance During Healthcare Crises: The Role of Work-As-Done

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Abstract. Healthcare institutions are complex systems subjected to outcome variabilities and disruptions. As such, resilient performance (RP) is paramount to providing the system's functionality under crises, approximating the gap between the work-as-imagined (WAI) and the work-as-done (WAD). Resources for action to support RP include Standard Operating Procedures (SOPs), usually interpreted as part of the WAI. We aim to discuss the role played by the WAD in the SOP design as a resource for action during the COVID-19 pandemic. This study is part of a broader research project and used content analysis from previous interviews. Three examples illustrate the findings related to SOP design as a resource for action and the implementation of COVID-19 patient prone maneuver: (i) case of a hospital that did not have the prone maneuver SOP in place; (ii) case of a hospital that expanded the use of prone maneuver to awake patients and patients without mechanical ventilation, generating a new SOP; and (iii) use of the checklist created during the COVID-19 pandemic for the prone maneuver. Conclusions state that designing and implementing SOPs based on insights from the WAD is a consistent approach to alleviate the gap with the WAI, contributing to RP to cope with healthcare crises while supporting safe and efficient work for employees, patients, and the organization.

Keyword: Resilience Performance · Resource for Action · Work-As-Done · Standard Operating Procedure

1 Introduction

Through the perspective of resilience engineering, resilient performance (RP) in healthcare services explores the mechanisms organizations must consider ensuring system continuity in the face of disruptions [1]. RP implies attempts to bridge the gap between the work-as-imagined (WAI) – e.g., protocols and guidelines – and the work-as-done (WAD) in the reality of complex systems such as healthcare [2]. WAI refers to the rules and standards that define how system elements should work, representing the vision of

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designers, managers, regulators, and authorities regarding how work happens (or should happen). On the other hand, WAD describes the work performed by frontline employees, such as doctors who deal directly with patients. Although protocols and guidelines are important, these professionals understand that work requires continuous adjustments, sometimes involving improvisation and flexibility about established rules [3]. From this perspective, protocols and guidelines come to be understood as a resource for action and not as rigid prescriptions [4].

Different features can support RP and, in this study, are described as resources for action. According to Carim Junior et al. [5, p.148], a resource for action is "one among many resources that provide support for operators to deal with or avoid local constraints". Such a definition is complemented by Wachs and Saurin [6], approaching resources for action as available or triggered by the operator to assist in activity execution. One example is the standard operating procedures (SOPs), which can include procedures, checklists, protocols and guidelines as resources for action [4, 7]. Therefore, while SOPs are considered part of the WAI, they are closely aligned with the WAD as a resource for action and support for RP. Thus, this study aims to discuss the relationship between the WAD and the design of SOPs as a resource for action that contributes to RP during healthcare crises such as the COVID-19 pandemic.

2 Work-As-Done and SOP as Resource for Action

The SOP can never be comprehensive enough in complex and high-risk environments such as healthcare. The so-called sociotechnical complex systems will always have great variability and uncertainty and, consequently, always have a gap between WAI and WAD [4]. Considering that SOP is generic and limited in the face of real work, Hale and Boris [7] pointed to the necessity of translation and adaptation before its application to specific situations. Applying and adapting procedures can be understood as a substantive cognitive skill [4].

For example, Hyisong et al. [8] studied healthcare workers' perceptions of the clinical practice guidelines. Some respondents perceived the guidelines as a decision-making resource that helped them deliver better care. In line with the concept of procedures as resources for action, those respondents believed the guidelines were not meant to be rigidly followed, and it was acceptable to exercise clinical judgment.

Moreover, Hale and Boris [9] highlighted procedures as enacted routines for sociotechnical complex systems. They stated, "It would appear that it is very often more productive to start with the enacted routines and derive the procedures from them and not vice versa". Aligned with this idea is the role of the WAD in the emergence of the guidelines, procedures, checklists, and SOPs. Understanding the WAD and engaging the front-line workers on the design of the SOPs (a bottom-up SOP design) will present a more meaningful SOP. This SOP will probably perform better as a resource for action.

3 Method

This study has a descriptive exploratory character with a combined approach (i.e., survey and interviews), part of a broader research that assessed the relationships between the resources for action and RP. The resources for action were interpreted as five aspects supportive of decision-making in healthcare organizations: information and communication; team, equipment, and tools; SOPs (the focus of the present study); training; and built environment. The research project was approved by the Ethics Committee of the responsible institution. Partial results of this research were published by Bertoni et al. [10], Bertoni et al. [11] and Righi et al. [12].

Firstly, a survey with online questionnaires was sent to front-line healthcare workers in Brazilian hospitals from June to August 2020 during the first waves of COVID-19. The questionnaire addressed two categories of questions. The first category addressed the participants´ professions and hospital characterization, including city, department, and funding type (i.e., private or public). A total of 111 valid responses were obtained, with participants distributed as follows: 47% nurses, 14% physiotherapists, 10% doctors, and 5% others. As for the departments, 40% were in the ICU, 9% in the emergency room and 13% in wards, while 39% worked in other hospital units. Regarding funding type, 8% worked in private hospitals, 62% in public hospitals and 30% in public-private hospitals. Data were analyzed with descriptive statistics. The second category of questions referred to the four resilience potentials based on the Resilience Analysis Grid (RAG) using a 5-point Likert scale [13]. RAG assesses an organization's resilience in daily work, considering how the organization responds, monitors, learns and anticipates everyday activities [14]. Examples of questions present in the survey: i) your institution's procedures (SOP, protocols, flows) support responding to the demands of infected patients (respond); ii) your institution's procedures (SOP, protocols, flows) support monitoring the institution's status in the face of the pandemic (monitor); iii) your institution's procedures (SOP, protocols, flows) support anticipating your response to demands (anticipate); and, iv) your institution's procedures (SOP, protocols, flows) are designed considering situations and lessons experienced (inside and outside the institution (learn).

Then, interviews were conducted using the questerview technique [15]. Thus, online interviews were carried out individually with a doctor, a physiotherapist, two nurses, and a nursing technician, led by two researchers, during June and July 2021, between COVID-19 waves in Brazil. The analysis took place using the content analysis technique [16], which identifies words, expressions or phrases whose meaning is related to the object under study. In this case, the analysis categories were defined in advance: WAI, WAD, SOP and RP.

4 Results and Discussion

The pandemic placed a significant demand on managerial and front-line workers in terms of communication, cooperation, decision-making, and emotional skills [17]. In addition, at the beginning of the pandemic, there was a lack of evidence of physical, technical, organizational, and psychological resources to rely on [18]. Therefore, RP played an important role to compensate for this lack of evidence. Regarding RP, respondents strongly agreed that their institutions are resilient (M = 4.13). The potentials of learning (M = 4.23) and responding (M = 4.05) stood out, followed by monitoring (M = 3.73) and anticipating (M = 3.67) [10, 11]. Concerning the relationship between SOPs and the four potentials for RP, the learning potential scored the highest (M = 4.13), followed by monitoring (3,97), responding (M = 3.96) and anticipating (3,68) [10, 11].

The mean for SOPs was 3.93, indicating that the respondents agreed that SOPs support RP when facing a challenging situation such as the COVID-19 pandemic.

In complex systems such as healthcare, the WAI cannot anticipate and address all possible conditions [2, 19]. It can partially explain the lowest score for the potential of anticipating, as SOPs are commonly associated with the WAI – i.e., protocols. However, if SOPs are also considered resources for action, they can support the potentials of anticipating (scores 3.68 out of 5), learning, monitoring and responding potentials. This study illustrated a scenario based on interviews highlighting the WAD used to design an SOP for the prone maneuver in COVID-19 patients during the pandemic, supporting RP.

4.1 Work-As-Done and the Design of SOP

The SOP design should align with the WAD to act as a resource for action and support RP. The content analysis of the interviews showed the SOP design that emerged from the WAD in combination with previous evidence – e.g., the prone maneuver for COVID-19 patients – which illustrates an SOP design based on practice and research. The physiotherapist report demonstrates that:

> *"The best example is the prone procedure implementation for patients, an SOP that we didn't have [in the hospital]. We did the maneuver, but we didn't have it written down. With the pandemic, we wrote this and other SOPs. In general, all of our SOPs are research-based. The prone one was set up based on research, how-to studies, and the experience" (interviewee #4).*

Another change that emerged during COVID-19 was the implementation of the maneuver for patients without mechanical ventilation and awake patients. At that stage, this strategy was not covered by any procedure, raising the need to design an SOP strongly influenced by the WAD for proning awake COVID-19 patients. The report from the physician reinforces that:

> *"It already existed with the difference that we proned around one patient/month. During the pandemic, there were 3-4 patients/day, a difference in volume. We created the prone protocol for an awake patient. We had never done this, and the literature had almost no details - only mechanically ventilated patients with severe hypoxemia were prone. Reports have emerged that the patient would benefit from the prone maneuver, even without mechanical ventilation, only with oxygen. And we created the protocol" (interviewee E#5).*

Checklists are another example of a resource for action. According to Dekker [4], the checklist helps the worker to structure activities, even in different situations, considering the inevitable variability. The use of the checklist as support for decision-making and execution of the prone maneuver, influencing the monitoring and response potential, is shown by a nursing technician who works in an ICU:

> *"We ran a checklist before, during, and after the maneuver, and one person was responsible only for reading this checklist. We stayed basically in silence; we*

communicated the basics, listened to the checklist and confirmed the facts, and then at the time of the maneuver, the doctor commanded the maneuver right there" (interviewee #1).

The excerpts presented bring reports from three professionals from different institutions and illustrate the emergence of SOPs from the WAD. The SOP, mostly recognized as a manifestation of the WAI, when emerging from the WAD, strengthens the role of the SOP as a resource for action at the meso level. Bergstrom and Dekker [20] argued that resilience can be investigated in three scales: micro level – related to individual or group level and their relationship with the context; meso level – organizational level; macro level – society and policy making. Thus, WAD experienced at the micro level contributes to SOP design at the meso level, demonstrating the complex sociotechnical interactions in healthcare systems. This is an example demonstrating how to bridge the gap between WAI and WAD through RP during a pandemic.

5 Conclusions

Healthcare systems require RP in daily work, especially during crises. This study discusses the relationship between WAD and SOP design, shedding light on a clinical scenario in which practices that emerged from the WAD contributed to designing and implementing an SOP for COVID-19 patient proning. The study demonstrates, through three examples, the SOP design from daily work during the pandemic: (i) case of a hospital that did not have the prone maneuver SOP in place; (ii) case of a hospital that expanded the use of prone maneuver to awake patients and patients without mechanical ventilation, generating a new SOP; and (iii) use of the checklist created during the COVID-19 pandemic for the prone maneuver. We argue this is a consistent approach for designing SOPs to bridge the gap between WAD and WAI, contributing to RP to cope with healthcare crises while supporting safe and efficient work for employees, patients, and the organization.

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A Context-Sensitive Approach for Integrating Fuzzy Set Theory and the FRAM

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Abstract. Work within sociotechnical systems involves inherent performance variability, which can lead to undesirable outcomes. In this study, a framework has been developed to model this variability and identify critical activities within sociotechnical systems. To this purpose, we propose integrating Ergonomic Work Analysis (EWA), the Functional Resonance Analysis Method (FRAM), and Fuzzy Set Theory. A case study in the healthcare sector is presented to demonstrate the model's applicability.

The results indicate that improvements such as updating the hospital's internal system, formalizing procedures, and enhancing information flow coordination across departments could benefit the process. Although the model is still in an intermediary development phase, it has demonstrated promising results, particularly in its potential for prospective investigations to understand how interventions could impact the system's behavior. By using work analysis, the model can account for contextual factors that influence a system-oriented analysis. Therefore, the model could be valuable in managing sociotechnical systems, particularly those with a higher level of complexity and numerous functions.

Keywords: Ergonomics · resilience engineering · fuzzy logic · variability

1 Introduction

Work in sociotechnical systems has performance variability as an inherent property, which may lead to undesirable outcomes. This study develops a framework for modeling variability and identifying critical activities in sociotechnical systems. This study seeks to answer the following research question: How do we encode workers' knowledge and experience to understand variability behavior and improve the management of sociotechnical systems?

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1.1 Quantitative Approaches in FRAM

FRAM has been applied in various domains, with promising results for understanding the effects of variability in complex systems and identifying strategies to manage variability and enhance system resilience. FRAM has a qualitative approach, so many efforts have been made in the past decade to combine the method with quantitative techniques [1].

Among the efforts to bridge FRAM with quantitative approaches, it is worth mentioning Patriarca et al. [2], who proposed combining FRAM with Monte Carlo Simulation. Other proposals include the combination of FRAM with Graph Theory [3], data mining techniques [4], and Bayesian Networks [5].

The literature also presents the integration of FRAM with Fuzzy Theory. As Karwowski et al. [6] point out, fuzzy-based methodologies provide an important framework for modeling systems in the Human Factors and Ergonomics discipline by accounting for the reality of the interactions. Fuzzy systems excel in modeling situations where it is only possible to rely on expert knowledge, and they can be easily implemented. Besides, as suggested by Hollnagel [7], the FRAM lexicon and logic can be integrated into fuzzy systems, allowing a better exploration of FRAM theory.

Takayuki et al. [8] proposed the combination of FRAM with the Cognitive Reliability and Error Analysis Method (CREAM) [9] and fuzzy logic. The authors claim that the method allows for visualizing the system's variability dynamics and potential risks. Following that, Hirose and Sawaragi [10] used the same approach to investigate how variations in the work environment generate variability in a medication dispensing process. Finally, in an evolution of this method, Hirose and Sawaragi [11] combined the approach with the cellular automata model to investigate the system's dynamics.

Slim and Nadeau [12] present another method of combining fuzzy logic and FRAM. Slim and Nadeau [13] extended this research by combining the method with the Rough Set Theory to aid in generating inference rules and thus avoid the rule explosion problem. Both approaches were demonstrated using hypothetical scenarios; however, they emphasize that the modeling requires additional analyses with real data to produce more reliable and representative results.

Lastly, De Souza et al. [14] investigate the ability to respond to the variability of functions using fuzzy inference systems. Furthermore, the authors used the Union Rule Configuration method to reduce the number of rules. It is worth noting that, among the proposals for the combination of fuzzy logic and FRAM, this is the first to present an application in a real-world scenario using data gathered from study participants [15].

We intend to refine the combination of FST with FRAM so that the fuzzy system is not apart from the FRAM model but built from a perspective that dialogues with FRAM theory and the knowledge elicited in the ethnographic work.

2 Methodology

We have established three premises for our modeling process: the model must accommodate the context of work activities, describe variability occurrence, and recognize the sociotechnical nature of the system. Thus, an integration among Work Analysis [16], the Functional Resonance Analysis Method (FRAM) [7], and Fuzzy Set Theory

(FST) [17] is made. The model was then applied to the vacancy opening process in a high-complexity hospital for demonstration [18].

Field data (interviews and observations) was subject to a thematic analysis [19]. Quotations were codified and classified into themes. We identified four relevant themes for the process: organizational culture, information flow/communication, information systems, training, and protocols.

The data collected from the ethnographic work supported the building of an FRAM model of the system under analysis. Variability was modeled regarding endogenous/exogenous disturbances, dampening mechanisms, and output variability [20]. Using the findings of thematic analysis, contextual factors were modeled as embedded in FRAM functions to represent exogenous variability, and the dampening mechanisms for the functions were made explicit as secondary functions.

A Mamdani System was built [21] to assess the overall variability of functions. This model was chosen because it allows the modeling of approximate reasoning through linguistic terms. We establish three terms to describe the outputs: non-variable, variable, and highly variable. Thus, a human function that varies "with high frequency and high amplitude" [7] could have its output represented by two triangular functions (non-variable and variable) and one trapezoidal function with a larger support set than the others and a large core, for instance. For input modeling, we adopted a similar set of terms; however, we represented them through triangular membership functions.

For the rules, we consider the function aspects (except the output) as the antecedents, and the output as the consequent. Rules were derived from the impact of upstream-downstream couplings described by [7]. The min method was applied for the implication and the max for aggregation of the rules. For defuzzification, we employed the centroid method. As a last step, the functions were ranked based on the defuzzified value of their outputs.

We used evaluations provided by the researchers to pilot the model. They assessed the system's performance regarding the specified themes using a 1 to 9 scale. The evaluations were aggregated using simple averages, and the model was implemented in Python. The model allows for ranking the functions according to variability occurrence and understanding the role of contextual factors in system performance.

3 Results

We display the model's results in Fig. 1: a heat map of the functions highlighted according to their criticality and organized as a digraph, allowing us to understand the index formation process. The highest index values were found at the functions *Build medical schedule*, *Check data in the internal system,* and *Select and insert data into the platform*, each with an index value of approximately 0.7741. These functions are interconnected and are affected by similar factors. Building the schedule requires information provided by other departments (*Inform changes in the offer of vacancies*), which is seen as an issue by the workers; one points out, "Our problem has always been information." Besides, there is no formal training or protocol for how the function should be accomplished. Therefore, the outcome strongly depends on the worker's expertise (*Consult own expertise*). A worker explains "I haven't been trained. What I do is based on observation, looking at…, and because of the contacts that helped me." Entering the data into the referral platform implies first accessing it (*Access referral platform*), but the system may be down, impairing the process. A worker reports "We have already been without the system [referral platform] for a week." Finally, checking the data in the internal system requires information beyond the one provided by the system, forcing the worker to rely on their knowledge (*Consult own expertise*). Regarding this situation, the worker highlights "I already know all the names [of the physicians] by heart". Thus, results suggest that improvements such as updating the hospital's internal system to provide the required information and formalizing the processes in guidelines or protocols could help manage system variability. Besides, better coordination of the information flow across the departments also seems important to improve the outcomes.

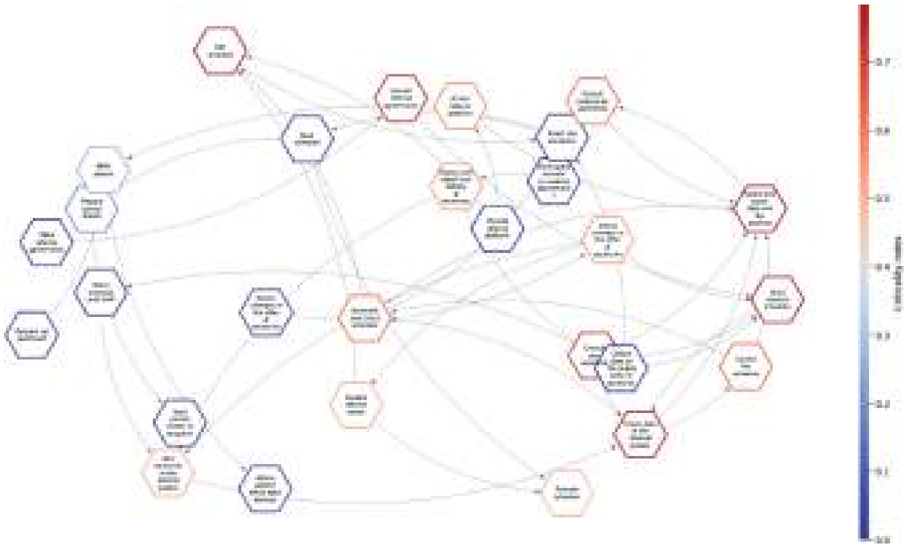

Fig. 1. Model results

4 Discussion

Recent advances in integrating fuzzy logic with FRAM, e.g. [14], attempt to address the shortcomings of this combination, such as the explosion of rules and the use of field data.

Our model explicitly discusses the role of the influence of environmental and organizational factors on system performance. By using work analysis, it can account for contextual factors that influence a system-oriented analysis and a strong understanding of the system's dynamics. An approach centered on work-as-done seems to provide adequate support for encoding human knowledge in the application of fuzzy systems.

This model is still in an intermediary phase of development; therefore, improvements are being made. Despite this, the model shows promising results, especially regarding prospective investigations to understand how interventions impact the system's behavior. In this sense, a sensitivity analysis could be useful.

As a future endeavor, we intend to apply this framework to other cases and domains and improve the systematization of the modeling process.

5 Conclusion

This framework integrates FST, FRAM, and EWA to provide adequate support for encoding human knowledge in system analysis. Hopefully, the model will support the analysis of variability behavior and assist in managing sociotechnical systems, specifically when these show a higher level of complexity and many functions.

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Robotics (I)

Evaluation of Passive Occupational Exoskeletons in Port Embarkation and Disembarkation of Ships: Two Case Studies

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Abstract. Despite numerous laboratory studies, assessments of occupational exoskeletons (OEs) with experienced workers remain limited in the state of the art. This work presents a study conducted in the port operations of containers and goods load and unload inside cargo ships, to investigate the effectiveness of two OEs. Such operations are manually demanding and can increase the physical burden of port operators, which may result in the development of work-related musculoskeletal diseases. Two commercially-available passive OEs were tested, an upper-limb and a lower-back exoskeleton. Electromyography (EMG) data and subjective perceptions of effort were collected. Results show significant reductions in EMG activity for both exoskeletons, particularly in shoulder and trunk muscles. The results of the questionnaires indicated a good perceived usability and acceptance of the devices. This study demonstrates the potential effectiveness of passive OEs in reducing physical strain in port operations. Results align with findings in other work contexts.

Keywords: Occupational exoskeletons · ergonomics · port workers

1 Introduction

Work-related musculoskeletal disorders (MSDs) are among the most common occupational diseases in the EU [1]. Most blue collars report backache (43%) and pain in the upper extremities (41%), which are primarily due to overexertion and repetitive motion, in some cases performed in poorly ergonomic postures [1]. MSDs impose an economic burden on industries due to lost workdays and reduced productivity, while healthcare systems must ensure that workers undergo appropriate physical rehabilitation before returning to work [1].

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Occupational exoskeletons (OEs) are emerging as new tools to improve ergonomic conditions in the workplace. OEs are personal assistive devices that can reduce the physical load on specific body districts while performing demanding activities [2]. Their potential, yet not demonstrated, effectiveness in reducing the risk to develop work-related musculoskeletal disorders (MSDs), improving workers' well-being, and enhancing productivity, is gaining the interest of multiple players worldwide [3]. Among the numerous studies performed to demonstrate the potentialities of OEs, recently field trials with experienced workers have been conducted more frequently than in the past [4], as shift toward field testing has been recognized paramount to foster OEs large-scale adoption [5].

This study was focused on port operations and aimed to investigate the effectiveness of two OEs. Such operations are manually demanding and can increase the physical burden of dockworkers, which may result in the development of work-related MSDs [6]. In line with the types of activities performed by dockworkers, this paper investigates two use cases: in *use case A*, an upper-limb exoskeleton is used to support dockworkers in works requiring arms elevation, whereas in *use case B*, a lower-back exoskeleton is used in activities involving manual material handling of heavy goods. Efficacy of the OEs was assessed in terms of their capability of reducing strain on specific muscle groups. Usability and acceptability were also investigated.

2 Methods

Two commercially-available passive OEs were tested in this study[1], namely an upper-limb (UL-EXO) and a lower-back exoskeleton (LB-EXO). The UL-EXO (Fig. 1a) was designed to assist workers performing physically demanding work activities typically involving keeping the arms overhead for prolonged periods or performing repetitive arm movements [7]. The LB-EXO (Fig. 1b) was designed to reduce back strain during manual material handling activities, like repetitive load lifting.

The effectiveness of the two devices was assessed through test sessions conducted in realistic scenarios simulating the actual job operations performed by port workers of Compagnia Portuale di Livorno (Livorno, Italy) in their daily practice. The UL-EXO was tested to support workers in three tasks: handling of long rods for lashing activities (Task A1), handling plates for fixing containers to vehicles with trailers (Task A2), and handling long rods for removal of twists (Task A3). The LB-EXO was tested to support workers in lifting fruit boxes to fill pallets. Two different 20-kg fruit box lifting gestures were tested: (i) from shoulder height to the floor (*Task B1*), and (ii) vice versa (*Task B2*). For each task, experimental procedures were conducted in realistic simulation conditions.

Twelve workers volunteered to participate in the experimental sessions, six for each use case. Upon arrival, the participants were informed about the study and signed the informed consent. Before starting the experimental activity, the subjects were equipped with electromyography (EMG) sensors. EMG activity was collected following the procedures described in [7]. The following muscles were monitored: for the use case A, the Anterior Deltoid (AD), Medial Deltoid (MD), Pectoralis Major (PM), and Upper

[1] https://www.comau.com/en/competencies/wearable-robotics-exoskeletons/.

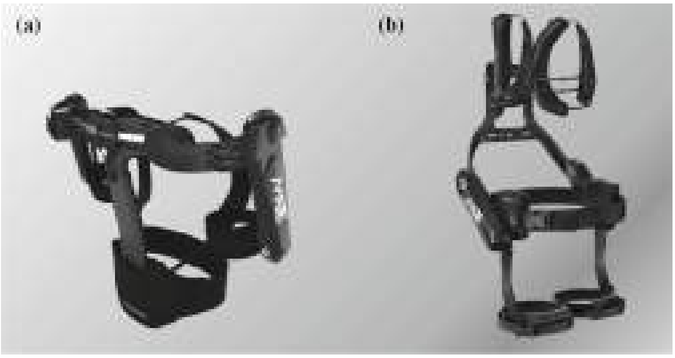

Fig. 1. The devices tested in this study: (a) the upper-limb exoskeleton (UL-EXO) and (b) the lower-back exoskeleton (LB-EXO).

Trapezius (UT); for the use case B, the right and left Thoracic Erector Spinae Longissimus (TESL), Lumbar Erector Spinae Longissimus (LESL), and Erector Spinae Iliocostalis (ESI). The subjects were asked to perform each experimental task in two different conditions, namely without the exoskeleton (NO EXO) and wearing the exoskeleton (EXO). Between conditions, the following subjective questionnaires were administered: the Local Perceived Exertion Test (LPET) and the Borg Scale questionnaires to measure the local perceived effort in specific body areas and at a global level. Finally, the System Usability Scale (SUS) and Technology Acceptance Model (TAM) questionnaires were administered to capture OEs' usability and acceptability.

Data analysis was performed in MATLAB (The Mathworks, Natick, MA, USA). The EMG signals, collected at 1 kHz, were processed to obtain the linear envelope (EMG_{env}) as in [7]. For each gesture repetition, the integral of the EMG signal (*iEMG*) was computed as in [7] and then normalized by the corresponding MVC values. LPET and Borg Scale scores were averaged across subjects for each task and tested condition. TAM and SUS scores were processed to obtain acceptability and usability indices by averaging, for each questionnaire, the individual scores given by the subjects to each single item of the questionnaires, and finally averaged across subjects.

3 Results

In both scenarios, the OEs showed effective in reducing the EMG activity of the main muscles involved in the movements, compared to the NO EXO condition.

The UL-EXO acted specifically on the reduction of the activity of the anterior and medial deltoids (Fig. 2a–c). In Task A1, significant reductions were observed in the AD, MD, and PM muscles of about 34%, 26%, and 19%, respectively; in Task A2, all muscles significantly reduced their activity, up to the 24%; in Task A3, the AD MD and PM muscles showed reductions higher than 30%.

The LB-EXO was effective in reducing the strain on the erector spinae muscles, with reductions in the range of 11–22% (Fig. 2d–e). The highest reductions were observed in the LES and ESI muscles up to 22%.

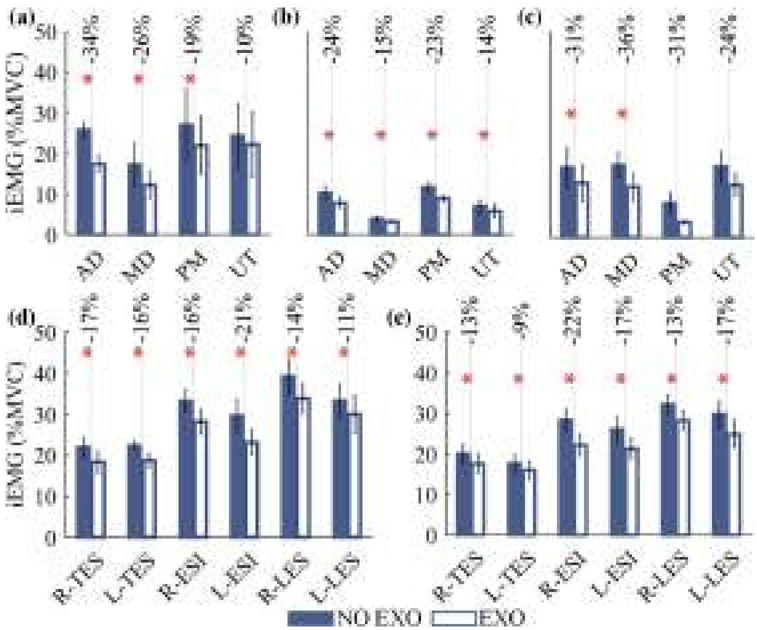

Fig. 2. EMG results for (a) task A1, (b) task A2, (c) task A3, (d) task B1, and (e) task B2 for each monitored muscle.

Table 1 shows the perceived effort quantified by the participants. In Tasks A1, A2 and A3 reduced effort was perceived at the upper limbs and in the lower back. The perceived global effort resulted in at least a one-point reduction in the Borg Scale. In Tasks B1-B2, the results of the LPET and Borg Scale indices showed reduced perceived effort when using the exoskeleton. Reductions were observed in the target areas (upper, middle, and lower back, thighs, and legs). A similar trend was observed for the Borg Scale and the sum of the LPET scores of all body areas.

Both exoskeletons surpassed the usability and acceptability thresholds (Fig. 3).

4 Discussion

This study is the first to investigate the effectiveness of OEs in the context of port operations, through the analysis of instrumental (EMG) and perception-related (questionnaires) measurements. In both investigated scenarios, the use of the exoskeletons led to significant reductions in the EMG activity of the muscles that are more involved during the identified work gestures, namely the shoulder and back muscles. Results of this work were in line with previous studies carried out in different application scenarios, such as in the automotive field [8] or in the manufacturing sector [9].

Additionally, the subjective evaluation of perceived effort demonstrated overall positive feedback from the users, both when looking at specific body areas and when considering the global effort. Similarly, also usability and acceptability of the two exoskeletons were well-rated. Usability and acceptability aspects are particularly important when

Table 1. Perceived effort. For each body area, the median and interquartile range of LPET and Borg Scale scores of the difference between NO EXO and EXO are reported.

	Tasks	A1	A2	A3	B1-B2
LPET	Neck	0 (0:0)	0 (-0.5:0)	0 (–0.5:0)	0 (0:0)
	Shoulder	0 (–2:0)	–1 (-1:-0.5)	–1 (–1.5:0.5)	0 (–1:0)
	Upper arm	0 (–1:0)	–1 (–1:–1)	–0.5 (–1:0)	-
	Forearm	0 (–2:0)	–1 (–2:0)	–0.5 (–1.5:0)	-
	Back (up)	–0.25 (–1:0)	0 (–0.5:0)	0 (–0.5:0)	–2 (–3:–1)
	Back (mid)	–0.25 (–1:0)	–0.75 (–1:0)	–0.25 (–0.75:0)	–2.5 (–3:0)
	Back (low)	–1 (–2:0)	–1 (–1:0)	–1 (–1:–0.5)	–2.5 (–3:–1)
	Abdomen	0 (0:0)	–0 (0:0)	0 (-0.5:0.5)	0 (0:0)
	Thighs	-	-	-	–1.5 (–2:–1)
	Legs	-	-	-	–1 (–2:0)
	Total	–1.5 (–8:0)	5 (–7:–2)	–2.75 (–6.5:–0.75)	–9.5 (–13:6)
Borg		0 (0:0)	–0.75 (–0.5:-1)	–1 (–1.25:0.5)	–1 (-2:–1)

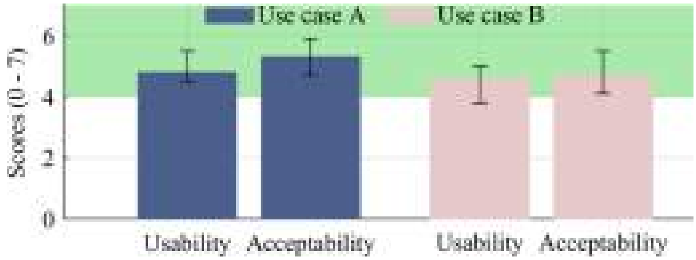

Fig. 3. Usability and acceptability scores. Scores are shown as median across subjects and interquartile range. The green band represents the usability/acceptability region. muscle.

experiments are conducted with experienced workers since they can provide relevant information regarding the practical implementations of the technology into daily practice [10]. In this study, the combination of instrumental metrics, perceptive feedback, usability and acceptability of the two devices provided a comprehensive overview of their impact in realistic scenarios of use. Moreover, this approach could innovate the ergonomics assessment methodology of assisted manual handling of loads.

The major limitation of this study is related to the limited number of participants. Future works will focus on testing the technology in daily activities to unveil practical issues that may affect the use of the technology by the workers.

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Video-Based Framing Can Alter the Negative Attitude Toward Service Robots

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Abstract. Mental models influence how we interact with our environment and help us form expectations. The attitude toward a robot can influence how we interact with it. This study examines video-based positive and negative framing of a delivery robot. 102 participants reported their attitude toward robots on the Negative Attitudes toward Robots Scale (NARS) before and after watching either the positive or negative framing video. The results show significant influences of both framings in the intended directions with a stronger impact of positive framing.

Keywords: Mobile Robots · Framing · Attitudes · Mental Model

1 Introduction

It is important to consider people's attitudes and mental models (MMs) toward robots when designing appropriate robot behaviors for effective and efficient communication. MMs vary due to individual experiences, motives, and goals [11]. The literature outlines how MMs can be manipulated through priming [7], framing [13], and social influence [1]. Darling et al. (2015) demonstrated that framing anthropomorphism influences people's reactions to robots: people hesitated significantly longer to strike a robot when it was personified through a name and a background story [4]. Framing, therefore, does not only work when people read certain formulations but also through storytelling and provided information. [11] state that MM "are the mechanisms whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (p. 49). This definition indicates that humans will make predictions of future system states based on prior experiences and knowledge. Furthermore, [10] formulates a robust definition for MMs by describing them as a "concentrated, personally constructed, internal conception, of external phenomena (historical, existing or projected), or experience, that affects how a person acts" (p. 42). Finally, [2] describe MM as the "[...] conceptualization that allows the user not only to construct actions for novel tasks but also to explain why a particular action produces the results" (p. 47). Research shows that humans prefer robots that align with their MM [14]. MMs can be activated by internal or external stimuli and function as cognitive schemata for describing, explaining, and predicting actions via *mental experiments* [9]. The main research question for this experiment is:

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Can video-based framing alter the negative attitude of humans toward robots?

We hypothesize that (H1) negative framing increases and (H2) positive framing decreases negative attitudes toward robots. Additionally, we are interested in whether humans recognize changes in their attitudes and how they think framing can be more effective on them. Furthermore, we explored whether positive or negative framing has a stronger influence.

2 Methodology

This online survey examined whether our positive framing video positively changes the mental model and a negative stimulus achieves a contrasting result. The survey was divided into three parts: a pre-framing questionnaire, the viewing of the framing stimulus, and a post-framing questionnaire.

Text Development To create comparable stimuli, two texts were developed. The audience is intended to be primed. Targeted formulations, referred to as *framing* by [13], reinforce the direction. One text positively portrayed the robot, while the other text described the robot negatively. The wording differed subtly between the texts, aiming to provide them with connotations while not altering the content. The selection of text content mainly based on influencing factors on message framing, as well as items from the Frankenstein Syndrome Questionnaire (FSQ, [12]). Both texts describe the robot, providing information about its functionality, impact on the delivery process, benefits compared to costs, insights from studies, reports by third parties, and the narrator's opinion. Other people's opinion and the results of studies may further manipulate the formation of opinions in line with the Asch experiments [1]. As a result, the two created texts convey the same information and are similar in language and length, but intend to alter the opinion regarding the described robot. For example, the positive framing included the phrase '70% of people like interaction' while in the negative framing stated that '30% find the technology inappropriate'. Table 1 in the digital appendix provides the complete list of differences.

Video Creation The texts were incorporated as voice-overs in two video clips. These videos introduce the robot, a Innok Heros delivery robot [5], showcasing its movement and providing details about its appearance, such as shape and size. Figure 1 illustrates the storyline of both videos. The sequences were filmed at the Technical University of Munich's Garching campus and a neutral, quiet room. A teleprompter was used for consistent speaking speed, and a camera mounted on a tripod ensured smooth footage. Each video consists of clips in the same order, ensuring the robot is visible for approximately equal time. Both videos are divided into five sequences: three showing a speaker and two showing the robot. Consequently, robot images account for about 56% of the videos, while 44% show the narrator. The videos differ in length by approximately three seconds: positive framing video 2:51 min, negative framing 2:48 min. Both videos are included in the digital appendix.

Dependent Variable: We measured the negative attitude toward the robot. To quantify the change in attitude, the attitude before the framing stimulus is compared to the attitude after the framing stimulus. To assess this attitude, the NARS questionnaire was used [8].

Fig. 1. General Video Storyboard, own illustration.

Sample: The required minimum sample size of n=102 for a medium effect size was estimated using G*Power. In total, 110 participants completed the survey. They were recruited online via social media platforms and offline at the faculty. Eight data sets were excluded from the sample: inclusion criteria were the indication of a German language level of at least C1 according to the Common European Framework of Reference for Languages (CEFR) (n=4 excluded), incorrect recall of the robot's shape after watching the video ($n = 4$ excluded). Demographics of the remaining 102 participants are shown in Table 1.

Table 1. Demographics across framing groups. N/A did not disclose their gender.

Group	Mean Age	SD Age	Male	Female	N/A	Mean NARS-pre	SD NARS-pre
Positive	32.04	11.84	18	31	2	2.82	0.63
Negative	33.53	12.96	17	33	1	2.71	0.67

Data Analysis The change in attitudes toward robots (=NARS-delta) was calculated by subtracting each participant's NARS-pre score from the NARSpost score. Resultingly, a positive delta value means the score increased, and the negative attitude intensified. Within the NARS-pre and NARS-post scores, there were no extreme outliers. The scores were normally distributed ($p > 0.05$) for each cell, as assessed by Shapiro-Wilk's normality test. There was homogeneity of variances, as assessed by Levene's test ($p > 0.05$). Homogeneity of covariances could also be assumed, as assessed by Box's test of equality of covariance matrices ($p > 0.001$). The NARS-delta in the positive framing group was normally distributed (Shapiro-Wilk $p = > 0.05$). On the contrary, the negative group violated normal distribution (Shapiro Wilk $p = 0.04$). Therefore, the non-parametric Wilcoxon-Test was computed for the delta values.

3 Results

There is a statistically significant main effect of framing group ($F(1,100) = 0.068, p = 0.0006$) and time (pre/post, $F(1,100) = 4.698, p = 0.002$) on the NARS score. There is a statistically significant interaction between framing group and time on NARS score, $F(1,100) = 22.740, p = 0.01$. The comparisons pre vs. post showed a statistically significant effect of framing for both groups (negative: $F(1,50) = 4.02, p = 0.05$, positive:

$F(1{,}50) = 20.8, p < 0.0001$). Therefore, the alternative hypotheses are confirmed for H1 and H2. The Wilcoxon test showed a significant difference in the NARS-delta (post minus pre-value) between the positive group ($M = -0.2, SD = 0.32$) and the negative group ($M = -0.08, SD = 0.27$) with $W = 1903.5, p < 0.001$. Figure 2 (left) shows boxplots of the NARS-deltas in the framing groups. In the positive group, the median negative attitude score was 2.79 [pre-framing video] compared with 2.57 [post-framing video]. The median did not change in the negative framing group (median = 2.71). The Wilcoxon effect size of $d = 0.4$ can be considered a moderate effect according to Cohen [3]. Figure 2 (right) shows the NARS-deltas connected to the participants' answers on whether they felt influenced by the framing video. Thirty-three participants reported that the framing influenced their opinion, of which n = 28 were in the positive framing group. This aligns with the median shift in the positive group, which is non-existent in the negative group. The majority indicated that the video they watched did not change their attitude toward robots (n = 21 for the positive and n = 42 for the negative variant) or were undecided (n = 6). Participants who indicated that the video did not manipulate them or were undecided (N = 69), were asked how the video could be adjusted to fulfill its intent. The three most often mentioned suggestions for improvement per group are listed in Table 2. Please refer to Table 2 in the digital appendix for the full list of suggestions.

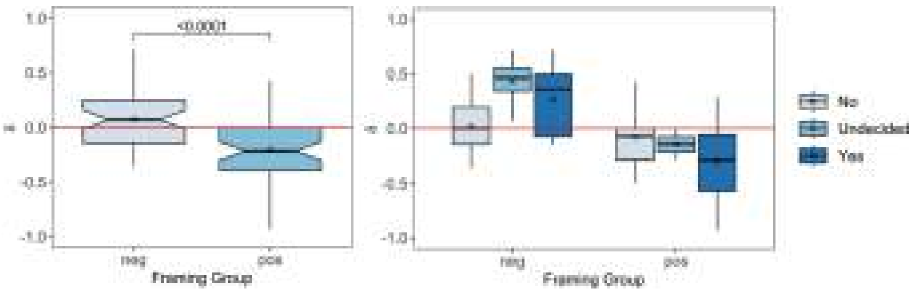

Fig. 2. Left: NARS-delta for the two framing groups. Right: Nars-delta grouped by participants' self-reports on whether they felt influenced by the framing. X = means.

Table 2. Clustered answers on how the framings could be made more effective.

Positive Manipulation	N	Negative Manipulation	N
Show interactions with humans	9	Show a critical situation	14
Show a critical situation	3	Explain disadvantages for workers	12
Show illustrations or graphs	3	Robot design/anthropomorphism	7
		Show collisions/accidents	7

4 Discussion

For this study's sample, the framing was generally effective in altering the participants' negative attitudes toward robots in the intended direction. Positive framing was more effective than negative and is mainly responsible for the significant difference in NARS-deltas between the groups. This aligns with the participants' self-reports, where the majority of the negative group did not feel successfully influenced by the framing videos. Only 5 out of 51 participants reported that the video influenced their opinion negatively (as intended), 42 participants in the negative framing group reported that they felt no impact of the video on their attitude and 4 were undecided. In comparison, 28 out of 51 people in the positive framing group reported that the video had influenced them positively as intended, 21 thought their opinion was not influenced, and 2 were undecided. Many participants criticized that no critical situations were shown in the video. Participants' self-reports on whether they felt influenced aligned well with their actual attitude changes, especially in the positive framing group. Surprisingly, participants in the negative framing group who selected "undecided" had the strongest intensification of negative attitude. This could be because participants possibly felt a stronger dissonance between the negative framing video and their own (possibly more positive) attitude toward robots. The negative information (if perceived as an attempt to manipulate their opinion of the robot in a negative way) was then possibly rejected, preventing an actual negative influence of the video, whereas if the video was not perceived as a negative manipulation intent it potentially had a stronger effect on participants. Whether the subjects followed the video attentively from beginning to end remains unclear, compared to presenting the framing stimulus in a face-to-face situation. It is possible that the video-based framing has less influence on the manipulation since, the subject was not supervised or guided by an experimenter. Another aspect besides the presentation of the framing is the content. The storytelling might not have addressed the participants adequately. The information in the framing video describes the robot as an element in a delivery process and its impact on the process and the workers. It is possible that this reduces the participants' identification with the problems or benefits the robot causes, as MMs describe one's personal conceptualization [2]. Qualitative feedback shows that stronger manipulation would occur when the (dis-) advantages for humans are emphasized more clearly. As the MM is created by persons themselves [10], the impact of robots for the delivery process seems to be of lower interest than a robot implemented into a person's daily routines. For instance, [6] framed workers' perceptions of a robot at their workplace. Since the workers could correspond better to the work context, this caused a change in their MMs. This relation is not necessarily given in this study. The framings are used in a subsequent Virtual Reality proxemics study in which participants indicate their comfort distances to the same robot.

Disclosure of Interests. The authors declare no competing interests.

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Communication of Safety Area Violations in Interactions with Industrial Autonomous Mobile Robots

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Abstract. This paper evaluates communication methods for safety area violations in human-robot interactions with Autonomous Mobile Robots (AMRs) in industrial settings. The study compares auditory, visual, combined auditory-visual communication concepts to each other and baseline without explicit communication. The concepts are implemented on a real robot and used in a within-design study with 33 participants. Results reveal that visual cues are significantly more effective in terms of perceptibility and intelligibility than auditory cues. The combination of auditory and visual signals shows comparable perceived safety and comfort to visual signals alone but with a lower level of frustration than auditoryonly. Overall, trust in the robot significantly increases post-experiment. The paper concludes by highlighting the potential of integrating visual or combined audio-visual cues for communicating safety area violations in AMRs.

Keywords: human-robot-interaction · safety area · autonomous mobile robot · projection · sound · visual · auditory

1 Introduction

This paper addresses a critical challenge in the context of a large and growing market for Autonomous Mobile Robots (AMRs) [13] leading to an increase in human-robot interactions within the industrial sector. Specifically, it focuses on AMRs that will reduce their maximum speed or even stop when detecting an unexpected or dynamic obstacle within their safety area [15]. There are several terms for these zones in the literature and industry.

The ones used here are the stop zone, where the robot will stop completely, and slow zone for the area, where the robot's speed is reduced. A warning zone can also be defined that does not alter the robot's behavior but signals the detection to its surroundings. All of these zones can make up the safety area, although not all robots have all three implemented. Figure 1 shows an overview of the zones. Usually, humans cannot directly see or perceive whether they are approaching or in one of these zones. This lack of awareness can lead to reduced robot efficiency due to the reduction of the robot's speed in proximity to humans [8] and potential frustration among humans. While the significance

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of this research underscores the need to identify communication modalities and concepts best suited for enhancing usability regarding safety areas, the realm of robotics has explored various methods, each offering distinct advantages.

Fig. 1. Safety area zones of an AMR, starting from the innermost: stop zone (red), slow zone (yellow), and detection zone (grey). The size and shape may vary depending on, e.g., the manufacturer and robot speed.

Communication in human-robot interaction can be broadly classified into verbal and nonverbal forms. Verbal communication involves transmitting information, thoughts, and feelings through language in speech and writing [5]. Information, thoughts, and feelings can be transmitted through verbal cues, such as language in speech and writing [5]. On the other hand, exchanging information, conveying emotional reactions, and expressing intentions can also occur through nonverbal communication, that is, non-linguistic means [10].

There are several modalities and communication tools that can be used to communicate an intent from a robot to humans in its surroundings.

Sound-based interaction can involve using the natural operating sounds of robots to provide their internal state [12]. Additionally, synthetic non-verbal utterances such as beeps and musical sounds can be applied to convey intentions and emotions, where pitch, intonation, and timbre are key parameters [3, 7]. Haptics refers to the perception of tactile sensations through contact with the physical world and may also be used by a robot to communicate [2, 14]. Graphical user interfaces can be used to visually communicate information by integrating text, images, and graphics through screens [2], whereas other visualizations use light signals as simple indicators of device status and notifications using color, intensity, and rhythm to provide, e.g., emotional states or messages [3]. Gesturebased interaction uses visible movements of hands, arms, faces, and other body parts to express ideas or meanings [10]. Information about goals, knowledge, and intentions can be conveyed through gaze-based interactions and targeted attention to objects or events [1].

Considering various possible communication tools, especially for visual and auditory cues, the primary objective is to answer the question: 'Which modality of communication is best suited for conveying information regarding safety area violations?' The aim is to assess the effectiveness, comfort, safety, and trust of different communication methods and identify the preferred type to ensure seamless interaction within safety areas.

2 Methods

Our study involved a real robot moving along predefined trajectories. The communication of the safety area was implemented in four concepts: auditory, visual, auditory and visual combined, and a baseline without any additional communication. Our participant study was conducted with n = 33 subjects, with the number of required participants calculated using the G*Power tool beforehand. The visual and auditory concepts were chosen because of their relevance for AMRs in intralogistics. The study used a within-subject design with randomized order to minimize order effects and to ensure a balanced assessment of the different concepts.

To measure the impact of these approaches, we have developed a set of metrics that are collected through questionnaires and interviews. Demographic data forms the basis by providing an overview of the age of the subjects, their field of activity, their previous experience with mobile robots and their general trust in them. Furthermore, signal effectiveness is measured based on perceptibility and comprehensibility, which are queried with four questions. Two open questions are used to investigate whether the signals are perceived and how participants would interpret the robot's intent from them. The other two questions are used to determine how well the safety area limits of the AMR are perceived and to what extent the signals contribute to understanding the safety area limits of the robot. In addition, the NASA TLX [6] questionnaire was used to quantify factors such as frustration and mental load. The standardized questionnaire "Trust in Automation" [11] is used to assess the general trust in the system with the help of six questions. The participants are asked about the reliability of the system, its predictable behavior, knowledge of the system status and the comprehensibility of the system responses. They are also asked whether they trust the system and whether it is difficult to predict its next actions. Furthermore, the feeling of safety and comfort is assessed based on two questions, asking how safe and comfortable the participants felt during the interaction with the robot and its safety area limits. All non-open questions are asked using a five-point Likert scale, while qualitative findings are obtained through open interviews.

Each concept communicates the violation of one of three different zones around the robot: stop zone, slow zone, and detection zone. The size of these zones is carefully determined by stopping tests and supplemented by sufficiently large safety margins to ensure a minimum stopping distance. This is based on a method developed by the company SICK [9] that enables AMRs to calculate their protective field limit. Using formula 1, they determined the size of the stopping zone S_L based on the stopping distance S_A, the general safety supplement (100 mm) Z_G, the allowance for reflection-related measurement errors of the sensor Z_R, the reserve for any lack of ground clearance of the vehicle Z_F and the reserve for the reduction in the braking power of the vehicle Z_B following the relevant vehicle documentation [9].

$$S_L = S_A + Z_G + Z_R + Z_F + Z_B \tag{1}$$

As a result, the robot stops in the stop zone when a LIDAR sensor detects an obstacle. A detection in the slow zone triggers a speed reduction, and a detection in the detection zone activates communication of the safety area.

Four concepts were examined: the baseline concept, which only included implicit communication through a reduction in maximum speed (present in all four concepts); an auditory concept, which relies on sound-based cues only; a visual concept, which employs visualizations; and a combined concept, which combines both previous concepts.

Auditory signals in both the detection and slow zones emit a single tone, while the stop zone emphasizes urgency with three identical tones. Rhythmic changes by increasing the playing speed of the tones when transitioning from larger zones to smaller zones, such as from the detection zone to the slow zone, emphasize the immediacy of the message. The sounds are triggered once each time the outermost limit of one of the zones is undercut and are not triggered again until another zone has been detected. The visual signals consist of circles in red/yellow projected on the floor in front of the robot, as well as projected laser lines on the sides and back of the robot (see Fig. 2).

With objects outside the detection zone, these projections and lasers are inactive. A yellow circle is displayed when entering the detection zone. In addition, red laser lines appear at a distance of around 1 m from the robot to approximately represent the stop zone on the sides and behind the robot. The same visual cues are shown in the slow zone. When entering the stop zone, a smaller red circle appears inside the yellow one (see Fig. 2). Additionally, the laser lines flash three times and then project continuously. Below, we present Table 1 describing the zones, speeds, and sizes of each zone, as well as a diagram illustrating the implementation of our signaling concepts.

Table 1. Overview of individual zones with implemented communication concepts.

Zone	Radius	Communication methods		
		Visual	Auditory	Combined
		3x laser blinking, continuous		
			3x beeping (900 Hz)	
	Stop	1.0 m mode, red and yellow safety		both
			Upon entry	
		Area projection		
		Continuous laser, yellow		
Slow	1.6 m		1x beeping (850 Hz)	both
		safety area projectionContinuous laser, yellow		
Detection	2.4 m		1x beeping (800 Hz)	both
		Safety area projection		

Fig. 2. The robot with the implemented visual communication tools for a violation of the stop zone. Laser lines on the sides and in the back, a projector towards the front.

In Fig. 3, the predefined motion scenarios are depicted. The first scenario involves a person walking towards the robot and passing it. In the second scenario, a person crosses in front of the robot.

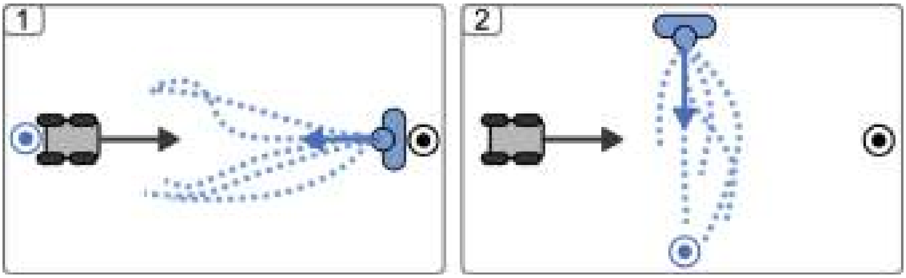

Fig. 3. Setup of the human-robot interaction scenarios as seen from above. Head-on (1) and crossing (2). The shown paths are examples, not recorded trajectories.

The statistical analysis of the study is conducted through SAS Analytics, which uses Null Hypothesis Significance Testing (NHST) to determine significance. Test results are reported, including degrees of freedom, test value, p-value, and effect size through Cohens D.

3 Results

All p-values and Cohens d comparing the different concepts can be seen in Tables 2 and 3. Box plots for each metric and communication concept are shown in Fig. 4.

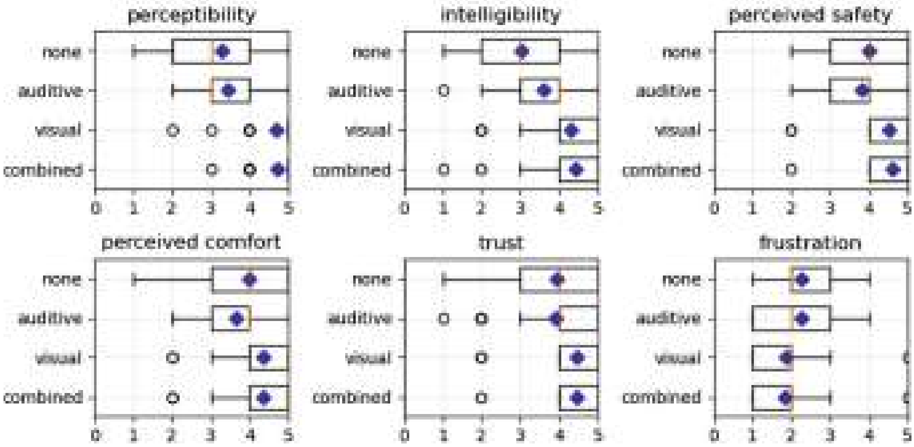

Fig. 4. Box plots of all four communication concepts ("none" = baseline) for six different metrics: perceptibility, intelligibility, perceived safety, perceived comfort, trust and frustration (top left to bottom right). Mean values = blue diamonds, median values = orange bar.

3.1 Signal Effectiveness

The effectiveness of the signals was examined in various dimensions: Perceptibility showed significant differences between visual signals and baseline ($p < 0.001$) and between combined signals and baseline ($p < 0.001$). Notably, the corresponding Cohens d values for visual to baseline $d = 1.45$ and combined to baseline $d = 1.57$ indicate large effect sizes ($d > 0.8$), underscoring the considerable practical significance of these observed differences. In terms of intelligibility, significant differences were found between visual signals and the baseline ($p < 0.001$) and between combined signals and the baseline ($p < 0.001$). With $d = 1.09$ for visual to baseline and $d = 1.16$ for combined to baseline, the respective Cohens d show large effect sizes.

The auditory concept did not differ significantly in terms of perceptibility and intelligibility ($p > 0.05$), and both comparisons with the visual and combined concepts resulted in Cohens d values below 0.5, indicating small effect sizes. The correct perception of the signals was 93.9% for auditory signals, 90.9% for visual signals, 78.8% for combined signals, and 39.3% for the baseline concept. The correct interpretation of the signals was 87.9% for combined signals, 78.8% for visual signals, 75.8% for auditory signals, and 45.5% for the baseline.

3.2 Safety and Comfort

Regarding the perception of safety and comfort, there were significant differences in the perceived safety between visual and baseline concepts ($p < 0.05$) and between combined and baseline concepts ($p = 0.01$). The corresponding Cohens d values for perceived safety revealed medium effect sizes, with $d = 0.53$ (visual to baseline) and $d = 0.66$ (combined to baseline). There were also significant differences in the perceived comfort between visual and baseline ($p < 0.01$), with a small effect size indicated by

Cohens d (d = 0.39). No significant differences and only small effect sizes were found in the perceived safety with auditory communication compared to the baseline ($p > 0.05, d < 0.5$), nor in the perceived comfort with auditory and combined communication compared to the baseline ($p > 0.05, d < 0.5$).

Mental load, according to the NASA TLX, showed no significant differences ($p > 0.05$) between any of the concepts, while frustration was significantly higher with auditory communication than with visual/combined communication (both $p < 0.05$).

3.3 Trust

With regard to the preferred communication concept in terms of trust in the system, there were significant differences found between visual and baseline ($p < 0.05$) and between combined and baseline ($p < 0.05$). The corresponding Cohens d values for trust were $d = 0.56$ (visual to baseline) and $d = 0.59$ (combined to baseline), indicating medium effect sizes.

3.4 Trust Before and After

Comparing the overall trust levels before and after the experiment revealed a significant increase in trust ($p < 0.001$). However, the Cohens d values indicate only small effects, with $d = -0.43$.

3.5 Interviews

Insights gathered from the open-ended questions revealed that participants found auditory signals in human-robot interaction to be challenging, occasionally nonintuitive, and at times unclear. The emergence of unexpected auditory signals upon exiting a protected zone induced a sense of discomfort in n = 3 test subjects. The utilization of auditory signals as warnings did not yield a consistent understanding and, in turn, contributed to a sense of unease in n = 8 participants. N = 2 participants encountered difficulties interpreting the meaning of color markings; however, they expressed that clear projected floor lines were instrumental in aiding comprehension.

Auditory signals proved effective in capturing the attention of n = 6 subjects, complemented by visual projections that assisted in gauging the robot's distance. Participants mentioned that, even when facing away, auditory cues succeeded in diverting attention, prompting participants to swiftly pick up on visual cues and maintain awareness of the robot's position.

4 Discussion

The key findings of our study shed light on the comparative effectiveness of visual and auditory cues, as well as their combination. In our investigation, we discovered a clear preference for visual cues over auditory ones in terms of the perception of safety and comfort.

Table 2. P-values for comparisons of all concepts. Significant effects below 0.05 are marked in bold type. The metrics compared are perceptibility, intelligibility, perceived safety, perceived comfort, trust, and frustration.

Concept 1	Concept 2	Percept.	Intelligib.	Perc. Safety	Perceived comfort	Trust	Frustration
Auditory	Visual	< .001	**0.043**	**0.012**	**0.001**	0.054	**0.030**
Auditory	Combined	< .001	**0.030**	**0.002**	**0.005**	0.060	**0.028**
Auditory	None	0.134	0.078	0.984	0.324	0.842	0.524
Visual	Combined	0.804	0.874	0.473	0.411	0.963	0.972
Visual	None	< .001	**0.001**	**0.011**	**0.006**	**0.033**	0.112
Combined	None	< .001	**0.001**	**0.002**	**0.005**	**0.040**	0.110

Table 3. Cohens d for the effect size for comparisons of all concepts. Strong effects over 0.8 [4] are marked in bold type. The metrics compared are perceptibility, intelligibility, perceived safety, perceived comfort, trust, and frustration.

Concept 1	Concept 2	Percept.	Intelligib.	Perc. Safety	Perc. Comfort	Trust	Frustration
Auditory	Visual	**–1.43**	–0.75	**–0.85**	**–0.85**	–0.60	0.41
Auditory	Combined	**–1.56**	**–0.85**	**–1.04**	**–0.85**	–0.64	0.44
Auditory	None	0.13	0.48	–0.18	–0.38	–0.03	0.00
Visual	Combined	–0.05	–0.13	–0.12	0.00	0.00	0.03
Visual	None	**1.45**	**1.09**	0.53	0.39	0.56	–0.42
Combined	None	**1.57**	**1.16**	0.66	0.39	0.59	–0.45

When the two modalities were combined, they demonstrated roughly equal perceived safety and comfort compared to visual communication only. This combination seemed to alleviate the issue of the communication being perceived as annoying or unclear, which was often associated with auditory-only signals. The choice between visual-only and combined signals for communicating the safety area of AMRs might depend on contextual factors, such as the ambient noise level, frequency of signals in a workday, and the ability to perceive sounds in a given environment.

Our study shows several opportunities arising from the integration of visual or auditory cues in the context of safety communication for AMRs. Communicating safety areas and violations through a combination of visual and auditory signals has the potential to foster understanding, acceptance, and trust among users, indicated by the increased trust rating given after the runs. Furthermore, this integration could contribute to the improvement of workflow efficiency in humanrobot interactions. Robots might not have to stop as much during encounters if their boundaries are known and perceivable by humans in their surroundings. This may, in turn, enable smoother and more efficient interactions.

Despite these opportunities, certain limitations in the study need consideration. Notably, there was a delay of around 0.3–0.5 s between the detection of an object and auditory cues, which was not ideal for such a communication system and may have increased the uncertainty associated with the auditory system. One argument against this theory would be the on-par performance of the combined communication concept compared to the purely visual one. Additionally, it is worth acknowledging that our investigation was based on testing only two specific implementations of auditory and visual communication. As such, the generalizability of our findings to other implementations may be limited, emphasizing the need for further research to explore the broader applicability of these results.

In conclusion, our research underscores the potential of integrating visual or combined audio-visual cues for effective safety area communication in AMRs. By understanding the preferences and nuances associated with each modality and their combination, we can make informed decisions in designing communication systems that enhance trust and transparency of these systems and contribute to the successful integration of AMRs into industrial settings.

5 Outlook

To investigate the true potential of communicating safety areas of AMRs, some questions still need to be answered. Firstly, the timing and type of communication warrants further investigation – should the safety area be communicated constantly or only when triggered by the detection of an unexpected obstacle? This inquiry would aim to understand the optimal balance between continuous awareness and targeted signaling. Secondly, it is still unclear if communicating safety areas can enhance coexistent interactions in terms of efficiency. Exploring the potential impact on human-robot interactions may show value in communicating beyond safety and comfort considerations. Addressing these questions offers the opportunity for valuable insights into the design and implementation of communication systems that not only prioritize safety but also contribute to the seamless and efficient integration of AMR into diverse industrial contexts.

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Adaptive Robot Behavior for Ergonomic Human-Robot Collaborations in Stationary Tooling Tasks

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Abstract. Growing automation needs in industries are likely to increase demand for collaborative robots (Cobots) to work in close proximity with humans. Cobots allow humans to utilize their advantages in terms of flexibility and decision-making capability. However, humans are prone to awkward working postures resulting in work-related musculoskeletal disorders when interacting with these cobots. This seeds the necessity for cobots to anticipate human actions and reconfiguring themselves to support good ergonomic postures during Human-Robot Collaboration (HRC). While addressing the ergonomic implications of a fully compliant (freely adjustable) cobot, this article evaluates and compares the performance of adaptive behaviors in cobots that aim to support good working postures of humans executing stationary tooling tasks. The qualitative and quantitative results of an experimental study conducted in a virtual reality framework were presented in terms of ergonomic evaluations, workload assessments, and usability analysis.

Keywords: Cobots · Adaptive Robotics · Ergonomic HRC · Virtual Reality (VR)

1 Introduction

The concept of Industry 5.0 envisions a transformation of production facilities from data driven automation systems into intelligent, human-centric interactive frameworks [1]. Compared to working with traditional industrial robots, cobots offer improved flexibility, versatility, and safety in HRC applications [2]. To improve work productivity and overall human safety in HRC/HRI applications, adaptive robot behaviors are studied over a broad spectrum of research topics including human safety. As humans can freely adjust cobots in production scenarios, they may tend to work in ergonomically poor postures that might affect their health in the long term. Therefore, there is a need for the development of adaptive robotic systems that support good working postures in humans, while they utilize their advantages in terms of handling tasks that require human agility. In this context, physical ergonomics can be accounted for in task- planning and allocations between humans and their robot counterparts. For instance, Ferraguti et. al. Proposed a unified architecture for HRC applications with industrial robots, initially delivering a

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large workpiece to the human in a manner that enables a comfortable posture in them [3]. Later for subsequent operations, the user had to adjust the workpiece position by manually switching the robot's mode of operation with the help of admittance control and payload compensation algorithms. Instead of implementing ergonomic adaptiveness only in some parts of HRC, Shafti et. al. Proposed a computationally efficient method to optimize human posture throughout the task [4]. This algorithm continuously checks the RULA score of the human arm and responds to the arm sections that leads to an ergonomic score deviation. However, the robot sequentially adjusts its configuration to eliminate any joint angle deviations while the user maintains the tool position at a fixed spot on the workpiece. Extending the capabilities of these robotic systems in dynamic tooling tasks, Zanchettin et. al. Proposed an adaptive HRC framework specific to industrial applications such as flaming of car bumpers [5]. Here, the robot movement would compensate for the human moving the tool around a fixed ergonomic reference frame, and thereby enhancing work productivity (reduced cycle time). Although these HRC frameworks have been proven to improve ergonomics in production processes, it is still crucial to evaluate them to understand human preferences in terms of cobot's adaptability and flexibility in such collaborative working scenarios. Since man-machine-interactions are the epicenter of growing applications with intelligent robotic systems, this article addresses ergonomic implications of the flexibility offered by cobots along with subjective and objective evaluations of their adaptive robot behaviors (during stationary tooling tasks) in terms of physical ergonomics, workload assessments and usability analysis.

2 Methodology

2.1 System Design and Implementation

In manufacturing industries, developers can simulate mechanical operations in VR to evaluate work productivity, optimize shop floor planning and train new workers onboard. These virtual reality frameworks also serve as a platform for human-in-the-loop immersive simulations to evaluate different adaptive robot behaviors in HRC/HRI applications. To evaluate ergonomic implications of cobots in stationary tooling tasks, an interactive demonstrator was developed to conduct VR-based immersive simulations with the help of human avatar visualizations, Digital Twin (DT) models of a laboratory setup and a mobile manipulator holding unwieldy objects. This platform was designed with the help of a Unity game engine, in which immersed participants could work with a virtual cobot, manipulate its configuration and experience collaborations with its adaptive behaviors in autonomous operations. The system design was also suitable for users with minimal working experience in the fields of VR and Robotics. To introduce these topics, audio and visual guides were included in orientation sessions for first time users. This interactive demonstrator was developed with the help of Captury - Motion Tracking software system estimating human body movements and publishing their joint information in real-time. On the other hand, the control architecture built on Robot Operating Software (ROS) framework was subscribed to this joint information of the human avatar. Thereby, the formulated Inverse Kinematics (IK) solutions were published for the virtual cobot to execute planned tasks over a predefined Finite State Machine (FSM) model. These robot reconfigurations and its movements were visualized back to the immersed humans wearing a pair of VR glasses, making this a closed-loop interactive DT demonstrator. Respecting safety concerns during such human-robot collaborations in proximity, the active-modes of robot operations (adaptive or stationary) were determined according to a zone logic, defined in terms of the tracked distance between the virtual machine tool held by the dominant hand of the human avatar and the digital model of the workpiece attached to the cobot's Tool Center Point (TCP).

2.2 Experimental Study

Experiments were conducted with (n = 22) participants to investigate different adaptive robot behaviors with the help of the demonstrator developed for human-in-the-loop simulations. As a part of the experimental design in VR, interactions with cobots in collaborative working scenarios (stationary tooling tasks) were designed for participants to utilize flexibility along with adaptive robot behaviors offered by a virtual mobile manipulator. During the initial set of tasks, participants were asked to screw at different target locations on a large wooden block, while exploiting the flexibility offered by a fully compliant cobot holding such an unwieldy workpiece. In these tasks, participants could adjust the workpiece to a suitable position with their non-dominant hand and use their dominant hand for the screwing task with the help of a joystick visualized as a power tool in the VR game scene. Later over another set of similar tasks, participants were asked to perform similar tooling operations by using their dominant hand alone, whereby they worked together with the same cobot adapting to their body movements to bring them into good ergonomic postures. With audio, visual, and haptic feedback indicating the task progress, human safety aspects were well adopted in these virtual interactions. Over a series of (n = 6) workpieces and each having (n = 10) screwing target locations (sequentially spawned in a randomized order), participant performance in terms of objective (ergonomic scores) along with subjective (usability, workload) assessments were evaluated in these working scenarios. The robot control strategy for these interaction scenarios includes submodules like participant specific optimal pose estimation, calculation of ergonomic scores (REBA), workpiece adjustment (task, path planning) and evaluation of the IK solutions. During participant interactions with a fully compliant cobot, they activate this control framework by triggering the joystick in their non dominant hand. In these scenarios as they reposition the wooden block, they define the intended trajectory of the cobot's TCP in the task space. Thereby, the end-effector poses of the cobot and the corresponding angles of its 6 joints (IK solutions in joint space) are determined, all in real-time. For participant interactions with ergo-adaptive cobot in autonomous operations, the wooden block was brought closer to participants and the following task sequence was determined according to the zone logic defined the FSM model. Here, the anticipating cobot adapts to human actions and eventually freezes into stationary mode to let participants execute their tasks. These adaptive behaviors were confined only to planar adjustments and were defined as a quadratic relationship between the speed of the end-effector and deviation of the actual tool endpoint from the optimal tool endpoint position in task space. The cobot's goal position was determined as an ergonomic window (a 2-D rectangular space, perpendicular to the tool axis) with a predefined threshold around the optimal tool endpoint position, specifically estimated for every individual participant. As participants finish screwing at a current location and move towards the next target, the cobot having no prior knowledge of the target locations inherently moves the workpiece in the direction opposite to that of the tool driven by the participant. Eventually it stops reconfiguring when the TCP has reached the ergonomic window, thereby enabling participants to work in good postures.

3 Results and Discussions

Objective assessments in terms of mean REBA scores for each participant during the whole experiment were evaluated with the lower and upper arms as the main focused body parts for optimizing adaptive robot behavior. Mann-Whitney U-tests ($\alpha = 0.05$) were performed to compare results from both the working scenarios, one with a fully compliant cobot (C) and the other with an ergo-adaptive cobot (A). While these ergonomic scores indicated no significant difference ($p = 0.66$) for the lower arm (C: 1.28 ± 0.19, A: 1.31 ± 0.23), significant decrease ($p < 0.001$) was observed in the upper arm (C: 1.67 ± 0.38, A: 1.12 ± 0.19) and in the overall arm (C: 1.40 ± 0.34, A: 1.10 ± 0.19). Although mean REBA scores of legs were close to an optimal value (1.0), higher scores were recorded for trunk (C: 1.28 ± 0.26, A: 1.17 ± 0.23, $p = 0.12$) and neck (C: 1.51 ± 0.40, A: 1.78 ± 0.32, $p = 0.007$) regions (Fig. 1). Over all, the ergo-adaptive cobot ensured good posture for 89.3% of the time, when compared to 44.6% for the fully compliant cobot.

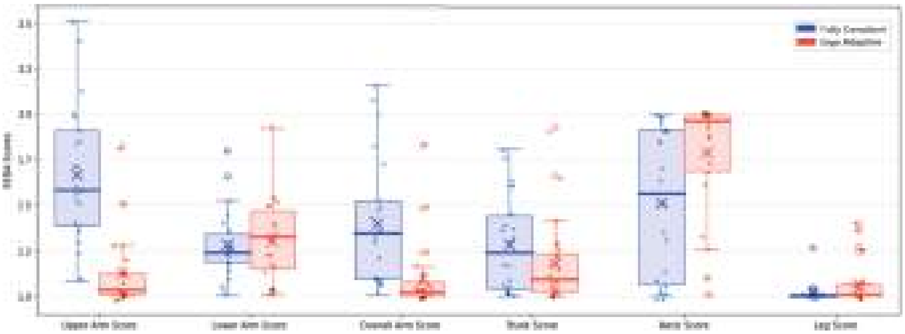

Fig. 1. Distribution of mean REBA scores for each participant (Optimal REBA Score = 1.0)

From subjective evaluations (NASA-TLX) in terms of average workload assessments [6], physical demand (C: 2.05 ± 1.36, A: 2.95 ± 1.52) and temporal demand (C: 2.18 ± 1.07, A: 2.55 ± 1.50) ratings were comparable in both the working scenarios, while mental demand (C: 1.36 ± 0.64, A: 3.23 ± 1.70) and performance (C: 2.64 ± 2.1, A: 3.91 ± 1.56) were rated relatively higher during participant interactions with ergo-adaptive cobot (Fig. 2). To calculate the perceived usability of both the systems, the raw SUS scores were processed over a range [0,100] and adapted to the acceptability ranges as defined by Chacón et. al. [7]. Although all the participants were randomly assigned into two groups with ($n = 11$) participants each, having different order of task execution (to work with fully compliant cobot before ergo-adaptive cobot and vise-versa), the fully compliant cobot was ranked higher in terms of usability (C: 90.23 ± 8.62, A: 51.25 ± 20.33).

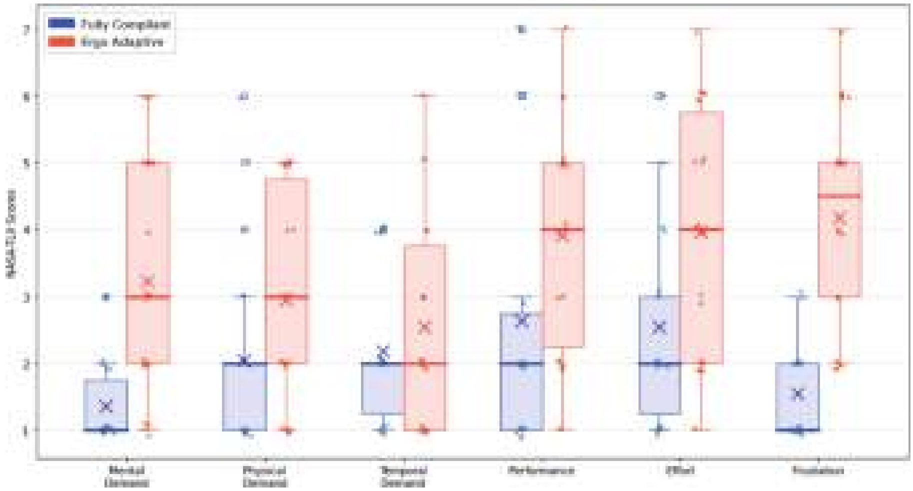

Fig. 2. NASA-TLX Scores for each participant

From these experiments, assessments, and interviews, it was observed that participants quickly learned to use the fully compliant cobot and they did not have an issue with using their non-dominant hand to drag the workpiece around. Despite having the order of the target locations randomized in all the 6 consecutive workpieces, some participants did adjust the workpieces during almost every subtask, while some adjusted them halfway (better postures but not optimal), and some did not adjust them at all. This could be due to lack of ergonomics understanding, negligence, or prioritizing performance (working speed) to good working postures. On the other hand, the adaptive cobot ensured close to optimal ergonomic scores for all the target locations (Fig. 3). Despite good ergonomic results with such an adaptive system, having to wait for workpiece adjustments even for nearby consequent targets was sometimes perceived as slow, counterintuitive, and interfering with human autonomy. However, the proposed adaptive robotic behavior succeeded in improving REBA scores of all the tracked body parts except for neck and wrist of their dominant hand, particularly for targets positioned lower in altitude. In such scenarios to have the virtual machine tool pointed perpendicular to the workpiece, participants tend to move their hand upwards to gain shoulder mobility and attain stable postures. As they moved the tool out of the predefined ergonomic window, the cobot might have moved the workpiece in the direction opposite to that of the tool. This interplay could have led the cobot to place the target at the lower edge of the ergonomic windows during the fine-tuning process, resulting in some participants involuntarily bending their wrist and neck while executing these tasks. Although, some participants simply rotated their wrists by 90 degrees to make the screwing process more comfortable, having a higher optimal endpoint could have been beneficial for users with more range of motion in the downward direction to compensate for the disparity in the vertical adjustment. These issues could be resolved in the future by integrating more holistic strategies for cobots to learn human ergonomic preferences and optimal goal postures in HRC applications. Also, there's still a need to thoroughly explore the influences of various factors on the resulting working postures such as adaptive control gains in cobots, along with refined shape and size of ergonomic windows.

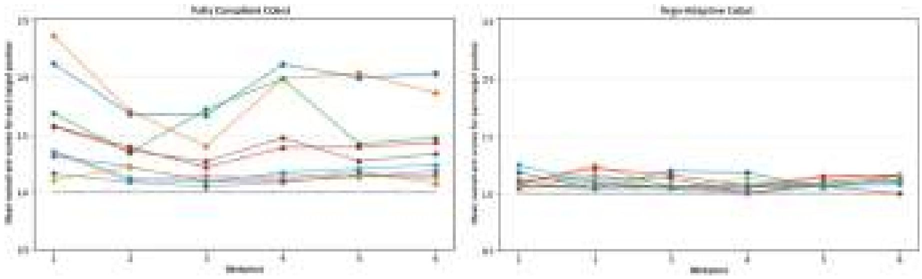

Fig. 3. Mean REBA scores (overall arm) for (n = 10) target positions (Optimal REBA score = 1.0)

4 Conclusions

This experimental study indicated that flexibility offered by a fully compliant robotic system to adjust a workpiece without corrective measures may not be sufficient for ensuring good working postures. As humans might prefer to work in certain postures which may not always be close-to-optimal from an ergonomics point of view, having a hybrid (time-varying) trade-off between ergonomics and human control might improve usability and acceptance of the proposed system. Overall, in terms of posture improvement, these results show the potential of adaptive behaviors in cobots along with more room for further developments and real-life implementations of such HRC applications.

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The Complexity of Teleoperation Systems: A Call for Ergonomic Participation on Every Level

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Abstract. Teleoperation systems are becoming increasingly popular due to the increased availability of suitable and affordable robots. This shift has moved the main challenge in system design from a lack of suitable robots and challenging network conditions to efficient and user-friendly human-machine interaction. Teleoperation systems are complex systems with highly interdependent elements. This paper aims to help researchers and developers achieve a successful human-centered design of user-friendly and effective teleoperation systems by analyzing the structure and interdependencies within teleoperation systems and identifying design challenges from an ergonomic perspective.

Keywords: system design · human-centered design · human-robot interaction · telemanipulation · usability

1 Introduction

Teleoperation allows humans to perform a task remotely using tele-controlled robots. This makes it possible to access locations that are difficult, dangerous, expensive, or physically impossible for humans to reach [5, 7, 9, 19].

Recent interest in teleoperation has increased due to more capable and affordable robots and better network reliability. However, research has lagged in developing accessible and user-friendly interaction designs. Consequently, the primary challenge in system design has shifted from suitable robots and difficult network conditions to creating accessible and user-friendly designs.

The development of teleoperation systems is mainly task-driven, with a variety of technologies available to effectively solve a specific task. However, user skills, knowledge, experiences, and affordances are often overlooked in system design [17], leading to limited usability and unsatisfactory interaction. Some design guidelines exist, such as Falcone et al.'s toolbox for enhancing embodiment in teleoperation [3]. Adamides et al. developed a taxonomy of guidelines for robot teleoperation, focusing especially on

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user interface design and evaluation but disregarding the interdependencies of system elements [1]. Moniruzzaman et al. identified over 70 techniques to improve teleoperation methods, suggesting that cross-domain research can enhance overall performance [12].

The structure of teleoperation systems is complex and involves multiple disciplines with extensive feedback effects between system elements. Most studies have focused on either an element-based evaluation of the human-machine interaction or on whole-system comparisons, often without thorough design justifications. However, optimization towards a local element-based optimum does not necessarily lead to a global system-wide optimum. A structured and holistic approach is needed to create technically efficient and user-satisfying teleoperation systems.

This paper examines the structure and interdependencies of teleoperation systems from an ergonomic perspective. Our goal is to highlight the complexity of these systems and encourage researchers and developers to adopt a holistic human-centered design approach.

2 The Complexity of Teleoperation Systems from an Ergonomic Perspective

Although many break down teleoperation systems into three elements—user interface, communication link, and robot—we argue for a broader perspective to understand these systems fully. Our analysis identifies seven interacting elements, revealing a much greater complexity.

The **task** to be performed and the **environment** where it occurs motivate the use of teleoperation systems, setting requirements on the **robot** and limitations on **network** properties. The network properties influence the control schemes, affecting the suitability of **human-machine interfaces** (HMIs) and the ease for specific **users** to operate the system. In recent applications, **digital twins** allow decoupling of command input and execution and data-based prediction of future states if all system elements are consistently integrated and reliable.

These interactions require careful consideration, impacting design decisions from interface hardware with implicit control schemes to automation and control modes. Therefore, understanding the consequences of design decisions on ergonomic factors is crucial, even for system elements that do not interact directly with the user.

Task. Historically, either the task or the environment motivates the use of teleoperation systems, setting technical requirements for the robot's functionality.

However, task characteristics may require additional actuators and sensors to enhance flexibility, reliability, and comprehensibility. These requirements range from static to dynamic and highly specific to diverse, often involving multiple subtasks needing different functionalities. For example, in complex tasks like surgery, procedures are divided into subtasks, such as cutting, separating, and stitching, each requiring different robot actuators. Different subtasks also imply different signals for task completion, which users must comprehend through different feedback modalities, such as visual, auditory, or kinesthetic cues, determining the necessary and suitable robot sensors.

Although task characteristics are often fixed, assessing and potentially shaping them can ease remote performance.

Environment. The two environments where the user and robot operate limit network solutions and directly impact the task, setting requirements for the robot's actuators and sensors.

Suitable network solutions are constrained by the distance between the user and task locations, affecting latency, and by the physical mediums between them, affecting transmission channels.

The environmental interference ranges from static and non-invasive to highly dynamic and invasive, requiring constant updates of environment, task, and robot states to enable orientation and situation awareness of the user and prompt adjustments to the robot's action plan. While some environments are static and non-invasive, most interact with the task or robot, adding to the task load. For example, a ruptured vessel changes the procedure from a diagnostic examination to a therapeutic treatment. In underwater and aerospace scenarios, currents affect the robot's position, requiring constant adjustment. In rescue and construction scenarios, unstable ground and falling debris require trajectory changes. Likewise, environmental disruptions on the user side can distract them, increasing the risk of errors.

Preventing environmental interference is rarely possible, but its effects can and need to be mitigated. Understanding the different environment states and their transitions is crucial, requiring deliberate design choices regarding suitable control schemes for robot actuators and consistent sensory feedback to enhance situational awareness.

Network. The network establishes and maintains communication between agents by transmitting data from the robot's sensors to the HMI and sending user or digital twin commands to the actuators. Network fidelity is crucial for maintaining the connection between remote and local system elements. However, network properties can change with environmental conditions. If network stability cannot be guaranteed, fallback processes must be designed to prevent destruction during partial connection loss and to restore connection and control of the robot.

The effects of different network properties have been addressed early in teleoperation research. Studies show that higher latency reduces the efficiency of manual control schemes [8]. The limited bandwidth in image data transmission requires balancing frame rate, resolution, and grayscale, affecting image clarity [16]. Thus, designers must prioritize and schedule processing tasks to optimize human-machine performance in constrained and unstable communication scenarios.

Robot. The robot's actuators extend human capabilities in space and user physical capabilities through its specific embodiment [20]. Choosing actuators and designing the robot's embodiment greatly impacts control schemes, devices, and mental models of robot functionalities. Mapping user inputs to robot actions poses a major challenge, requiring careful design to enable intuitive control and correct interpretation of the robot's actions by the user [11].

Robot sensors gather data on the robot's current state, the task, and the environment, which is especially crucial in remote locations where the robot is the primary data source. Selecting sensors that provide the necessary information in the right quality and at the right time is crucial. Redundant sensor data must be presented consistently. Inconsistencies must be resolved or highlighted by the digital twin or the HMI to help users understand potential issues.

Digital Twin. A digital twin automatically collects and integrates information from connected system elements, acting as a comprehensive intermediary as more elements are integrated. Beyond a mere representation of states, in model-mediated teleoperation systems, it acts as an intelligent coordinator by allocating tasks in shared control schemes, decoupling command input from execution until triggered by events or system states, enhancing system stability and transparency by substituting incomplete data, and predicting consequences of command execution [21].

The functionalities and responsibilities of the digital twin depend on network properties, technical reliability, and integration level of system elements. High integration can effectively support human-machine interaction by providing relevant information to the user at the right time. However, inadequate integration and unclear communication of functionalities can distort signals, add complexity, confuse and frustrate users, and potentially disrupt the task, environment, and robot.

Human-Machine Interface. The HMI receives user control inputs and provides feedback from the robot, environment, and digital twin. Designing an HMI for teleoperation systems is complex due to intertwined decisions about technology, control schemes, and mapping.

Control schemes range from direct/manual to shared and autonomous for each robot function. Each function must be distinguishably mapped to a specific (set of) action(s)/command(s) from the user through a device or technology (e.g., gesture and voice recognition). The most common control input devices are video game controllers with buttons and joysticks, leader/follower systems, and direct human-as-the-master/follower systems [2, 4, 6]. Studies comparing devices show no universally superior solution due to task and robot variability. Unfortunately, most studies on teleoperation systems lack a clear rationale for applied devices, control schemes, and mappings. In addition to suitable input controls, the HMI must also provide consistent feedback from the robot, environment, and digital twin to the user, using effective sensory modalities in separate or integrative control devices.

User. In traditional teleoperation applications, users are typically experts, such as surgeons, pilots, or astronauts, and hence are extensively trained to compensate for usability shortcomings through practice. However, as teleoperation expands into broader applications such as healthcare, manufacturing, and hybrid conferencing, it targets non-expert users who vary in training, technical background, experience, expectation, and frequency of use [15]. These users require more intuitive and efficient systems, necessitating design considerations that accommodate diverse user characteristics and mental models with respect to the mapping, control, task, and alignment of robot representation [13, 14, 18]. Recent studies support the argument that control schemes must be personalized to defined user characteristics to address different mental models [10, 18].

Many teleoperation system designs involve users late in the process, primarily during final system evaluations. By then, critical design decisions like control schemes and input mappings are typically fixed and costly to change. Molnar et al. advocate for a shift in approach, prioritizing user preferences early by identifying preferred mappings and designing adaptable control interfaces using simulation methods [10]. This approach reflects a promising step towards a more holistic design strategy aimed at addressing the system's complexity across all disciplines involved.

3 Conclusion

This paper delves into the inherent complexity of teleoperation systems, decomposing them into seven elements from an ergonomic standpoint and highlighting design challenges. While many teleoperation systems prioritize technical aspects, their impacts on users are often overlooked. Designing these systems requires a conscious selection of technologies that account for feedback loops and effects between design choices to avoid placing the burden of effective human-machine performance on the user. The analysis emphasizes the importance of an interdisciplinary approach that integrates the ergonomic perspective to optimize system performance and mitigate adverse effects across elements.

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The Cognitive Impact of Back-Support Exoskeleton Use on Hazard Identification and Brain Activation

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Abstract. This study aims to investigate the effect of exoskeletons on workers' cognitive processing during hazard identification tasks after physically demanding construction lifting tasks. To do so, a within-subject experiment was designed with 10 participants. They completed hazard identification tasks for various construction scenarios before and after performing lifting tasks for a specified duration, both with and without the exoskeleton. Brain activities in left and right dorsal prefrontal cortex (DLPFC) were measured and functional connectivity of the area was conducted using functional near-infrared spectroscopy (fNIRS). The results indicated significantly higher DLPFC activation during the cognitive tasks post-lifting with an exoskeleton ($p = 0.013 < 0.05$) compared to the same activity without an exoskeleton. The finding suggests that wearing exoskeletons could enhance cognitive processing and hazard identification performance by mitigating both physical exertion and mental load. This study provides valuable insights into the benefits of exoskeletons in construction settings, highlighting their potential to reduce fatigue-related cognitive decline and improve overall safety performance.

Keywords: Neuroergonomics · Back-support exoskeleton · Construction safety

1 Introduction

An exoskeleton is a wearable robotic device designed to enhance the wearer's movement with its sturdy sculpture and power or springs-assisted mechanisms [1]. It has been applied in industries requiring intensive physical activity [2] One of the sectors that can potentially benefit from exoskeleton is construction, where workers face high rates of work-related musculoskeletal disorders due to manual and repetitive work [3]. While previous studies have verified the validity of the physical assistance of exoskeletons in construction tasks [4], their cognitive compatibility with users remains unknown.

Due to dynamic site conditions, attention and working memory are critical for maintaining safety on construction sites. Identifying hazards within a dynamic construction jobsite is a cognitively demanding task for workers. Despite recent advancements in the industry regarding the use of exoskeletons, there is a lack of research on the cognitive

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impact of exoskeleton use, particularly concerning situation awareness and timely hazard identification. Therefore, using fNIRS, this study examines the cognitive impact of the exoskeleton based on the changes in brain activation and functional connectivity of DLPFC, known for its role in analytical thinking and problem-solving [5], during cognitive tasks following physical activities proceeded. The findings shed light on the importance of considering the use of exoskeletons in physically demanding and hazardous work environments to enhance the adoption process.

2 Methods

2.1 Experimental Design

The within-subject experiment, including the hazard identification and repetitive lifting tasks, was conducted over two days (Fig. 1). Participants were asked to wear fNIRS cap for the entire experiment. **Cognitive Task – Hazard Identification** For each hazard identification task, while resting their head on a chin rest, participants were asked to search for hazards in seven construction scenarios for 30 s while their visual attention toward hazardous areas of interest (AOI identified by safety managers) have been continuously monitored using a Tobii III Mobile Eye-Tracker. They were then required to verbally report identified hazards (i.e., ladder, elevated platforms, unprotected edge, and uncovered opening) in 30 s. Hazard identification tasks were conducted pre- and post-lifting tasks, each day with and without an exoskeleton. **Physical Task – Repetitive Lifting** Participants were asked to repetitively lift concrete blocks weighing 18 lb, for six minutes under the rhythm of a metronome set to adagio tempo. In the lifting setting, positions for placing the desk and feet were marked with tape to ensure all participants' consistency in the experimental setup. **Post-Experiment Survey** To define participants' subjective assessments of their physical and mental stress using NASA-TLX and the Borg Scale.

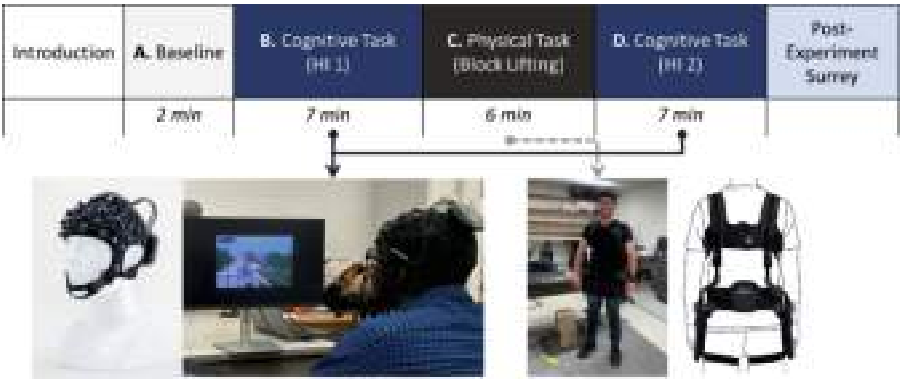

Fig. 1. Experimental design (HI: Hazard Identification)

2.2 Apparatus

A wireless fNIRS (Brite) device was used to measure left and right dorsal prefrontal cortex activation during cognitive and physical tasks. The fNIRS cap included four transmitter optodes to transmit near-infrared light at wavelengths from 730 nm to 850 nm, with a sampling frequency rate of 10 Hz, and four receiver optodes to receive the light, all three centimeters apart. During the physical tasks, a back support passive exoskeleton, Paexo Back (Ottobock), was used after adjusting its size for each participant.

2.3 Data Analysis

Raw fNIRS data was processed using the Homer 3 package for optical density conversion and bandpass and wavelet filters for noise reduction. The modified Beer-Lambert Law was then used to calculate oxyhemoglobin for each channel. This study only focused on oxyhemoglobin because it is less affected by cross-talk than deoxy-Hb [6]. The general linear method (GLM) was then applied for hemodynamic response function calculation [7]. For the statistical comparison of brain activity at each condcition (i.e., physical task, cognitive task pre-lifting, and cognitive task post-lifting), both with and without exoskeleton conditions, a permutation-based approach with 10,000 resampling iterations was employed. Pearson's correlation matrices were applied to compare the functional connectivity of conditions. In addition, the hazard-identification index (HII: number of identified hazards by participants over the total number of hazards in the scenario) was utilized to measure subjects' hazard identification skills.

2.4 Participants

Ten male civil engineering students with an average of 3 years of construction work experience were recruited for the experiment. Their average age was 29.40 $\pm$ 3.10 years (Mean $\pm$ STD), height 176.12 $\pm$ 2.73 cm, and weight 74.34 $\pm$ 9.86 kg. All participants reported no history of lower back injuries or eyesight problems. The study procedures were approved by the Purdue Institutional Review Board (IRB-2023-804).

3 Result

3.1 Changes in Cognitive Response

The average Oxy-Hb concentrations for participants during cognitive and physical tasks in each condition are presented in Table 1. A substantial decrease in DLPFC activation was observed in cognitive task post-lifting compared to cognitives task pre-lifting at both without exoskeleton condition, where the right DLPFC present a slightly more significant reduction than the left. Decreased HbO levels suggest reduced neural activity and engagement in cognitive functions due to less active neurons requiring less oxygen [8]. In contrast, in the exoskeleton condition, the left DLPFC showed an increased activation in the cognitive task post-lifting. While the right DLPFC demonstrated decreases in both conditions, it is less pronounced in the exoskeleton condition.

Table 1. DLPFC Activation (Oxy-HB concentration × 10^{-3})

Condition	Brain Region	Cognitive Task Pre-Lifting	Physical Task: Lifting	Cognitive Task Post-Lifting
Without Exoskeleton Condition	DLPFC	1.79	10.02	–12.16
	lDLPFC	2.07	9.68	–11.97
	rDLPFC	1.51	10.37	–12.35
With Exoskeleton Condition	DLPFC	2.48	7.01	2.38
	lDLPFC	1.51	7.44	4.65
	rDLPFC	2.66	8.66	–2.01

The results of the permutation test indicated that there are significant differences in brain activation (1) between cognitive tasks pre-lifting and post-lifting in the without exoskeleton condition (p = 0.005 < 0.05) and (2) between with and without exoskeleton conditions in the cognitive task after lifting ($p = 0.013 < 0.05$). Further analysis revealed significant differences in brain activation between with and without exoskeleton conditions during the cognitive task conducted after lifting in both the left and right DLPFC – Fig. 2. (No significant differences were found between cognitive tasks pre and post-lifting in the exoskeleton condition ($p = 0.557 < 0.05$) and between physical task during the with and without exoskeleton conditions ($p = 0.645 < 0.05$) during lifting.)These findings suggest that substantial DLPFC brain activity is observed during the cognitive task following physical activity without the exoskeleton. In contrast, during the physical task itself, no significant difference in brain activation was observed between the exoskeleton and non-exoskeleton conditions.

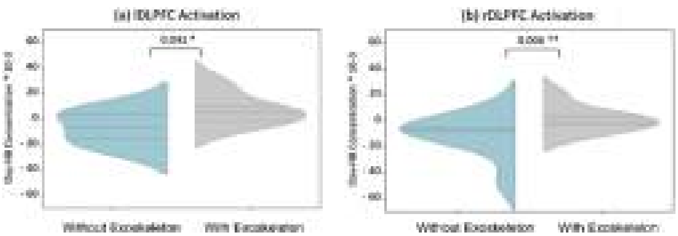

Fig. 2. DLPFC activation during cognitive tasks post-lifting (*: $p < 0.05$ and ** $p < 0.001$)

3.2 Functional Connectivity and Performance Metrics

Functional connectivity between left and right DLPFC channels among cognitive tasks pre and post-lifting was calculated to gain insights into the brain's functional adaptability shown in Fig. 3. Notably, connectivity between left and right DLPFC during a cognitive task post-lifting in without exoskeleton condition showed the highest correlation and frequent brain connectivity in the prefrontal region, while other three conditions presented comparably similar rates of correlation.

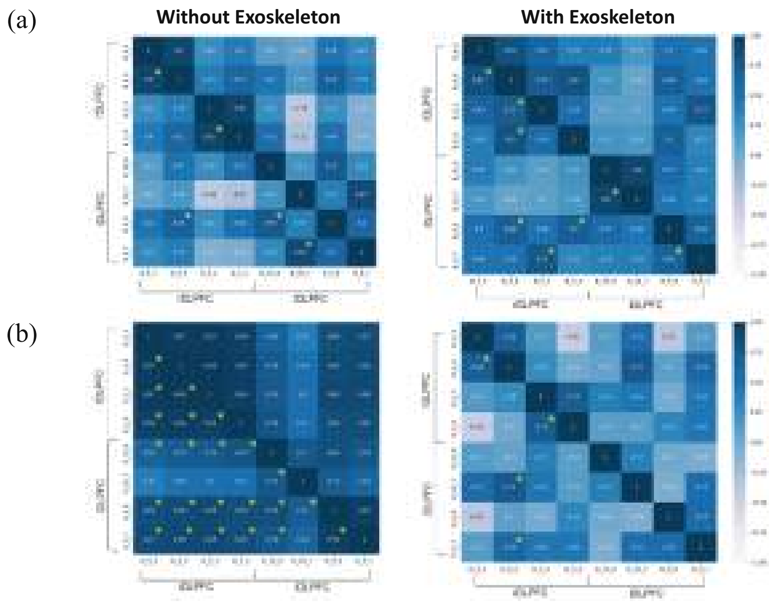

Fig. 3. Functional connectivity during cognitive tasks. *p*-values $<$ 0.05 are marked with an asterisk. (a) cognitive tasks pre-lifting and (b) cognitive tasks post-lifting.

In addition, the hazard identification task performance increased with using exoskeleton during lifting ($\text{Mean} \pm \text{STDW}_{\text{Without exoskeleton condition}} = 21.28 \pm 8.80$; $\text{Mean} \pm \text{STD}_{\text{With exoskeleton condition}} = 25.58 \pm 10.50$). NASA-TLX results showed reduced mental (5.17%), physical (7.62%), and temporal demands (19.22%), frustration (19.55%), and effort (6.53%), with a 10.42 increase in performance. The Borg test indicated lower physical exertion, particularly in the lower back, with exoskeleton use.

4 Discussion

The study found that the exoskeleton condition had higher DLPFC activation during cognitive tasks performed after lifting, compared to the without exoskeleton condition. Generally, physical movement causes heavy breathing and restricts the blood flow to the brain, leading to mental stress, and subsequently affecting physical performance [9]. Xing et al. [10] evaluated this phenomenon in the construction setting, showing that high physical fatigueno can contribute to mental fatigue and impact the following cognitive task, even with low cognitive load. The findings of this study are well-aligned with previous literature indicating that the exoskeleton assistance prevented further physical exertion, leading to alleviating mental stress.

Despite the use of the exoskeleton during lifting task, a reduction in rDLPFC suggests residual effects from the physical exertion in the previous stage. This shows that the exoskeleton can minimize physical exertion but cannot completely prevent it. The reduced activation in rDLPFC is associated with attention and spatial working memory, which is compensated by increased activation in lDLPFC, which is responsible for logical reasoning and problem-solving. Additionally, connectivity during cognitive task post-lifting tasks in the without exoskeleton condition was higher and more frequent, supported by the result of the previous studies that intensive exercise changes neurotransmitter levels and blood flow regulation with increased recruitment of neuron firing patterns [11]. Therefore, connectivity increases in specific brain regions during mental fatigue, serving as a compensatory mechanism to sustain attention and cognitive functions [12]. These findings indicate that exoskeletons can mitigate both physical exertion and mental load and increase workers' safety performance eventually.

5 Conclusions

This study examines the cognitive impact of using exoskeletons (measured by changes in hazard identification) in physically demanding lifting tasks, focusing on functional connectivity and brain activation in the prefrontal cortex. Exoskeletons can potentially facilitate cognitive processing in the left and right DLPFC after a physical task by minimizing physical exertion and improving hazard identification ability. These findings provide insights into the benefits of exoskeletons that can enhance safety and performance by reducing fatigue-related cognitive decline in construction activities.

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Fostering Human Agency and Autonomy in Human-Robot Interaction: An Interdisciplinary Approach for Industry 5.0

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Abstract. Industry 5.0 aims at harmonizing increased innovation, efficiency, and productivity in production through the alignment of advanced technologies with environmental sustainability, resilience, and the well-being of industrial workers. In this context, maintaining human agency and autonomy is crucial, especially in the face of increasing automation in production. This is particularly true for human-robot-interaction (HRI) as robots and their tools collaborate with humans in closest proximity as partners. Therefore, this article focuses on fostering human agency and autonomy in HRI. Our approach considers psychological, ergonomic, human diversity, ethical and engineering aspects. As a result, we provide an interdisciplinary and user-centered approach that facilitates the creation of supportive conditions for human agency and autonomy within HRI. This actionable approach supports stakeholders in research and industry who seek to enhance human agency, autonomy, and usability in Industry 5.0.

Keywords: industry 5.0 · autonomy · human agency · user-centered design · digital transformation

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1 Introduction

Industry 5.0 shifts the technological focus of Industry 4.0, by prioritizing broader societal goals and emphasizing human-centricity, sustainability, and resilience. It does so by envisioning humans as valuable collaborators with smarter machines and processes [1]. HRI plays a crucial role in this shift, as humans and robots leverage their respective strengths to optimize overall performance. The goal of this paper is to explore the role of human agency and autonomy in relation to such human-machine dynamics from an interdisciplinary perspective [2]. To this end, we clarify agency and autonomy in HRI and propose an approach to implement, evaluate, and optimize HRI that integrates perspectives from psychology, ergonomics, diversity-sensitive science, and technology studies (STS), ethics, and engineering. We explore key factors affecting human agency and autonomy across these dimensions. Aligned with the goals of the Internet of Production (IoP), our approach emphasizes human-centric manufacturing by aligning human and machine capabilities [3].

1.1 Perspectives on Human Agency

Human agency, a term used in various disciplines such as psychology, ergonomics, STS, ethics, and engineering, describes how individuals influence their surroundings. It emphasizes self-causation, individual control, and decision-making power [4]. By fostering agency, human involvement in routine tasks and complex decision-making is recognized, enhancing personal responsibility and job satisfaction. Various definitions of agency exist that include social action levels, autonomy, and intentionality. From psychological and ergonomic standpoints, agency encompasses cognitive, volitional, and behavioral capacities crucial for purposeful interactions in the work environment [5, 6]. Ethically, agency ranges from the basic capacity to act with purpose or intention to more sophisticated guidance by one's commitments or values [7]. In engineering terms, it enables user control and customizable interactions with systems [8]. A comprehensive understanding requires collaboration across the disciplines, ensuring alignment with psychological considerations, ergonomic principles, and diversity-related, ethical, and technical standards in HRI.

1.2 Perspectives on Autonomy

Like human agency, autonomy is a key concept in many research areas. Autonomy denotes the level of self-governance a system or entity has. In smart factories, autonomy typically applies to machines, robots, and automated systems, measuring their independence from human intervention. Psychologically, it acts as a basic psychological need, promoting intrinsic motivation and well-being. Autonomy and agency are intertwined with autonomy linked to acting in line with one's values [9]. Ethically, autonomy involves guiding behavior by core commitments and values, and is susceptible to internal and external threats [10]. In engineering terms, it signifies system independence, ranging from partial automation to full autonomy. Balancing human and system autonomy is vital for effective HRI, ensuring productivity without sacrificing human scope for decision-making and control.

1.3 The Interplay of Human Agency and Autonomy

Though distinct, human agency and autonomy are deeply intertwined, particularly in human-technology-interaction [4]. Autonomy can be viewed as a sophisticated form of agency characteristic of humans, in which one's actions are guided by one's core commitments and values; it is thus more than merely purposive agency [11]. Both concepts, however, frequently highlight activities and decision-making that are aligned with personal values, foster innovation, and are strongly related to job satisfaction. In the following, we elaborate on key factors from the perspective of different disciplines and then derive an interdisciplinary approach for optimizing HRI for human agency and autonomy.

2 Key Factors Determining Autonomy and Agency in HRI

To foster autonomy and agency in HRI from a ***psychological viewpoint***, it is essential to understand users' trust, attitudes towards privacy, technology literacy and preferences. User preferences, especially autonomy and the degree of control within the interaction, significantly influence the HRI experience, while trust in robots and attitudes towards privacy are important factors in user acceptance [12]. In addition, HRI design improvements that enhance trust and address users' attitudes towards robots can influence autonomy and agency. Moreover, technology literacy shapes users' proficiency, a vital dimension in HRI design and implementation [13]. ***Ergonomic*** considerations in HRI include both stable and situational factors. Stable, worker-specific factors, such as body dimensions and preferred practices, complement situational, interaction-specific factors like worker-robot positioning and current movements. The combination of these inputs enables digital human models for ensuring health and safety, and enhancing collaboration [14, 15]. Deliberations from ***Science and Technology Studies (STS)*** underscore the importance of diversity analyses throughout the HRI design and testing phases to ensure agency and autonomy in psychological and ethical terms for all individuals during HRI. Recognizing physiological diversity, such as mobility and age, promotes socially responsible interactions. Failure to integrate diversity dimensions risks exclusion and potential harm, highlighting the need for inclusive design practices [16, 17]. ***Ethical*** deliberations consider the value of human autonomy and the opportunities and risks it presents with respect to HRI. Avoiding problematic manipulation and protecting informational privacy is essential for fostering autonomy in data-intensive HRI environments, necessitating robust consent mechanisms and clear data usage policies [18, 19]. From an ***engineering*** standpoint, HRI evaluation focuses on process effectiveness, safety requirements, feasibility, and product quality. However, assessing safety requirements poses inherent risks, requiring vigilant monitoring and adaptation to unforeseen circumstances [20].

Interdisciplinary Approach. Next, we develop an approach that aims to create supportive conditions for human autonomy and agency within the HRI. Based on the interdisciplinary perspectives outlined above, key factors are identified that are crucial for a balanced and effective integration of human agency and autonomy and are gathered by, e.g., interviews, surveys, and technical data reviews.

Table 1. Interdisciplinary user-centered approach for industry 5.0.

Phase	Discipline	Methodological Approach
Requirement Anal.	Psychol.	Conduct interviews and focus groups to explore user preferences, trust, and privacy related attitudes towards HRI systems
	Ergo.	Assess physical attributes such as body dimensions and ergonomic requirements to ensure comfort and safety in HRI
	STS	Perform diversity analyses to address the needs of diverse user groups and ensure inclusivity in HRI design and implementation
	Ethical	Consider ethical implications related to manipulation, informed consent, and data usage
	Eng.	Identify technical req. and feasibility considerations for HRI systems, including safety req. And compatibility with industry standards
Concept development	Psychol.	Incorporate insights from user interviews and focus groups to inform the design of user-centered HRI systems
	Ergo.	Design intuitive and user-friendly HRI interfaces via cognitive ergonomic eval., considering workload and decision-making
	STS	Mainstream human diversity into all disciplines relevant to HRI to establish diversified data sets, which foster inclusivity and usability
	Ethical	Develop clear principles for ethical data collection, storage, and usage to protect user autonomy and privacy
	Eng.	Design HRI systems meeting safety and feasibility criteria, considering workspace and robot capabilities
Prototype Dev.	Psychol.	Prototype HRI systems reflecting user preferences, trust and privacy considerations identified during requirements analysis phase
	Ergo.	Develop digital models or physical prototypes to optimize comfort and safety in HRI based on ergonomic evaluations
	STS	Develop prototypes that can deal with diversified data sets and users
	Ethical	Introduce mechanisms for avoiding manipulation, obtaining informed consent, ensuring ethical data use in line with established principles
	Eng.	Build functional prototypes that meet safety requirements and demonstrate technical feasibility, integrating digital shadow techniques for real-time monitoring and optimization

(*continued*)

Table 1. (*continued*)

Phase	Discipline	Methodological Approach
Evalution	Psychol.	Evaluate prototypes through user testing and feedback collection to assess user satisfaction and acceptance of HRI systems
	Ergo.	Conduct ergonomic evaluations of prototypes to identify areas for improvement in physical and cognitive interaction aspects
	STS	Establish a pre- and post-testing protocol via diversity analyses
	Ethical	Assess prototypes for adherence to ethical principles related to human autonomy, informed consent, and data usage
	Eng.	Evaluate prototypes for safety, effectiveness, and compatibility with industry standards, utilizing technical assessments and risk analyses

By involving users throughout the design and implementation process, systems can be refined to meet users' needs, preferences and expectations while considering their attitudes, capabilities, and limitations. Based on these, our interdisciplinary approach for the optimization of HRI is orientated on the four iterative steps from ISO 9241-210: requirements analysis, concept development, prototype development, and evaluation. Each step integrates considerations from the different perspectives to ensure that user needs are prioritized, employee safety and comfort are optimized, ethical principles are adhered to, and engineering requirements are met (see Table 1). Iterating prototypes based on user feedback enables the continuous improvement of HRI to ultimately enhance human agency and autonomy in Industry 5.0.

3 Discussion

From an interdisciplinary perspective, this article discussed factors that promote human agency and autonomy in the context of HRI. By integrating insights from psychology, ergonomics, STS, ethics and engineering, a comprehensive set of requirements and methods needed to optimize HRI was collected and integrated into an interdisciplinary, user-centered approach. Based on the current state of HRI research, this work took a holistic approach that recognizes the multi-faceted nature of HRI and the need for a user-centered design approach. It shows that from a psychological perspective that user preferences, trust, privacy attitudes, and technical literacy are crucial for the design of user-centered HRI systems. From an ergonomic perspective, robust data about individual workers and situational data capturing interaction with robots must be integrated into digital human models to optimize working conditions and ensure worker safety and comfort. From an STS perspective, diversity and inclusion aspects need to be considered throughout the design and testing phase to promote socially responsible and non-exclusionary human-technology interactions. From an ethical perspective, HRI promises to foster human autonomy by empowering human participants, but this requires protection against problematic manipulation and violations of informational privacy. From an engineering perspective, the evaluation of process efficiency, safety requirements, technical feasibility and quality characteristics of the manufactured products are of utmost importance for the development of user-friendly HRI systems. Our approach is essentially an interdisciplinary perspective anchored in the principles of user-centered and participatory design and supported by methods from the fields of psychology, ergonomics, STS, philosophy, and engineering. It enriches our understanding and application of HRI in the digital transformation of production. Integrating insights across disciplines ensures that HRI systems are both technically robust and consider human factors, user preferences, ethical considerations, and technical requirements prioritizing human agency and autonomy. This approach enhances inclusivity, efficiency, and social responsibility in production environments and thus contributes to the vision of Industry 5.0.

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Safety and Health (I)

Reference Values for Elbow Joint Flexibility in Children

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Abstract. This study established reference values for elbow joint flexibility in children and examined the effects of age, gender, ethnicity, and anthropometry on elbow joint flexibility. Statistically significant differences in elbow joint flexibility were observed based on age, gender, and ethnicity. However, all the observed differences are clinically insignificant ($<10^{\circ}$). Body weight was observed to be the most significant anthropometric parameter associated with elbow joint flexibility in children.

Keywords: Elbow · Children · Range of Motion

1 Introduction

Several abnormalities have been reported in medical literature that affect elbow joint flexibility in children. These abnormalities can be either due to acquired or genetic conditions [1, 2]. Reference values for extremity joint flexibility are required for developing rehabilitation targets for children suffering from extremity joint impairments [3, 4]. However, previous studies on elbow joint flexibility have mainly focused on American [1–3], and Australian [4] children and cannot be generalized to children from other ethnicities as ethnicity has been observed to affect elbow joint flexibility [1]. Hence, this study was undertaken to establish reference values for elbow joint flexibility and to determine the effects of age, gender, ethnicity, and anthropometry on elbow range of motion (ROM) in children.

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2 Methodology

The number of children required for this study was determined according to the ISO 15535 standard [5] to be a minimum of 274 children at 2% relative accuracy and 95% confidence interval. A total of 295 children aged 1–12 years participated in the study that was conducted at six schools in Al Ain and Abu Dhabi, United Arab Emirates (UAE) between October 2023 and May 2024. Ethical approval was obtained from UAE University's Human Research Ethics Committee (ERH_2022_1306_15).

The passive (PF) and active elbow joint flexion and extension ROM was measured using an electro-goniometer (Vernier, Beaverton, USA) according to the protocol established by Norkin and White [6]. The measurements were obtained by a trained research assistant from the left elbows of the children. Additionally, the left elbow ROM data of American children provided by [3] corresponding to the age group of the current study was extracted for comparison with the data obtained in the current study. ROM is taken as the complete arc of motion of the elbow joint (total flexion plus total extension).

Five anthropometric parameters were measured in the children according to the guidelines established by the National Health and Nutrition Examination Survey for children [7]. These measurements include standing height, body weight, waist circumference (WC), shoulder-elbow length (SEL), and elbow-hand length (EHL).

The study sample was characterized by descriptive statistical analysis. Reference values were established for each age group and gender. Inferential statistical analysis including Two Sample t-test, Pearson's Chi-squared test, Pearson's correlation analysis, and independent t-test were performed as appropriate. The level of significance was set at 5%. All the analyses were performed using R (Version 4.3.0).

3 Results

Table 1 presents the demographic characteristics of the children involved in this study. Majority of the children were boys (50.5%) and of Arab ethnicity (67.5%). No significant difference was observed in ethnicity between both genders ($p = 0.384$). The average age of the children was 5.9 years while their average BMI was 16.8 kg/m^2 with no significant difference in both age ($p = 0.430$) and BMI ($P = 0.543$) between boys and girls.

Active flexion (AF) and active ROM (AROM) were higher in the adolescent age group for both boys and girls while both passive (PE) and active extension (AE) were greater in the children age group for both genders (Table 2). The biggest difference was observed in passive ROM (PROM) with children having 7° more PROM compared to adolescents. All the differences observed between children and adolescents were between 0° to 7°.

Passive elbow joint flexibility was observed to be significantly greater than active elbow joint flexibility (Table 3) in terms of extension ($p < 0.001$), flexion ($p < 0.001$), and ROM ($p < 0.001$). Children were observed to have significantly higher active ($p = 0.018$) and passive ($p = 0.039$) elbow extension as well as PROM ($P = 0.004$) while adolescents had significantly greater active elbow flexion ($P = 0.003$) and AROM ($P = 0.042$). No significant difference was observed in passive elbow flexion ($p = 0.108$) between children and adolescents (Table 4). Boys were observed to have significantly

Table 1. Demographic Characteristics of Children in the Study

Characteristics	Gender				p-value
	Girls		Boys		
	N	%	N	%	
Age Group					0.873
1–9	118	83%	124	83%	
10–12	25	17%	25	17%	
Ethnicity					0.384
Arab	92	64%	107	71%	
South Asian	38	27%	34	23%	
Others	13	9%	9	6%	
Age (years), Mean (SD)	6.1	(3.0)	5.8	(3.0)	0.430
BMI (kg/m^2), Mean (SD)	16.7	(3.3)	16.9	(3.1)	0.543

Table 2. Reference Values for Elbow Joint Flexibility in Children

Elbow ROM#	Age Group	
	Children*	Adolescents*
Boys		
Passive Flexion	145.3 (144.2, 146.4)	145.9 (143.5, 148.2)
Active Flexion	134.0 (132.9, 136.0)	139.0 (137.1, 140.9)
Passive Extension	–7.5 (–8.5, –6.5)	–6.9 (–9.0, –4.7)
Active Extension	–2.9 (–3.9, –1.8)	–2.8 (–4.6, –0.9)
AROM	138.0 (136.9, 139.9)	142.0 (140.2, 144.8)
PROM	153.0 (151.6, 154.2)	153.0 (149.7, 155.8)
Girls		
Passive Flexion	144.0 (142.7, 145.0)	140.0 (137.7, 142.4)
Active Flexion	132.8 (131.3, 134.2)	134.2 (131.9, 136.5)
Passive Extension	–9.0 (–10.5, –8.1)	–6.0 (–8.9, –3.1)
Active Extension	–4.1 (–5.2, -3.1)	–0.5 (–2.6, 1.7)
AROM	137.0 (135.8, 139.2)	138.0 (134.9, 140.4)
PROM	154.0 (152.1, 155.1)	147.0 (142.5, 150.5)

* Mean (95% confidence interval), # Degrees (°).

higher passive ($p = 0.003$) and active ($p = 0.006$) elbow flexion as well as AROM ($p = 0.047$) compared to girls while no significant difference was observed in passive ($p = 0.058$) and active ($p = 0.558$) elbow extension as well as PROM ($p = 0.583$) between the two genders. Arab children were observed to have significantly greater passive (p <

0.001) and active ($p < 0.001$) elbow flexion as well as AROM ($p < 0.001$) and PROM ($p = 0.039$) while South Asian children had significantly higher passive elbow extension ($p < 0.001$). No significant difference was observed in active elbow extension between the two ethnicities ($p = 0.219$).

Table 3. Comparison between Active and Passive Elbow Joint Flexibility in Children

	AE vs PE			AF vs PF			AROM vs PROM		
	AE*	PE*	p-value	AF*	PF*	p-value	AROM*	PROM*	p-value
Mean (SD)	–3.0 (4.6)	–8.1 (6.2)	**< 0.001**	134.3 (6.5)	144.3 (6.4)	**< 0.001**	138.4 (6.9)	152.6 (8.0)	**< 0.001**

*Degrees (°)

Table 4. Elbow Joint Flexibility Comparison based on Age, Gender, and Ethnicity among Children

EROM*	Age Group		p-value	Gender		p-value	Ethnicity		p-value
	Children	Adolescents		Girls	Boys		Arab	South Asian	
PF	145.0 (6.0)	143.0 (6.0)	0.108	143.0 (6.0)	145.0 (6.0)	**0.003**	146.0 (6.0)	141.0 (5.0)	**< 0.001**
PE	–8.0 (6.0)	–6.0 (6.0)	**0.039**	–9.0 (7.0)	–7.0 (6.0)	0.058	–7.0 (6.0)	–10.0 (6.0)	**< 0.001**
AF	133.0 (7.0)	137.0 (6.0)	**0.003**	133.0 (6.0)	136.0 (7.0)	**0.006**	136.0 (6.0)	130.0 (6.0)	**< 0.001**
AE	–3.4 (4.4)	–1.6 (4.9)	**0.018**	–3.2 (4.8)	–2.8 (4.4)	0.558	–2.7 (4.3)	–3.5 (5.2)	0.219
AROM	138.0 (7.0)	140.0 (6.0)	**0.042**	138.0 (7.0)	139.0 (6.0)	**0.047**	140.0 (6.0)	135.0 (7.0)	**< 0.001**
PROM	153.0 (8.0)	150.0 (9.0)	**0.004**	152.0 (9.0)	153.0 (7.0)	0.583	153.0 (8.0)	151.0 (8.0)	**0.039**

* Degrees (°), Mean (SD)

Significant but weak negative correlations were observed between PROM and all the anthropometric parameters (Table 5). Likewise, passive elbow flexion correlated negatively with all but two (BMI and WC) of the anthropometric variables. On the other hand, active elbow flexion correlated positively with all but one (BMI) of the anthropometric parameters. A similar pattern was observed with AROM which correlated positively with all but two (BMI and WC) of the anthropometric variables. Passive elbow extension correlated positively with 3 anthropometric parameters (weight, BMI, and WC) while active elbow extension correlated positively with only one anthropometric variable (weight).

American children were observed to have significantly higher passive elbow flexion ($p < 0.001$) and PROM ($p < 0.001$) compared to UAE children (Table 6). They were also significantly taller ($p = 0.007$) and older ($p = 0.019$) than their UAE counterparts. Conversely, children in the UAE had significantly greater elbow extension compared to American children ($p < 0.001$). No significant difference was observed between the two study groups in terms of gender ($p = 0.393$), weight ($p = 0.053$), and BMI (0.878).

Table 5. Correlation between Elbow ROM and Child Anthropometry

Parameters	PF	PE	PROM	AF	AE	AROM
Age (years)	**–0.184****	0.082	**–0.206****	**0.308****	0.134	**0.238****
Weight (kg)	**–0.136***	**0.162****	**–0.232****	**0.236****	**0.148***	**0.149***
Height (cm)	**–0.188****	0.081	**–0.207****	**0.305****	0.124	**0.240****
BMI (kg/m^2)	–0.067	**0.206****	**–0.216****	0.124	0.127	0.027
WC (cm)	–0.110	**0.151****	**–0.203****	**0.213****	0.085	0.129
SEL (cm)	**–0.274****	0.136	**–0.287****	**0.309****	0.169	**0.243***
EHL (cm)	**–0.242****	0.127	**–0.258****	**0.343****	0.146	**0.302****

** $p < 0.01$; * $p < 0.05$

Table 6. Passive Elbow ROM Comparison between American and UAE Children

Parameters	Nationality		p-value
	American	UAE	
Age (years)*	6.6 (3.0)	5.9 (3.0)	**0.019**
Gender			0.393
Boys Girls	61 (44%) 78 (56%)	143 (49%) 150 (51%)	
Weight (kg)*	27.0 (12.0)	24.0 (12.0)	0.053
Height (cm)*	122 (21)	117 (18)	**0.007**
BMI (kg/m^2)*	16.8 (2.6)	16.8 (3.2)	0.878
Passive Flexion*#	151.0 (5.0)	144.0 (6.0)	**< 0.001**
Passive Extension*#	5.0 (6.0)	–8.0 (6.0)	**< 0.001**
PROM*#	157.0 (7.0)	153.0 (8.0)	**< 0.001**

*Mean (SD), #Degrees (°).

4 Discussion and Conclusion

This study established reference values for elbow joint flexibility in children and examined the effects of age, gender, ethnicity, and anthropometry on elbow joint flexibility. Statistically significant differences in elbow joint flexibility were observed based on age, gender, and ethnicity. However, all the observed differences were clinically insignificant as they were less than 10° (1° – 6°). Additionally, the observed statistically significant differences in passive elbow flexion (7°) and PROM (4°) between American and

UAE children were also clinically insignificant. On the other hand, the observed difference in elbow extension between American and UAE children was clinically significant (13°). Similar trend was observed in the difference between active and passive flexion and extension (10°) as well as ROM (14°) which were all clinically significant. Conversely, the observed difference between active and passive elbow extension was clinically insignificant (5.1°).

Although elbow joint flexibility was observed to significantly correlate with all the anthropometric parameters examined, only a few of these correlations are noteworthy. These include the correlation between age ($r = 0.308$, $p < 0.01$), height ($r = 0.305$, $p < 0.01$), SEL ($r = 0.309$, $p < 0.01$), and EHL ($r = 0.343$, $p < 0.01$) with active elbow flexion and EHL ($r = 0.302$, $p < 0.01$) with AROM.

Table 7 presents a comparison between the results of the current study and previous studies on elbow joint flexibility in children. Differences in sample size, age groupings, and gender can be observed between these studies and the current study thereby making direct comparison between the previous studies and the current study difficult. Even so, most of the values reported in these studies were higher than that of the current study and can be said to assume clinical significance (>10°). This points to the need to use normative reference values for elbow joint flexibility in children.

Table 7. Comparison of Elbow Joint Flexibility with Previous Studies

Study	Passive Flexion	Passive Extension	PROM	Active Flexion	Active Extension	AROM
CS	144.3 (6.4)*	–8.1 (6.2)*	152.6 (8.0)*	134.3 (6.5)*	–3.0 (4.6)*	138.4 (6.9)*
CS	143.0 (6.0)[a]	–9.0 (7.0)[a]	152.0 (9.0)[a]	133.0 (6.0)[a]	–3.2 (4.8)[a]	138.0 (7.0)[a]
CS	145.0 (6.0)[b]	–7.0 (6.0)[b]	153.0 (7.0)[b]	136.0 (7.0)[b]	–2.8 (4.4)[b]	139.0 (6.0)[b]
[1]	-	-	-	144.5 (6.0)*	–4.0 (5.9)*	148.5 (8.6)*
[1]	-	-	-	143.8 (5.7)[b]	–3.5 (5.5)[b]	147.2 (7.9)[b]
[1]	-	-	-	145.3 (6.0)[a]	–4.4 (6.3)[a]	149.8 (9.1)[a]
[3]	152.9 (4.4)[a]	6.8 (5.2)[a]	-	-	-	-
[3]	151.4 (2.4)[b]	2.2 (5.0)[b]	-	-	-	-
[3]	149.7 (4.7)[a]	6.4 (6.3)[a]	-	-	-	-
[3]	148.3 (5.2)[b]	5.3 (6.0)[b]	-	-	-	-
[2]	142.0 (4.0)*	–11.0 (4.3)*	153.0 (6.0)*	-	-	-
[2]	141.0 (–)[b]	–11.0 (–)[b]	152.0 (–)[b]	-	-	-
[2]	143.0 (–)[a]	–12.0 (–)[a]	154.0 (–)[a]	-	-	-
[4]	-	-	-	146 (5.4)[b]	7.0 (4.6)[b]	-
[4]	-	-	-	147 (5.8)[a]	7.0 (5.1)[a]	-
[4]	-	-	-	148 (5.4)[b]	4.0 (5.4)[b]	-
[4]	-	-	-	150 (4.5)[a]	7.0 (5.6)[a]	-

* Entire sample; [a] Girls; [b] Boys; CS: Current Study

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Occupational Cancer Notifications and Their Impact During the COVID-19 Pandemic

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Abstract. Cancer notifications are tools used by health professionals to enable early detection of the disease, based on the premise of greater chances of cure, survival, quality of life, and more effective treatment. However, during the COVID-19 pandemic, work-related cancer notifications experienced a signifi- cant impact that altered the health-disease process of individuals. The objective of this study is to evaluate the historical series of work-related cancer notifications between the years 2015 and 2020 and to relate the data found to determine if there was an impact on notifications in the last year due to the COVID-19 pandemic in the State of Mato Grosso do Sul. This is a descriptive study with a quantitative approach, based on secondary data investigated from the Information System for Notifiable Diseases, Database regarding Work-Related Cancer Notifications filled between the years 2015 and 2020. Agricultural, forestry, and fishing workers, as well as service workers, salespeople in stores, and market vendors, were the most reported. There was a high incidence of skin cancer and a significant drop of more than 30% in notifications during the COVID-19 pandemic in 2020. Additionally, a high rate of underreporting was evident. The underreporting demonstrates the professionals' fragility in knowledge about the topic and the importance of notification. Cancer impacts the lives of workers, highlighting the need for discussions on Public Policies that improve working conditions and support individuals in prevention, promotion, and rehabilitation.

Keywords: Occupational Cancer · Occupational Diseases · Agrochemicals · Occupational Health

1 Introduction

The various causes of cancer have significant impacts on the lives of affected individuals, directly influencing their biopsychosocial state, causing feelings of uncertainty related to changes and problems to be faced by the individuals and their families. Currently, agrochemicals are one of the main contributors to the development of cancer, worsening health conditions, altering financial parameters, and causing absence from work activities. This leads workers to continue exposing themselves to these products even though they are aware of their potential health hazards [1].

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Among the groups of agents related to occupational cancer, the following stand out: agrochemicals, metals, solar radiation, formaldehyde, organic solvents, dust, and benzene. Brazil ranks first in the consumption of agrochemicals, which are primarily used in public health for vector control, in the production and treatment of grains and seeds, and in the treatment of wood. Workers and the rural population are the main protagonists exposed to these products, both in their work activities and through contact with food or the environment [2].

Among all these cancer risk factors, there is great concern about exposure to agrochemicals due to their increasing use. Brazil, being the world's largest consumer of agrochemicals, can affirm the relationship of direct health damage, justified by the intoxication process faced by exposed individuals. In 2014, an alarming incidence of intoxications due to agrochemical exposure was recorded in the Notifiable Diseases Information System (SINAN), with 6.26 cases per 100,000 inhabitants [3].

Between the years 2007 and 2015, notifications reached a total of 84,206 cases. Exposure to these products can cause mild, moderate, or severe intoxication, varying according to the amount of the product absorbed by the exposed individual's body, as well as the absorption time, the product's toxicity, and the time between exposure and medical attention after intoxication. Additionally, chronic exposure can lead to a clinical condition of disabling diseases, neurodegenerative disorders, and the development of câncer [4].

Cancer notifications are tools used by health professionals to enable the early detection of the disease, as well as to raise awareness among individuals about the importance of treatment and to identify the signs and symptoms that necessitate seeking medical support. Consequently, early diagnosis is based on the premise of greater chances of cure, survival, quality of life, and more effective treatment [5].

2 Worked-Related Cancer Notifications During the COVID-19 Pandemic

During the COVID-19 pandemic, health institutions recommended that people avoid seeking medical services. This directly impacted the progression of neoplasms, as early detection, as mentioned earlier, allows for a greater chance of curing the disease. Considering that rural workers already have a vulnerability in understanding cancer development, cancer notifications during the COVID-19 pandemic resulted in the non-detection of several cases of cancer related to the occupational handling of agrochemicals, as well as in the lack of treatment [6].

This study aims to investigate the notifications and the workers who had occupational cancer between the years 2015 and 2020, to identify the risk factors that may influence the worsening of the pathology, and to evaluate the impact of the COVID-19 pandemic on work-related cancer notifications in the year 2020.

This is a descriptive study with a quantitative approach, based on secondary data. Notification forms for work-related cancer from the Work-Related Notification Information System, provided by the Reference Center for Occupational Health of the State of Mato Grosso do Sul, covering its four health macro-regions (Campo Grande, Corumbá, Dourados, and Três Lagoas), were analyzed.

Data from the Work-Related Cancer Notification Forms were coded and subsequently grouped into categories. A re-reading of the information was performed, and irrelevant information was excluded, reducing the usable forms from 571 to 463.

For the identification of professionals, a categorization was performed according to the Brazilian Classification of Occupations (BCO), an enumerative and descriptive classification that documents and standardizes the recognition, naming, and coding of titles and content of occupations in the Brazilian labor market.

Frame 1. Brazilian Classification of Occupations (BCO).

Occupations:
Members of the Armed Forces, Police, Firefighters, and Military personnel;
Upper-level public officials, leaders of public interest organizations and companies, managers;
Professionals in sciences, arts, and healthcare;
Middle-level technicians;
Agricultural, forestry, and fishing workers;
Workers in the production of goods and industrial services;
Administrative services workers;
Service workers, salespeople in stores and markets;
Workers in repair and maintenance services.

Source: Brazilian Classification of Occupations, 2022.

3 Results and Discussion

The analysis found that of the patients notified with work-related cancer (n = 463), 51.52% were male and 48.8% were female; 79.48% were of white race; 30.67% were between 71 and 80 years old; 12.96% had low educational levels; 97.84% resided in the health macro-region of Campo Grande; 49.68% were agricultural, forestry, and fishing workers; 22.03% were service workers and salespeople in stores and markets; and 19.01% were production workers of goods and industrial services.

The individuals notified were exposed to one or more carcinogenic agents, with the following distributions: 8.42% were exposed to non-ionizing radiation, 2.81% were exposed to ionizing radiation, and 88.34% were exposed to other unspecified substances at the time of notification. Additionally, 51.84% of the individuals were exposed to harmful carcinogenic agents within the last 30 years, and in 31.75% of the cases, information about the exposure was ignored during the notification. After exposure, individuals received various diagnoses, described in the table below (Table 1):

The results demonstrated that rural, agricultural, and fishing workers are the most exposed to the risk of cancer in their occupational activities. The highest prevalence was among workers in this sector (49.68%), establishing a relationship between occupation and risk factor, considering that these workers are exposed to pesticides for long periods, and many do not use Personal Protective Equipment (PPE).

Table 1. Cancer Diagnoses Reported in Work-Related Cancer Notification Forms between the years 2015–2020 in the cities of Campo Grande, Corumbá, Dourados, and Três Lagoas.

Diagnoses	N = 463	%
Malignant neoplasms of the skin	**426**	**92,01**
Carcinoma in situ of the skin	**10**	**2,16**
Malignant neoplasm without specific location	**3**	**0,65**
Malignant neoplasm in other locations	**10**	**2,16**
Malignant melanoma of the skin	**3**	**0,65**
Skin conditions and alterations	**11**	**2,37**

Source: Work-Related Notification Information System, 2022.

The data from this study reveal a significant rate of low educational attainment among the researched individuals, with 12.96% being individuals who have not completed elementary education. This suggests that this determinant may influence the workers' understanding of the risks they are exposed to daily. Low educational attainment is a factor that can contribute to the development of diseases, and regarding cancer, it involves difficulty in understanding instructions provided on product labels, as sociating information and prevention mechanisms with exposures, as well as literacy about what is considered a health hazard [7].

Another important factor that we can observe in this study is the exposure to solar radiation, which justifies the higher incidence in notifications of skin neoplasms. The most affected workers were those in agriculture, forestry, and fishing, who are exposed daily to solar radiation. The higher incidence of skin cancer is related to ultraviolet radiation, and to professionals who are daily exposed to the sun. Agricultural and rural workers are the most affected individuals with solar exposure, considering their low educational attainment and limited information about available skin protections. These individuals are also exposed to agrochemical agents such as insecticides, pesticides, and herbicides, which contribute to a future diagnosis of cancer [8].

It is evident that agricultural workers are among those most exposed to agents that cause various types of cancer, which translates to a higher risk for esophageal, laryngeal, and pancreatic neoplasms. Exposure to these agents and improper use of personal protective equipment (PPE) can also contribute to this process. Low educational attainment may foster misunderstanding about the importance of this practice, as well as contribute to the improper handling of products without adequate knowledge of the risks and health hazards involved. As the duration of work and exposure to risk agents increases, the use of PPE tends to decrease, despite knowing the importance of these equipment. This contributes to workers continuing to expose themselves to products, disregarding the possibility of developing diseases [9].

To contribute to the Health Surveillance of these individuals and the situations to which they are exposed, notifications are of utmost importance. This practice assists in identifying the health status of individuals and in planning actions to be developed for health promotion and rehabilitation. Notification of work-related cancer is still very recent, which may justify the high incidence of missing data in notification forms. However, underreporting and failures in records hinder the development of strategic actions aimed at workers' health. Nevertheless, this may also be related to the COVID-19 pandemic, where people stopped seeking health services due to institutions' guidance, which could contribute to the non-detection of cancer [10].

In this study, we noticed that in 2015, the number of properly filled and validly informative notifications was very low. In the following years, between 2016 and 2019, the number of notifications increased significantly, and in 2020, there was a decrease of more than 30% in notifications compared to the previous year. This likely occurred due to the COVID-19 pandemic, where cancer screening institutions began advising healthcare services to counsel users not to seek medical care, not even for cancer screening and diagnosis tests, to reschedule test collections, and to postpone appointments. This could have directly impacted these notifications since the user is the main agent in seeking services for the detection of these cases. Therefore, individuals staying away from reference services leads to the non-detection of cancer cases, which explains this decrease in data.

Work-related cancer has been a compulsorily notifiable condition in the Unified Health System since 2004. However, healthcare services have not fully incorporated this practice into their work routines. Actions aimed at training and capacitating healthcare professionals in data collection should be carried out, encouraging the participation of these individuals in this process so they can understand the importance of correctly recording data on forms.

Among the limitations of this study, the high rate of underreporting and poor quality of form completion stood out, which did not allow for statistical analysis. Considering the significant impact of cancer on the life and health of workers, as well as the high rate of underreporting of these cases, it is necessary to implement health surveillance actions for workers aimed at promoting health education for those subject to these processes. Additionally, professionals need to be trained to manage these cases effectively. Discussions on public policies to improve the working conditions of these individuals and the mechanism for addressing their needs are also crucial, considering that cancer is a serious disease that can progress rapidly, making prevention challenging and severely compromising the health of workers.

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Psycho-Social Impact of the Disaster on Employees in Terms of Occupational Health and Safety: The Case of Turkey

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Abstract. The earthquakes that occurred in Maraş, Turkey, on February 6, 2023, with intensities of 7.7 MW and 7.6 MW, deeply affected the lives of millions of people in economic, social and psychological terms within a few seconds and caused loss of life. The aim of this study is to examine the moderator role of disaster preparedness plans in workplaces on the relationship between post-traumatic stress levels and depression, anxiety, stress levels of people who are directly or indirectly exposed to these earthquakes and have an active work life. The data was obtained from a total of 206 blue-collar employees who were actively working in a private company and were directly and indirectly exposed to the effects of the earthquake. In data collection, demographic information form, The Impact of Event Scale-Revised (IES-R) and Depression Anxiety Stress Scale-21 (DASS-21) were used. According to the findings analyzed using structural equation modeling showed that having a disaster preparedness plan in workplaces weakens the strength of the relationship between post-traumatic stress level and depression, anxiety, stress levels.

1 Introduction

According to the records of the Disaster and Emergency Management Authority of Turkey (AFAD), the earthquakes that occurred on February 6, 2023, with magnitudes of Mw = 7.7 and Mw = 7.6, and on February 20, 2023, with a magnitude of Mw = 6.4, caused significant damage in a region with a total population exceeding 15 mil-lion [1], and more than 50,000 people lost their lives [2].

Natural disasters can have adverse effects on the physical, economic, and mental health of individuals who are directly or indirectly exposed to earthquakes [3, 4]. According to the World Health Organization [5], individuals affected by natural disasters are more likely to experience social and psychological problems. Additionally, pre-existing mental health problems may worsen, and emergency-related mental health issues such as grief, acute stress reactions, harmful alcohol and drug use, depression,

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anxiety, and post-traumatic stress disorder (PTSD) may develop. Symptoms of PTSD can arise from directly experiencing a natural disaster or witnessing the event happening to others [6, 7].

Disaster preparedness encompasses measures and preparations taken in advance by individuals, communities, and workplaces to minimize the effects of natural or man-made disasters [8]. As is well-known, Occupational Health and Safety (OHS) is a systematic effort aimed at protecting the physical and mental health of employees and preventing workplace accidents that result in injury or death. In this context, it is important to examine the effectiveness of disaster preparedness planning carried out under the Disaster and Emergency Management Regulation, which was issued based on the OHS Law No. 6331 that came into force in Turkey in 2013 [9].

The aim of this study is to examine the moderating effect of the disaster preparedness planning in workplaces on the relationship between PTSD levels and depression, anxiety, and stress levels among individuals with active work lives who were directly or indirectly exposed to the earthquakes. No model investigating this moderator effect has been found in the literature. This study will contribute to understanding how the variables examined in the model predict each other. The hypotheses created in this direction are as follows:

H_1: Post-traumatic stress levels of employees who are directly or indirectly exposed to natural disasters positively predict their depression, anxiety and stress levels.
H_2: Having a disaster preparedness plan affects the relationship between post-traumatic stress levels and depression, anxiety and stress levels of employees who are directly or indirectly exposed to natural disasters.

2 Method

This study is a cross-sectional study providing information about the current conditions of the population and was carried out with a quantitative method based on descriptive-relational survey research. As the sampling method, convenience sampling technique was used. Data was collected online via a structured survey form.

2.1 Participants

The population of the research is a total of 341 blue-collar employees working in a private company operating in the energy sector in a province in Turkey. Within the scope of the research, feedback was received from 284 people, but as a result of data cleaning, 206 people were included in the analysis. 56% of whom were female and 44% were male. The average age of the participants is 39.69 (±9.76) years. 86.9% of the participants reported that they experienced a disaster indirectly, and 51.9% reported that their relatives experienced a direct disaster. Out of 206 individuals who were asked about support and treatment related to disasters, 91.7% stated that they did not receive any support or treatment after the earthquake. When asked if their workplace has a disaster preparedness plan, 58.7% said "no". When participants were asked about their belief in their workplace's readiness for a disaster, 45.1% stated they were "somewhat prepared," while 43.2% indicated they were "not prepared.

2.2 Measures

The Demographic Information Form: This form includes questions to understand the participants' age, gender, natural disaster direct or indirect experience, whether their close ones have experienced direct or indirect a disaster, whether they have received support or treatment related to the disaster, their belief in their workplace's preparedness for disasters and whether their workplace has a disaster preparedness plan.

Impact of Event Scale-Revised (IES-R): The scale was developed by Horowitz, Wilner and Alvarez [10]. It was revised by Weiss and Marmar [11] and by Creamer et al. [12] to align with the criteria for PTSD set by the American Psychiatric Association. The Turkish validity and reliability of the revised form were conducted by Çorapçıoğlu et al. [13]. The scale measures PTSD symptoms in individuals exposed to a traumatic event. The IES-R consists of three subscales: Intrusion, Avoidance and Hyperarousal.

Depression Anxiety Stress Scale (DASS-21): This scale is a 42-item self-reporting measure of depression, anxiety, and stress which were developed by Lovibond & Lovibond [14]. Brown et al. [15] stated that shorter forms (21-item version) can be used as a reliable scale for measuring levels of depression, anxiety and stress, according to research conducted across various cultural and ethnic groups, including clinical populations [16, 17]. Turkish validity and reliability were conducted by Sarıçam [18].

2.3 Procedures and Statistical Analysis

Ethical approval was obtained for the research from Fenerbahçe University (Date: 23.03.2023, No: E-80385749-100-6796). The data was collected within one week in a company via e-mail through a structured questionnaire prepared in Google Form.

First, descriptive statistics and reliability values were examined, along with the correlations between the Impact of Event Scale (IES-R), DASS-21 and disaster preparedness plan. Using a two-step approach, the relationships between variables and their respective scale items (indicators) were determined with a measurement model. Then, the relationships between the variables were identified using a structural model. Subsequently, the moderating effect of the disaster preparedness plan on the relationship between the Impact of Event Scale (IES-R) and DASS was tested. Data analyses were performed using SPSS 26.00 and AMOS software.

3 Results

3.1 Correlation and Descriptive Statistics of Variables

Information regarding the correlational relationships between the variables, mean, standard deviation, skewness-kurtosis, and reliability coefficients of the Depression, Anxiety, Stress, and impact of events scales used in the study are provided in Table 1.

Table 1 shows the correlational relationships between variables are generally consistent with our theoretical expectations; with depression, anxiety, stress and IES-R respectively. ($r = 0.724$, $p < 0.01$; $r = 0.716$, $p < 0.01$; $r = 0.702$, $p < 0.01$).

Table 1. Correlations and Descriptives

Variable	Bivariate Correlations					Descriptive Statistics and Reliabilities			
	1	2	3	4	5	M±SD	Skewness	Kurtosis	α
Depression	1					9.70±5.66	0.253	-0.693	0.95
Anxiety	0.724**	1				9.82±7.85	1.032	0.931	0.94
Stress	0.716**	0.732**	1			16.28±9.06	0.39	-0.116	0.94
IES-R	0.702**	0.710**	0.724**	1		32.97±18.76	0.415	-0.189	0.96
Company's disaster preparedness plan during disaster	0.196	0.166	0.183	0.208	1	1.59±0.43	-1.88	0.33	

* p <0.05; ** p <0.01.

3.2 Measurement Model

In the measurement model, there are 3 latent variables (DASS, IES-R, Company's Disaster Preparedness Plan) and 30 observed variables. The fit indices for the measurement model are as follows: ($\chi2$/df) = 2.26; CFI = 0.996; NFI = 0.994; TLI = 0.989; SRMR = 0.0103; RMSEA = 0.079. These fit indices show that the measurement model has adequate fit.

3.3 Structural Model

Since the disaster preparedness plan is a categorical variable, the moderating model was constructed based on whether the plan was present or absent. The results are indicated in Fig. 1. Below:

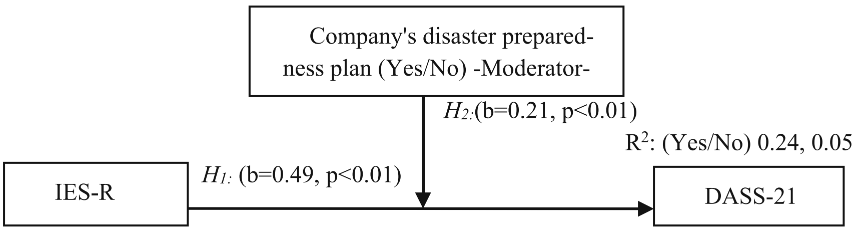

Fig. 1. Research Model

The moderating effect of having a disaster preparedness plan on the relationship between IES-R and DASS is significant. IES-R significantly predicts DASS when a disaster preparedness plan is in place (b = 0.49, $p < 0.01$). The moderating effect of not having a disaster preparedness plan is also significant between IES-R and DASS. IES-R significantly predicts DASS when there is no disaster preparedness plan (b = 0.21, $p < 0.01$). The effect value from IES-R to DASS is Critical Ratio: −4.317, which is higher than the z-value of 1.96, indicating that the presence of a disaster preparedness plan has a moderating effect on the relationship between IES-R and DASS. These results support hypotheses H_1 and H_2.

4 Discussion

The research findings show that the presence of a disaster preparedness plan in the workplace weakens the relationships between employees' post-traumatic stress levels and their levels of depression, anxiety, and stress. This result indicates that disaster preparedness plans implemented in workplaces serve as a protective factor for employees' mental health in the event of potential natural disasters.

Perceived control refers to individuals' beliefs about the extent to which they can control objects of control (themselves, their environment, people, objects, emotions, and activities) that have occurred in the past or may occur in the future. According to the Health Locus of Control model the level of healthy behaviors individuals exhibit is related to their belief in their ability to perform these behaviors. In this approach, based on Social Learning Theory, individuals with an internal locus of control are better able to manage their symptoms compared to those with an external locus of control [19]. From this perspective, it can be said that disaster preparedness plans implemented in workplaces increase employees' sense of control over future natural disasters through awareness programs and training. Therefore, it is important for employees to be psychologically prepared for disasters in order to achieve an adequate level of physical preparedness in workplaces. Industrial and organizational psychologists employed in companies can benefit the organization and its employees in terms of occupational health and safety by taking on roles such as enhancing post-disaster work motivation, improving focus on work, and establishing communication channels.

Given that this study highlights the importance of trauma psychology and disaster preparedness plans, it is considered to contribute to the fields of Occupational Health and Safety and Industrial and Organizational Psychology.

In conclusion, although it is not possible to prevent disasters from occurring, mechanisms for coping with disasters need to be developed in all segments of society in order to reduce the damage they cause as much as possible. At the same time, disaster awareness should be created and behaviors that will help them combat disasters should be gained. In this context, by the help of disaster preparedness studies to be carried out in the institutions where individuals work, the individual, social, economic and environmental impacts of disasters can be reduced as much as possible, and organizational and systematic solutions can be produced.

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Sociotechnical Systems and the Sewol Tragedy: How Culture and Structure Impact Decision-Making and Safety

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Abstract. Major accidents, such as the 2014 Sewol ferry sinking in South Korea, rarely occur due to a single failure, nor exclusively due to human error. Technical and systemic factors in addition to human factors, contribute to a disaster. Applying the PCM (Perceptual Cycle Model) method, this work performs parallel analyses for the captain and crew's decision-making during the Sewol sinking and identifies factors that contributed to the failure of passengers' rescue. From this perspective, this article demonstrates that the PCM method is capable of proposing recommendations at all layers of the complex sociotechnical system in which the accident is inserted, since wrong decisions could be consequence of flaws and gaps at any level of the hierarchical structure. The proposed methodology also provides a holistic view of the decision-making that occurred within the Sewol's bridge, highlighting the strong influence of Asian social culture.

Keywords: PCM · Perceptual Cycle Model · NDM · Sewol

1 Introduction

South Korea, April 2014: After making a sharp turn in a channel with a strong current, the Sewol ferry lost stability, capsized and sank, resulting in the deaths of 304 people. The official investigation report appointed several causes for the accident, including the crew's failure to evacuate passengers [1], mainly due to the vessel captain's poor decision-making [2], associated with the predominantly hierarchical social culture typical of Asian countries [3].

Tools for analyzing naturalistic decision-making (NDM) can aid in understanding decision processes in contexts characterized by uncertainty, urgency, ambiguity and time constraints [4]. For instance, the PCM (Perceptual Cycle Model) method, proposed by Neisser [5], is based in human cognition and their interaction with the environment.

Given the introduction, this article aims to (1) apply the PCM method to analyze the decision-making of actors directly involved in the Sewol ferry accident; (2) demonstrate that the PCM can identify contributing factors and generate recommendations at different levels of the hierarchical structure of the complex sociotechnical system; and finally (3) evaluate how cultural issues may influence naturalistic decision-making.

It is important to emphasize that this article does not intend to assess decisions and actions through a criminal point of view, nor even to assign culpability.

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2 Methodology

The proposed methodology applies the PCM method to analyze the decisions made by the captain of the Sewol during the sinking, in parallel with the application of the PCM method to the crew's decision-making. This approach aims to understand the interaction of decisions and actions of those involved as well as their influence on the failure of rescuing passengers.

Developed in a table format, the PCM analyses are arranged sequentially over time, based on the accident timeline and additional data obtained from references. In order to analyze the captain and crew members' decision-making under the same conditions, the same perception of the environment (world) is considered for both PCMs, denoted by the letter 'W'. Mental models (schema) and actions are considered individually, denoted by the letter 'S' and 'A', respectively. Following the letters W, S and A, a sequential numbering in chronological order is adopted, composing the PCM coding.

From the PCM analysis, contributing factors are identified and recommendations are proposed to mitigate recurrence of similar events in the maritime environment in future.

3 Development

3.1 Accident

The sequence of events is entirely based on the following documents: "The Special Sewol Accident Investigation Report" [1] and "System theoretical safety analysis of the Sewol ferry accident in South Korea" [6].

3.2 Actors' Definition

Following the Rasmussen [7] hierarchical structure, the main actors involved in the Sewol's accident is presented in Table 1.

Table 1. Main actors involved in Sewol's accident.

Actor	Description
Government and legislation	Korean Government
Regulatory bodies and associations	Korean Shipping Association (KSA) Korean Register of Shipping (KSR) Korean Coast Guard (ROKCG)
Company	Cheonghaejin Marine Co.
Technical and operational management	Station Jeju-VTS, Station Jindo-VTS Rescue units (Patrol vessel, helicopters, other vessels)
Staff/directly involved	Passengers Captain and crew (1st-mate, 2nd-mate, 3rd-mate, helmsman, chief-engineer, engineers, communication-officer)
Equipment/means	Sewol ferry

3.3 Analysis

The PCM analysis is presented in Table 2.

Table 2. PCM Table.

Time	Captain		Crew members	
	Code	Description	Code	Description
8:48AM	W1	Ferry made a sharp turn and decelerated; a bang was heard		
8:50AM	S1.1	Captain noticed the abrupt movement	S1.2	3rd-mate considered necessary to call captain
	A1.1	Captain returned to the bridge	A1.2	3rd-mate called the captain
8:50AM	W2	List of 30-degree to port		
	S2.1	Captain believed the anti-heeling pumps should be turned on	S2.2	2nd-mate followed the captain's order
	A2.1	Captain ordered the 2nd-mate to turn on the pumps	A2.2	2nd-mate turned on the pumps
8:50AM	W3	Anti-heeling pumps did not work properly		
	S3.1	Captain believed that it was possible to stabilize the vessel	S3.2	Chief-engineer followed the captain's order
	A3.1	Captain ordered the Chief-engineer to stop the engines	A3.2	Chief-engineer stopped the engines and ordered the room evacuation by his own judgement
8:52AM	W4	No announcement had been broadcasted to passengers until that moment		
			A4.1	Communication-officer believed that an announcement would calm down the passengers and would prevent movement
			S4.1	Communication-officer broadcasted the announcement "passengers to stay put"
8:55AM	W5	No contact with the Korean Coast Guard (KCG) had been made		
			S5.1	1st-mate believed a distress call should be made
			A5.1	1st-mate made the first distress call to the Station Jeju-VTS
8:55AM	W6	Station Jeju-VTS requested the passengers to put on the lifejackets		

(*continued*)

Table 2. (*continued*)

Time	Captain		Crew members	
	Code	Description	Code	Description
	S6.1	Captain agreed	S6.2	2nd-mate followed the order
	A6.1	Captain ordered to 2nd-mate to broadcast the announcement to passengers	A6.2	2nd-mate instructed the communication officer to broadcast the announcement
8:55AM	W7	Audio system appeared to not be working properly		
	S7.1	Captain assumed the audio system was not working	S7.2	Crew also assumed the audio system was not working
	A7.1	Captain made no other attempt to communication	A7.2	Crew also made no other attempt to communication
9:00AM to 9:25AM	W8	Captain did not assume any communication task		
			S8.1	Crew believed that they should assume the communication by their own judgement
			A8.1	Several calls were made to KCG, Station Jindo-VTS, rescue units, to inform the situation and to ask about the ferry evacuation
9:25AM	W9	Station Jindo-VTS said that the ferry evacuation is the captain's decision		
	S9.1	Captain believed they should wait for the rescue units	S9.2	Crew believed the evacuation should be ordered
	A9.1	Captain did not order the evacuation	A9.2	Communication officer asked several times about evacuation
9:27AM	W10	First helicopter arrives at the scene		
	S10.1	Captain agreed to order the evacuation	S10.2	2nd-mate followed captain's order
	A10.1	Captain ordered 2nd-mate to announce the evacuation	A10.2	2nd-mate ordered the communication officer to announce the evacuation

(*continued*)

Table 2. (*continued*)

Time	Captain		Crew members	
	Code	Description	Code	Description
9:27AM	W11	Evacuation order was not received by communication-officer, and it was not broadcasted to passengers		
	S11.1	Captain believed the evacuation order was broadcasted	S11.2	Crew believed the evacuation order was broadcasted
	A11.1	Captain did not check the announcement	A11.2	2nd-mate informed Station Jindo-VTS about evacuation
9:38AM	W12	Patrol vessel-123 sent a lifeboat to Sewol ferry		
			S12.1	Engineers were scared and believed they would not be saved
			A12.2	Engineers were rescued
9:44AM	W13	Patrol vessel-123 approached the ferry bridge		
	S13.1	Captain was in panic and believed there was nothing to do	S13.2	Crew also believed there is nothing more to do
	A13.1	Captain was rescued	A13.2	Crew were rescued

3.4 Results

Upon entering Maenggol channel, the captain's absence on the bridge posed risks, as his presence was essential for navigation in critical areas [3]. His reactive responses and lapses in decision-making indicated a failure in leadership under stress. Despite his critical responsibilities, such as making distress calls and coordinating safety operations, intense stress induced him to experience a mental collapse, resulting in a 25-min period of inaction [6].

Guidelines for succession in case of captain's incapacitation were missing in Cheonghaejin Marine Co.'s Operation Management Regulations Document (OMR) [6], leading the crew to rely on an incapable captain. Furthermore, disordered communication with KCG stations, rescue units, and the company, highlights deficiencies in OMR's emergency procedures.

Modifications to the vessel upon acquisition reduced ferry recovery forces, affecting stability restoration. The captain, who was replacing the regular captain, was unfamiliar with the vessel's peculiarities, indicating the need for fleet familiarization training. This issue, typical of hiring temporary staffing, highlights deficiencies in labor policies and safety training.

In the face of imminent risk, passengers' communication and safety procedures are crucial. When the captain failed to act, the communication officer, at his own judgment, made an announcement to the passengers to stay put, though deviating from OMR [6].

Regarding the evacuation order, the captain hesitated due to the rescue timing and passengers' survival in strong, cold currents. When he finally ordered evacuation, the announcement was not received by the crew and was not broadcast.

Finally, the vessel abandonment by the captain and crew reveals serious issues regarding seamanship and safety culture in the organization.

3.5 Recommendations

After analyzing the decision-making of those directly involved in the Sewol ferry accident, recommendations were generated at various levels of the hierarchical structure of the complex sociotechnical system, as presented in Table 3.

Table 3. Recommendations.

Level	Recommendation
Government and legislation	Regulate and monitor the part-time work
Regulatory bodies and associations	Monitor compliance with safety training Review and approve OMR
Company	Provide and ensure safety and fleet familiarization training regularly, for all employees, including part-time staff Reformulate part-time staffing hiring policies Review and improve the safety procedures in the OMR Reinforce employee duties and responsibilities Establish and maintain a safety culture within the organization
Technical and operational management	NA (out of scope of this work)
Staff/directly involved	Comply with safety and fleet familiarization training Be acquainted with and adhere to the OMR Be conscious of duties and responsibilities Adhere to the safety culture
Equipment/means	Ensure safety equipment and communication system comply with OMR procedures

4 Conclusion

The analysis of the Sewol ferry tragedy highlights the critical interaction between situational awareness, seamanship, safety culture, and power dynamics in maritime safety management.

Crew members lacked situational awareness, failing to recognize the gravity of the situation and prioritize passenger safety. Seamanship principles, essential for safe navigation and emergency response, were disregarded, evidenced by delayed evacuation and crew abandonment. The accident emphasizes the importance of a robust safety culture, where organizational values and behaviors prioritize safety over economic interests. Referring to Hofstede's concept [8], hierarchical power distance had a strong influence on effective communication and crisis management in the context of the accident. Reflections on the Fukushima disaster emphasize how entrenched cultural norms, such as obedience and reluctance to question authority, can contribute to catastrophic events [9].

The tragedy highlights cultural factors deeply ingrained in South Korean society, such as deference to authority and hierarchy, complicating communication and decision-making. While recognizing the cultural significance, the article advocates introducing a safety culture within organizations, not opposing the traditional culture of the Asian people, but prioritizing safety to preserve everyone's lives. Ultimately, it emphasizes the need for an understanding of sociotechnical systems and human cognition to mitigate future accidents.

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Effects of Noise on the Cognitive Performance of Undergraduate Students

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Abstract. Noise is prevalent in homes, schools, offices, public spaces, and the general industry. Defined as unwanted sound, noise is a form of pollution perceived to cause disturbance, annoyance, cognitive impairment, cardiovascular disorders, and sleep disturbance. The study offers a deeper understanding of the relationship between noise and cognitive performance, specifically in the context of learning spaces at Mapua University. The non-probability sampling method, specifically purposive sampling using an online survey was conducted in the study. The data were gathered from a total of 306 respondents from Mapua University attending onsite classes. Results from Pairwise Pearson Correlations revealed that cognitive performance in terms of concentration, attention, mood, mental fatigue, and overall performance have a significant relationship with the perceived noise level. Therefore, it is crucial to manage noise levels in learning spaces to optimize students' learning and prevent compromising their productivity and academic performance.

Keywords: noise · cognitive performance · perceived noise level

1 Introduction

Noise levels affect student cognitive performance by causing distraction and impairing the ability to process information efficiently. Noise is an essential factor concerning impairment of cognitive function [1]. Following the pandemic, people are steadily progressing to a "new normal" setting in accordance with government- mandated health protocols. In universities, students are returning to fill different learning spaces. Libraries, student halls, and lobbies are crowded with students clamoring to complete tasks. Noise levels in school environments are a growing concern in educational institutions [2]. Considering the student and employee's health as the utmost priority of the university, it is vital to consider these matters to avoid compromising the learning efficiency and productivity of both students and employees.

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Noise is prevalent in homes, schools, offices, public spaces, and the general industry. Defined as unwanted sound, noise is a form of pollution perceived to cause disturbance, annoyance, cognitive impairment, cardiovascular disorders and sleep disturbance [3]. Students' extensive exposure to noise can result in various complications such as fatigue, tiredness, and loss of hearing. In a school environment, noise affects the learning process, students' attention, memory capability, and motivation for studying [2]. According to the American National Standard Institute (ANSI), the recommended noise level for an unoccupied classroom should not exceed 35dB. This is also similar to the recommended standard noise in a classroom by the World Health Organization (WHO). These standards are established to ensure health safety for both students and teachers as well as the effectiveness of learning and productivity. Inability to follow these standards, listening and communication within a particular learning space would be challenging for both students and teaching staff.

The National Institutes of Health generally define cognition as the product of many integrated processes carried out by the brain allowing humans to be aware, think, learn, judge, plan, and execute behavior [4]. In recent studies, cognitive performance is associated with students' learning ability and academic performance. Primary cognitive operations including orientation, attention, and memory are prerequisites to higher-level thinking abilities [5]. Cognitive performance is also affected by other factors including heredity, diseases, lifestyle, and social factors. Recent studies have also shown environmental factors including air pollution, social environments, and residential noise to be related to cognitive performance [6].

While the study aims to provide insights into the effects of noise levels on the cognitive performance of undergraduate college students at Mapua University, there is a gap in understanding the duration and frequency of noise exposure. The potential consequences of extended noise exposure on cognitive function, a key aspect in comprehending the long-term impacts of noise on academic performance, are not explicitly addressed in the study. Thus, this study aims to determine the noise sources observed in a learning space within Mapua University. This study also seeks to determine the significant relationship between noise and the students' cognitive performance.

2 Methodology

The researchers utilized a modified questionnaire from various authors in measuring the factors affecting cognitive performance in terms of concentration, attention, mood, mental fatigue, and overall performance. The target respondents are undergraduate college students currently enrolled and attendees of onsite classes for the school year 2022–2023. The respondents are only eligible if they have used the available learning spaces with Mapua University.

The non-probability sampling method, specifically purposive sampling using an online survey will be conducted in a study. The online survey was conducted by self-administered type and will be distributed via Google Forms. The survey consists of 30-item questions, the demographic of the respondent will be determined in the first section of the questionnaire using 5-item questions, including age, gender, year level, program of study, and area of residence. The second part of the questionnaire consists of the indicators to measure the perceived noise level and factors for cognitive performance in terms of concentration, attention, mood, mental fatigue, and overall performance.

In this study, the researchers utilized Descriptive Statistics to describe, characterize, summarize, analyze, and interpret the socio-demographics of the respondents. Using Descriptive Statistics, the researchers were able to obtain the minimum, maximum, average, and standard deviation of the measures of each factor affecting cognitive performance. Consequently, the researchers utilized Minitab software to perform a correlation analysis to determine and describe the significant relationship of perceived noise and students' cognitive performance in terms of concentration, attention, mood, mental fatigue, and overall performance.

3 Results and Discussion

Perceived Noise Level (PNL) is defined as the listener's subjective assessment of how loud a noise is. It is expressed in terms of "sones," based on the listener's assessment of a sound's loudness compared to a reference sound. Several factors, such as sound pressure level, frequency spectrum, duration, and temporal characteristics of a sound, can influence PNL. Additionally, the age, sex, and hearing acuity of the listener can also affect PNL. It proves to be a valuable metric for assessing how individuals subjectively perceive different types of noise and how that affects their health and well-being. [7] Based on the result of the study, the researchers were able to construct the five (5) measures of perceived noise level. Findings revealed that 31% did not concur that the noise level in their current environment was excessively high. Similarly, 33% did not find the noise level distracting, while 37% disagreed that it was disturbing. Furthermore, 33% of the participants denied that their work was affected by noise in their current environment. Finally, 27% agreed that multiple noise sources were present in their surroundings.

The present study utilized measures derived from previous works to examine the impact of background noise on students' concentration levels [8, 9]. Findings demonstrated that noise considerably impacted students' academic achievement, primarily attributable to poor performance. Results revealed that 30% acknowledged that noise levels in their study areas adversely affected their concentration. Furthermore, the data revealed that 25% of participants could not sustain their focus for prolonged periods due to background noise, while 31% experienced difficulty concentrating in the presence of noise. On the other hand, 25% of respondents could effectively tune out distractions, and 29% reported being highly susceptible to external stimuli arising from noise.

The present study also examined the impact of varying background noise levels on students' cognitive performance, particularly regarding attention. The results indicate that 35% found it challenging to focus on tasks requiring attention due to background noise. Conversely, 29% reported being relatively unaffected by noise while working on attention-demanding tasks. Moreover, 27% of respondents agreed that they could not sustain their attention on a task for extended periods due to the noise in their environment. Interestingly, 31% of participants neither experienced difficulty nor ease in concentrating due to background noise. Lastly, 26% reported finding it challenging to shift their attention from one task to another due to background noise.

The present study also investigated the impact of noise on students' emotions in the learning environment. Results showed that 24% of participants strongly agreed that they felt annoyed or irritated by the noise in the learning space. However, 30% disagreed that noise made them feel stressed or anxious, and 27% neither agreed nor disagreed that noise made them feel fatigued. Additionally, 24% of respondents strongly agreed that noise interfered with their ability to feel relaxed or comfortable. Interestingly, 31% of participants neither agreed nor disagreed that noise affected their overall mood negatively.

The study results also reveal that 27% of respondents disagreed with the statement that they felt mentally exhausted or fatigued due to the noise. In contrast, 24% strongly agreed that they had difficulty thinking clearly due to the noise, and 26% strongly agreed that they felt mentally drained due to the noise. Furthermore, 40% of the respondents reported finding it challenging to complete their tasks due to the noise, while 25% neither agreed nor disagreed that they felt mentally stressed due to the noise.

Moreover, according to the findings, a significant portion of the respondents held varying opinions on the impact of noise on their task performance. Specifically, 24% expressed disagreement with the notion that noise affects their task. In contrast, 25% strongly agreed that noise had a detrimental effect on their work performance by causing them to make more errors, slowing down their work speed, and hindering their ability to remember or recall information. Additionally, 24% of the participants felt that noise impeded their ability to communicate effectively.

Using correlational analysis, the Table 1 presented the strength of relationship of the perceived noise level to the factors affecting students' cognitive performance. Setting perceived noise level as the response variable and the following factors as independent variables.

Table 1. Correlational Analysis Results.

	Perceived Noise	Concentration	Attention	Mood	Mental Fatigue
Concentration	0.796				
Attention	0.816	0.935			
Mood	0.799	0.870	0.899		
Mental Fatigue	0.814	0.824	0.867	0.883	
Overall Performance	0.798	0.856	0.889	0.907	0.914

The results of the correlation analysis showed that all factors have a strong significant relationship with the levels of perceived noise. With correlation values greater than 0.5, this indicates that there is a direct strong significant relationship between the factors implying that as the perceived noise levels increase, the weight on each factor also increases. Among the factors, attention has the highest correlation value of 0.816 followed by mental fatigue with a correlation value of 0.814, mood with a correlation value of 0.799, overall performance with a correlation value of 0.798, and concentration with a correlation value of 0.796.

The correlation value of perceived noise and concentration is 0.796, which indicates that there is a direct strong relationship between the two variables. To further illustrate, as the perceived noise level increases, the students' inability also increases. This explains that the higher levels of perceived noise mean higher levels of inability to concentrate, maintain focus, and tune out distractions from external stimuli. With a correlation value of 0.816, attention is also seen as directly proportional and strongly related to the levels of perceived noise. This implies that high levels of perceived noise result in difficulty in focusing on tasks, difficulty in ignoring distractions, difficulty in shifting attention between tasks, and getting distracted easily. In terms of mood, the results indicated a directly proportional strong relationship with perceived noise with a correlation value of 0.799. The results suggest that perceived levels of noise are strongly related to the students' mood while studying. Analyzing the data, noise can affect students' overall mood in a negative way. Noise, as seen by students, is a form of annoyance and irritation. Noise can also make the students feel stressed, anxious, tired or fatigued interfering with their ability to relax and feel comfortable.

Students' mental fatigue is also affected by perceived noise in the students' study areas. With a correlation value of 0.814, data analysis implies that students feel mentally exhausted or fatigued due to the noise resulting in difficulty in thinking clearly and challenging to complete tasks. Lastly, the overall cognitive performance of students is also recognized as directly proportional to perceived noise. With a correlation value of 0.798, results show that there is a strong significant relationship. This indicates that noise, in general, hinders the ability of students to communicate effectively with others. Analyzing the obtained data, noise also causes interference with students' ability to focus on tasks, impairing their ability to work efficiently and productively.

4 Conclusion

In conclusion, noise levels have a significant impact on cognitive performance, especially in learning environments such as universities. Studies have shown that high noise levels impair the ability to process information efficiently, negatively affect memory recall, reading comprehension, attention, and concentration, among others. Therefore, it is crucial to manage noise levels in learning spaces to optimize students' learning and prevent compromising their productivity and academic performance. This study aims to determine the relationship between noise and cognitive performance in the context of learning spaces at Mapua University. The study's significance lies in providing insights into the potential adverse consequences of excessive noise levels on cognitive performance. By establishing peaceful and favorable learning environments, the study aims to enhance students' learning experience and advance the growing environmental factors that affect academic performance.

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Effects of the Left Foot State During Emergency Braking

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Abstract. In this study, we examined how young drivers respond to emergency braking while driving an experimental vehicle. To simulate a traffic signal, we installed an LED light in front of the vehicle which randomly turned from yellow to red. When the LED turned red, participants had to perform an abrupt brake and maintain it for 3 s. We varied the ground contact position by adjusting the left knee joint angle during the experiment. However, changing the left foot's position did not show any significant effects on reaction time, accelerator release time, muscle activity, or foot pressure. Thus, we suggest that altering the left foot's position without adjusting the seat may not affect young drivers' ability to use the right foot pedal We recommend that future studies focus on older individuals and investigate the impact of the left foot grounding position during emergency braking, as well as during normal driving conditions.

Keywords: Traffic Safety · Emergency Braking · Driving Position · Joint Angle · Electromyography

1 Introduction

Various factors contribute to traffic accidents during automobile driving, and inappropriate pedal operation is considered one of them [1]. While automobile driving mainly involves the manipulation of pedals with the right foot, the left foot also plays a supporting role in maintaining body stability during driving [2]. Instructors at driving schools have been reported to exert more force on the footrest during emergency braking than experienced drivers, particularly at the onset of deceleration [3]. Training in footrest usage results in improved upper body stability during sudden vehicle braking and leads to a relaxed grip on the steering wheel.

During emergency braking, the braking action of the right foot involves switching from the accelerator pedal to the brake pedal by extending the right knee joint and applying pressure through the dorsiflexion of the ankle joint. Although the left foot, which stabilizes posture, is considered to affect the operability of the right foot during switching and pressing actions, none of the previous studies have investigated the effect of the left foot during emergency braking. The role of the left foot as a support for swift right foot maneuvers during emergency braking is crucial for avoiding even slight

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delays in operation. Given the potential association between the state of the left foot and operational errors of the right foot, it is essential to understand the impact of the left foot on driving to prevent traffic accidents caused by human factors.

Therefore, we conducted experiments altering the ground contact position of the left foot during emergency braking. We hypothesized that raising awareness of the left foot's condition could enable drivers to apply stronger braking and drive safely.

By focusing particularly on emergency braking scenarios, we expect to contribute valuable insights to enhancing traffic safety.

2 Method

2.1 Participants

Twelve young participants (mean age 22.8 ± 1.3 years) with driving experience participated in the study. Participants were recruited if they held a driver's license for over a year, had no orthopedic disorders affecting driving, and presented with sufficient visual acuity. Prior to measurements, participants received detailed explanations orally and in writing, provided written consent, and the study was approved by Niigata University's ethics review board, Japan.

2.2 Instruments

Test Vehicle. A Nissan NOTE e-power was used for the experiment, equipped with devices to detect accelerator pedal position signals, brake pedal operation signals, and LED signals (red, yellow, blue). Accelerator pedal position was considered at 10% when it outputted a signal at 2.9 V, similar to the brake pedal activation threshold. LED signals were considered illuminated at 2.9 V. The measurement computer for surface electromyography received analog signals from the vehicle and LED lights.

Surface Electromyography. The Ultium EMG system from NORAXON was used for surface electromyography (EMG) measurements. Sampling frequency was set to 2000 Hz, with 24-bit quantization. Ambu's Blue Sensor M electrodes, spaced 35 mm apart, were utilized for surface electrodes. NORAXON myoResearch3 (MR.3.16) software was employed for waveform analysis and reaction time extraction. Before electrode attachment, skin was cleaned by alcohol disinfectant sheets and gel. Electrodes were centrally placed on muscle bellies, avoiding nerve-rich areas. Relevant muscles included four thigh and three lower leg locations on the right foot, and two thigh and three lower leg locations on the left foot, with electrodes also attached to vastus lateralis (VL), vastus medialis (VM), and soleus (SL) muscles on the thigh due to knee joint involvement. The two locations on the thigh for both feet were the rectus femoris (RF) and the biceps femoris (BF), while the two locations on the lower leg for both feet were the tibialis anterior (TA) and the medial gastrocnemius (MG).

Plantar Pressure Gauge. The Ultium Insole Smart Lead system from NORAXON was used to measure plantar pressure distribution, with a sampling frequency of 2000 Hz. Data was saved wirelessly via the receiver to the measurement personal computer. The device included an insole-type measurement unit and a communication unit.

2.3 Experimental Protocol

Participants had surface electrodes and muscle sensors attached to both feet, and maximal voluntary contraction (MVC) measurements were taken. They then sat in the driver's seat, adjusted to their usual driving posture, and placed their right foot on the accelerator pedal. The angle of their right knee joint was measured, and the angle of their left knee joint was adjusted accordingly using a goniometer. Seven angle conditions (90°, 100°, 110°, 120°, 130°, 140°, and Both knees have the same angle (RLsame)) were tested (Fig. 1). Participants were instructed to start the engine and maintain the tachometer at 2000 rpm while counting down from 50 to the rhythm of a metronome. At random intervals, the LED light changed from blue to red, prompting participants to quickly switch from the accelerator to the brake pedal and depress it firmly, maintaining the depression for 5 s. This process was repeated three times per condition in a randomized order. The objective of the experiment was to simulate signal recognition while driving at 60 km/h, thus multiple tasks were included to simulate real-world driving conditions. Throughout the experiment, the vehicle remained stationary, and the distance between the vehicle and the LED light was 4.85 m, with the light positioned 2.00 m high.

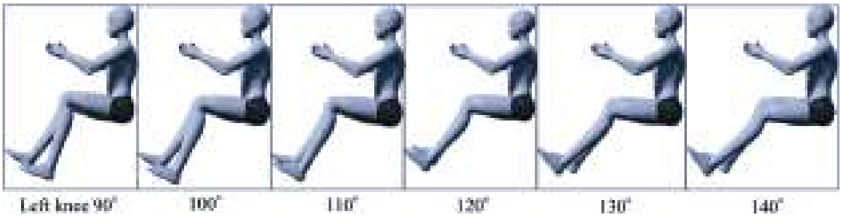

Fig. 1. A diagram illustrates the posture condition of the left knee. In addition to this, experiments were conducted with the left and right knees at the same joint angle.

2.4 Data Analysis

The study focused on measuring pedal switching speed and pressing intensity during emergency braking. Reaction time (RT) and accelerator pedal release time (ART) assessed pedal switching speed. Surface electromyography (EMG) and plantar pressure were analyzed in two intervals: reaction time interval and a 3-s interval post-brake activation. Muscle activity was evaluated using root mean square (RMS) processing and manual muscle testing, normalized by MVC.

$$\%\text{MVC}[\%] = \frac{\textit{Amplitude at the time of brake pedal depression}\,[\mu\text{V}]}{\textit{Maximum amplitude during manual muscle testing}\,[\mu\text{V}]} \times 100 \quad (1)$$

Our study focused on plantar pressure distribution, using peak pressure to evaluate pedal force. Based on Hirata et al.'s findings, which underscored foot weight's impact as the knee joint angle decreases during pedal depression, we normalized measurements by dividing them by the subject's body weight. This enabled us to calculate the body weight percentage of plantar pressure (%BW) using Eq. (2).

$$\%BW[\%] = \frac{\text{Plantar pressure at the time of brake pedal depression [N]}}{Subject's\ body\ weight\ [kg]} \times 100 \quad (2)$$

2.5 Statistical Analysis

A Shapiro-Wilk test was used to examine RT and ART normality for each angle. Subsequently, one-way ANOVA was performed, and if significant, Tukey's Honestly Significant Difference (HSD) test was used for angle comparison. Muscle activity and plantar pressure mean and max values were calculated for two intervals: reaction time and 3 s post-brake activation. One-way ANOVA compared data among angles, with Tukey-HSD test for significant cases. Statistical analysis used R v4.1.2, and significance level was set at $p < 0.05$.

3 Result

3.1 Reaction Time

Results showed no significant differences in reaction times across different knee joint angles (Table 1). While no significant differences were observed, the condition "RLsame," where both knees had the same angle, showed a slight delay of approximately 0.03 s compared to other angles.

Table 1. Reaction Time and Accelerator Pedal Release Time

Left knee flexion angle	RLsame	90°	100°	110°	120°	130°	140°	P value
Mean								
ACC Release[s]	0.37(±0.11)	0.34(±0.06)	0.35(±0.08)	0.35(±0.09)	0.34(±0.05)	0.34(±0.06)	0.35(±0.06)	0.96
Reaction Time[s]	0.57(±0.14)	0.54(±0.10)	0.55(±0.12)	0.55(±0.12)	0.54(±0.09)	0.54(±0.08)	0.55(±0.11)	0.99

3.2 Muscle Activity and Plantar Pressure

No significant differences were found in muscle activity or plantar pressure based on knee joint angles for both average and maximum values. Additionally, varying the grounding position of the left foot did not result in significant differences in the intensity of right foot braking or muscle activity (Tables 2 and 3).

Table 2. Muscle Activity and Plantar Pressure of Reaction Time Interval

n=12(mean age:22.8±1.3years)	Left knee flexion angle															
Reaction Time Interval	RLsame		90°		100		110°		120°		130°		140°		P value	
	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max
Right vastus laterails [%]	12.8	42.4	11.1	39.0	12.2	41.6	14.8	50.2	11.9	42.1	13.1	45.9	13.6	48.2	0.99	1.00
Right vastus medialis [%]	11.3	35.7	10.8	35.2	11.3	34.1	11.5	34.5	11.6	36.1	11.3	32.7	11.2	35.1	0.99	1.00
Right rectus femoris [%]	10.4	31.5	10.6	28.8	11.0	30.9	12.0	32.8	11.0	30.4	11.2	30.6	10.3	28.3	0.99	1.00
Right biceps femoris [%]	5.4	16.2	4.5	13.6	5.1	14.2	5.5	15.4	5.4	15.2	6.0	16.8	4.9	15.4	0.99	0.99
Right tibialis anterior [%]	22.3	59.2	22.5	58.6	21.5	57.3	23.1	61.0	21.9	57.5	20.5	54.6	21.6	56.2	0.98	0.99
Right medial gastrocnemius [%]	11.0	41.3	10.2	36.6	10.1	34.6	11.0	37.6	11.5	40.5	10.6	38.8	10.5	39.5	0.99	1.00
Right soleus [%]	16.3	57.0	15.3	54.0	15.3	51.9	16.4	55.3	14.4	52.2	13.9	51.6	16.4	50.5	1.00	1.00
Left rectus femoris [%]	2.7	8.0	2.0	4.6	2.8	6.7	3.4	8.3	2.6	6.4	2.9	7.0	2.7	7.2	0.24	0.79
Left biceps femoris [%]	5.5	16.5	4.7	12.8	7.2	20.8	7.1	21.2	8.1	21.5	6.1	17.7	5.5	15.8	0.85	0.98
Left tibialis anterior [%]	3.4	8.2	1.4	3.7	2.7	7.8	2.8	7.9	3.6	9.3	3.0	7.6	2.8	7.6	0.62	0.86
Left medial gastrocnemius [%]	4.8	12.0	2.5	6.9	3.8	11.7	4.5	11.2	5.3	13.8	5.0	11.7	4.7	15.1	0.84	0.69
Insole right [%]	3.6	18.8	5.4	49.6	4.6	16.8	4.7	17.6	5.2	24.0	3.6	16.9	5.4	39.3	0.96	0.54
Insole left [%]	8.5	28.6	10.4	21.2	11.2	27.0	11.6	29.5	11.6	29.3	10.1	27.1	8.8	21.0	0.05	0.74

Table 3. Muscle Activity and Plantar Pressure of 3-s Interval

n=12(mean age:22.8±1.3years)	Left knee flexion angle															
3-second Interval	RLsame		90°		100		110°		120°		130°		140°		P value	
	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max
Right vastus laterails [%]	11.0	33.6	11.4	34.2	12.5	35.8	12.4	43.4	12.1	36.5	12.2	38.7	12.1	37.8	1.00	1.00
Right vastus medialis [%]	9.0	25.4	10.3	29.3	11.2	28.3	10.8	27.1	10.3	28.8	9.9	28.4	9.6	29.4	0.99	1.00
Right rectus femoris [%]	5.1	17.8	5.7	17.5	6.5	19.5	6.8	20.0	6.7	19.7	6.3	19.3	6.0	18.0	0.99	1.00
Right biceps femoris [%]	4.4	13.1	3.0	11.5	4.1	9.9	3.9	10.6	4.4	12.2	5.1	14.7	4.4	13.9	0.94	0.98
Right tibialis anterior [%]	8.8	20.3	8.0	18.5	8.9	19.3	9.1	19.9	9.9	23.8	9.3	20.0	10.0	22.0	1.00	0.99
Right medial gastrocnemius [%]	13.6	36.3	12.5	31.9	13.6	31.1	13.7	33.1	14.8	36.2	14.7	36.5	14.9	36.1	0.99	0.99
Right soleus [%]	13.7	51.0	14.2	47.3	14.8	45.6	14.2	44.0	15.1	49.4	13.3	42.7	12.5	45.6	0.99	1.00
Left rectus femoris [%]	4.3	10.7	1.8	4.5	2.6	6.3	3.8	9.7	3.6	8.1	4.0	8.5	4.2	9.7	0.75	0.76
Left biceps femoris [%]	7.7	21.3	6.0	12.6	5.9	20.6	7.3	25.7	7.2	18.8	6.8	18.4	6.5	20.9	0.99	0.96
Left tibialis anterior [%]	5.4	11.5	3.2	6.8	4.9	10.6	4.8	10.4	4.9	9.7	4.7	9.2	4.1	9.0	0.99	0.98
Left medial gastrocnemius [%]	9.1	20.0	4.6	14.8	5.2	14.0	6.4	13.4	8.2	18.2	6.4	14.4	9.5	20.5	0.69	0.89
Insole right [%]	54.3	72.3	89.9	101.3	59.7	70.9	61.4	72.5	62.6	86.2	63.9	75.4	61.9	73.9	0.72	0.81
Insole left [%]	35.5	48.9	23.9	34.1	29.7	39.7	29.8	43.3	32.5	46.6	32.3	45.1	22.3	34.8	0.88	0.79

4 Discussion

This study aimed to investigate the effect of altering the left foot's ground contact position during emergency braking on right foot pedal operation, focusing on reaction time, muscle activity, and plantar pressure. After conducting a practice session to ensure participants could correctly follow the experimental procedures, the main experiment was carried out. Measurements were taken to confirm that there was no impact on operational familiarity with different angles among young participants, but no significant changes were observed. Additionally, it was anticipated that altering the left foot's ground contact position would influence the strength and speed of pedal depression during emergency braking. However, in this study targeting young participants, no differences were observed in muscle activity, reaction time, or plantar pressure based on variations in the left foot's ground contact position. The lack of significant differences in reaction time among the younger age group participants suggests that the left foot's ground contact state does not affect the speed of operation during emergency braking. In this experiment, only the left foot's ground contact position was altered, and the slide and lift were kept fixed. During emergency braking, there is a tendency to press the upper body against the seat and extend the arms against the steering wheel to gain counterforce [4]. This suggests that young individuals can compensate for variations in driving posture and emergency braking operations by stabilizing their posture muscles with their upper body and arms. Furthermore, since pedal depression involves a complex motion of knee extension and ankle dorsiflexion, declines in lower body muscle strength and reduced range of motion are predicted to have an impact. Particularly, women are said to experience faster declines in muscle strength and have more collision accidents than men. Conversely, it is conceivable that pedal operations may vary depending on the left foot's ground contact position in older individuals or those in other age groups where postural muscles are weakening [5, 6]. Therefore, it is necessary to consider gender-based classification.

5 Conclusions

Despite conducting experiments under different left knee joint angle conditions, there are no specific ideal angles or driving postures for the left foot for healthy young people. The ground contact condition of the left foot during driving does not affect emergency braking operations. However, maintaining posture stability during driving is crucial for preventing operational errors. Further studies across different age groups are warranted to determine more precise optimal states for the left foot.

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Investigating Airborne Dust at Construction Sites

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Abstract. Many construction trades are characterised by exposure to respirable crystalline silica (RCS) dust. Realising effective dust control measures is core to minimise workers' exposure and thus protect their health. The distribution of the exposure in time can provide key information to risk reduction. Therefore, direct reading instruments combined with video recording can identify hazardous situations and illustrate effective preventive measures. We conducted two sets of recordings at a residential construction site where several types of silica-based materials were machined. The PIMEX system integrated data from a personal dust sampler with the images of the video camera. Static samplers provided input to estimate RCS content. Tasks ranged from cutting grooves into the wall with a hand tool with/without extraction to manual sweeping. Exposure without extraction exceeded the European occupational limit value for RCS, even with the use of personal protective equipment. On-tool dust extraction reduced the exposure without causing too much discomfort to the worker. This emphasises the need for comprehensive safety measures and ongoing monitoring in construction environments.

Keywords: occupational health · dust measurement · PIMEX · construction safety

1 Background

1.1 Respirable Crystalline Silica in Construction

Respirable crystalline silica (RCS) is among the most common exposures in the construction sector because many building materials contain it, like bricks and blocks, mortar and concrete, several natural and artificial stones. [1] RCS is classified as a human carcinogen by the International Agency for Research on Cancer [2] and the European Union [3]. Therefore, exposure must be minimised. Besides lung cancer, RCS can cause silicosis and other irreversible lung impairments. [4].

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1.2 Risk Management

The central element in creating healthy and safe workplaces is the quantitative and qualitative assessment of workplace risks, applying evidence-based correlations, and implementing measures in line with technological advancements. [5]. If workers can be exposed to hazardous substances regulated by exposure limits, the employer is obliged to determine the concentration of these substances through workplace environmental monitoring and to continuously monitor it according to EN 689:2018 + AC:2019 standard or an equivalent method, taking into account the extent of exposure, the hazardous nature of the substance(s), and the stability of the technology employed. [6] As process-generated RCS dust was not subject to chemical safety classification in 2017, the European Union included "work involving exposure to RCS dust generated by a work process" in a directive establishing the limit value (OEL) of 0.1 mg/m^3 for the respirable fraction [3]. This is a very strong driver for implementing effective risk management processes.

1.3 PIcture-Mix-EXposure

While PIMEX (PIcture-Mix-EXposure) is the principle of concurrent measurement of sensor data and visualisation of real work situations (by capturing video sequences of work tasks) [7], and PIMEX-based methods apply this principle – usually in the context of occupational health. A PIMEX intervention is the process of performing a work system analysis that visualises exposures and the participation of the involved people in focus. [8] This prevention process may further follow an intervention approach, such as the "workplace improvement strategy by PIMEX" (WISP) [9].

The German Social Accident Insurance Institution for the construction sector (BG BAU) also uses PIMEX in their program: Low-dust techniques [10]. Here the visualisation is used to inform manufacturer on potentials to improve the work tools themselves (risks communication).

2 Methods and Materials

2.1 Working Environment and Tasks

The measurements were carried out at a residential construction site where a series of single-storey houses were built using traditional methods. Walls were made from clay bricks or calcium silicate (Silka) blocks and could be covered by mortar. Pipes ran in grooves that are cut into the surfaces afterwards. The measurements focused on the task where wall chasers could not be used as grooves had to be 70 mm net deep (e.g. sinks).

The self-employed worker used an industrial disc grinder to cut the groove into the wall. He cleaned out the remaining material with a hammer. Finally, he swept the debris. This activity took place indoors in bigger (e.g. open-plan kitchen) and small (e.g. toilet) rooms. Windows could be opened to foster ventilation. Measurements were done in February and March in the morning. The weather was calm: there was no rain, and the wind speed was around 12–24 km/h.

On the first day, the worker exclusively used his own hand tool (Makita GA9020 with Diamond Blade). On the other day, he tested a hand tool (HILTI AG230-24 with

Diamond Blade) with and without on-tool extraction (HILTI DC-EX 230/9”) connected to the wet/dry construction vacuum (HILTI VC 40-UL). He wore his customary halfmask with P2 filter cartridges.

2.2 The PIMEX System with Dust Sampler

For this action, the measurement of the exposure to silica dust, a Respicon TM sampler connected to a kohs.PIMEX.system (version 4, 2015) has been used for real-time measurement and video data capturing. When assessing dust exposure risks at construction sites a suitable measurement instrument has to be selected considering information on the actual work task and risks. A direct reading instrument is needed to perform a PIMEX intervention, which should be placed into the breathing zone of the proband.

The Respicon TM personal sampler is a direct-reading, combined gravimetric/photometric instrument for measuring inhalable, thoracic and respirable dust fractions. The instrument has been developed for time-resolved monitoring and sampling of these three fractions as defined in European standard 481. The instrument combines inertial classification, filter sampling, and photometric aerosol detection. [11].

The harness on the worker holding the sampler also held the pump that provided the required flow rate. The data logger transferred real-time data to the laptop computer via a dedicated cable. The video camera was connected to the system by HDMI.

The main results of a PIMEX intervention are so-called PIMEX observations (the synchronised video and sensor data material), which can be used for analysis, participation, and, later, learning activities.

2.3 Static Samplers

On Day 2, static samplers (SKC 224-PCMTX8) were placed near the work activities. Sampling followed MDHS 14/4:2014, and adjustments were made according to ISO 8756:1995. The total uncertainty of the sampling was estimated to be 25%. Inhalable and respirable fractions were measured.

Quartz content was analysed using an X-ray diffractometer (Siemens D5000), according to MDHS101.

3 Results

On the first day, 32 min of activity were measured during the 3 h of observation. On the second day, 12 min of activity were measured during the 3 h of observation. The measurement data of each site and the circumstances are detailed in Table 1. These concentration values are means for the measurement period. The difference between cutting activities with and without extraction is striking.

The static samplers provided similar data patterns (not shown). Analysis of the sampling filters at cutting Silka and clay bricks without extraction showed that in these scenarios spot RCS concentrations are estimated to be 38.9 mg/m^3 and 44 mg/m^3.

The PIMEX observations provided an opportunity to follow the course of exposure. It could highlight work elements that created peak exposures. An example is illustrated

Table 1. Dust concentration levels in the various settings on Day 1 (white) and Day 2 (grey)

room	task	brick	plastered	extraction	duration (min.)	respirable (mg/m^3)	thoracic (mg/m^3)	inhalable (mg/m^3)
bath	Cut	clay	yes	no	5	195	215	300
bath	Hammer	clay	yes	no	10	22	25	33
bath	Sweep	clay	yes	no	1	21	20	32
living	Cut	clay	yes	no	1	197	219	303
bath	Cut	clay	yes	no	4	202	224	314
bath	Hammer	clay	yes	no	5	21	25	33
bath	Sweep	clay	yes	no	1	22	25	34
living	All 3	clay	yes	no	5	178	198	274
bath	Cut	clay	no	yes	6	10	11	16
living	Cut	clay	no	no	2	186	207	286
toilet	Cut	clay	no	no	1	200	222	308
living	Cut	Silka	no	yes	1.5	17	19	26
living	Cut	Silka	no	no*	1.5	34	37	52

* hood only, without extraction

in Fig. 1. The spikes on the time series are due to the following activities: starting the machine to stir settled dust from the ground; after finishing the cut, the worker bends into the dust gathered around the ground. The natural ventilation (open windows and the mild draught) reduced dust concentration to initial levels in around 3 min.

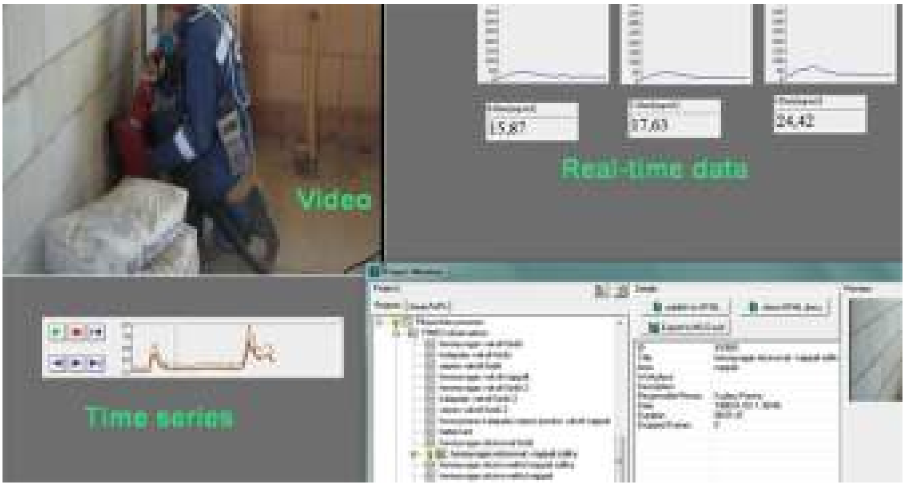

Fig. 1. Screenshot of PIMEX observation: cutting a Silka wall with on-tool dust extraction. The time series shows two exposure spikes during the activity.

4 Discussion

Cutting walls with power machines causes extreme dust concentration: the dust was so thick that the worker could not be seen. Using simple hand tools and sweeping were a magnitude less dusty.

Calculation of 8-h time weighted averages with Day 1 data (no extraction) results in the following mean concentrations: 10.4 mg/m^3 for the inhalable fraction, 7.5 mg/m^3 for the thoracic fraction and 6.75 mg/m^3 for the respirable fraction. These are slightly beyond the OEL values for inert dust. However, background dust levels were also rather high (data not shown), adding to the daily exposure. Considering RCS exposure, our calculations show that a person would exceed the OEL in one minute doing this activity without personal breathing protection. The 95% filtration rate of a well-kept FFP2 respirator can push the figure up to 20 min. This is far beyond the time spent with this activity on a single day, and further exposure sources are not yet considered. Note that other trades, like electricians, may cut walls for entire shifts.

On-tool extraction visibly suppresses dust exposure. Measurement data show a reduction of up to 20 times. Calculations show that an appropriate extraction system can help meet the OEL for RCS; furthermore, it has the added benefits of preventing every worker on the site and enabling a cleaner working area. We measured with the extraction hood on the tool for a single test, but no vacuum tube was attached. This scenario gave higher concentrations than extraction but was lower than without the hood. The hood projected the dust behind the worker. Thus, the breathing area was not in the centre. When the worker stepped back, a marked spike could be observed on the sampler, reminding everyone of the presence of the dust.

Data from the PIMEX system was in line with the static samplers, which were run by an accredited laboratory. Therefore, PIMEX data can be taken as reliable input for exposure assessments. In the context of the implementation of measures, two aspects of PIMEX-based methods have to be considered: participation and learning / teaching.

While participation is indeed linked to learning (motivation to change [12], "seeing is believing" [13]), it also has a relevant link to the analysis process itself. The investigator benefits from applying this approach of participatory ergonomics by potentially increasing the quality of assessment. Further, the activity of visualising exposures can be seen as a relevant element of a participatory working-system analysis [14].

5 Summary

Creating healthy workplaces includes assessing risks and implementing measures, which, in other words, constitutes a change process. The action presented in this paper was performed using the "PIMEX intervention" approach to address both of these two aspects. The methodical application of PIMEX allows an objective assessment of risks at work and facilitates the efficacy of an occupational health intervention. [12–15]. It provided valuable insights into the effectiveness of dust extraction systems in reducing airborne dust concentrations during various construction activities. The data cable caused minor discomfort to the worker, which is overcome in present wireless systems.

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Assessing the Influence of Mental Workload and Stress on Firefighters in Manila Using the NASA TLX: Implications for Performance and Well-Being

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Abstract. In the Philippines, fire outbreaks increased during the dry season, which prevails from December to May. This period critically threatens firefighters' psychological and physical abilities as emergencies increase in frequency and intensity. Firefighters in Manila battle a disturbingly high rate of fire incidents, particularly during the dry season spanning from December to May, which critically tests their cognitive and psychological resilience. The incessant exposure to traumatic incidents and high-stress environments increases their vulnerability to mental health problems, such as acute stress disorder, PTSD, depression, and anxiety, that would affect their operational functioning and well-being. The NASA TLX was used to measure the mental workload, and it was found that it depicted significant mental, physical, and temporal demands leading to stress and strain on firefighters. The study found that these demands strongly correlated with low performance and high frustration levels. With this in mind, the strategies should hence be holistic in nature, being designed and implemented considering the physical realities and psychological health of the firefighters to preserve the efficiency and safety of the firefighters under critical conditions. Some recommendations to fire departments will be solidifying support structures around mental health for firefighters. This includes structured debriefing sessions, resilience training programs, and routine mental health screenings to ensure early detection and management of stress-related conditions. This will further be augmented by strategies in modifying and upgrading cognitive workload management strategies, primarily through instruments like NASA TLX, to do better assessments of the cognitive strains that firefighters face, thus informing better intervention strategies.

Keywords: Stress · Mental Workload · NASA-TLX · Cognitive · Firefighters

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1 Introduction

Firefighters play a crucial role in public safety through emergency response, inspection, and community outreach. Their high-intensity work exposes them to trauma, making them susceptible to mental stress. The NASA Task Load Index (NASA TLX) is used to assess mental stress, and addressing it is crucial for their well-being. In Manila, with over 20 fire incidents per month during the dry season, firefighters face challenges such as handling hazardous materials, emergency responses, and community involvement. Despite tools like NASA TLX, a psychological support system tailored to firefighters' demands is not yet available.

2 Related Literature

A survey was conducted to establish the psychosocial pressures and their effects on the psychological health of firefighters. Firefighters from Khorasan Razavi Province were evaluated using the NASA Task Load Index (NASA-TLX) questionnaire to assess stress and quality of life. The findings indicate an increase in psychological health-related problems in the case of emergency responders. Another survey directed at assessing workload and psychological health among Malaysian firefighters was conducted using the NASA-TLX and Depression, Anxiety, and Stress Scale questionnaires, which favored the validation of the association of psychological impacts and mental workload of firefighters. An assessment of firefighters in Tehran has found complex interaction of physical loads, the mental workload of the professional activity, and its relationship with musculoskeletal disorders. Another study about wildland firefighters found a relationship between the effects of induced stress and a firefighter's cognitive function.

3 Methodology

The research was conducted to provide an effective mental workload assessment that will focus on the cognitive state of Manila City firefighters during operations (Fig. 1).

The figure above highlights the Bureau of Fire Protection's fire stations in Manila City. The researchers used the following stations as a guide for where to conduct their data collection.

3.1 Sampling Technique

According to an initial interview of firefighters, five are in each station. There are currently 14 stations in Manila City; thus, the registered population in this study is 70 firefighters. The researchers used Slovin's Formula to calculate the sample. The researchers gathered 60 samples with a confidence level of 95% and a 5% margin of error.

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Fig. 1. Map of Manila City Fire Stations

3.2 Data Gathering Tool

To assess the mental workload of firefighters, the researchers chose NASA-TLX (National Aeronautics and Space Administration Task Load Index). This method comprises six parameters: mental demand, physical demand, temporal demand, performance, effort, and frustration.

3.3 Scoring Interpretation

The researchers interpreted the quantitative data to draw a descriptive conclusion. Score interpretations for NASA-TLX are shown in the table below (Table 1).

Table 1. Scoring Interpretation of NASA-TLX

Weight	Scale
Low	0–9
Medium	10–29
Rather High	30–49
High	50–79
Very High	80–100

4 Results and Discussions

The researchers have found that Temporal Demand (TD) is the highest factor that increases the mental workload of firefighters. The reason is the need to respond to fire incidents promptly, thus being under time pressure when operating. This factor is followed by Physical Demand (PD) because it is a physically demanding job, while being in a constant state of readiness for 24 h, night or days, for seven days, which can affect their physical state. That constant state of readiness would also directly affect firefighters' mental demand (MD), as evidenced by the results, being the third highest factor concerning mental workload scores. This is followed by Performance (OP), Effort (EF), and Frustration (FR), respectively. The following relationships show a statistically significant result, such as these relationships' p-values are less than 0.05. The relationship between Performance (OP) and Physical Demand (PD) suggests a positive relationship, $r = .333$; thus, physical demand will also increase if performance goes up. Looking at the relationship between Performance (OP) and Mental Demand (MD) would give us a negative relationship, $r = -.426$, pointing out that as the performance of firefighters increases, mental demand decreases. Subsequently, sharing the same interpretation, the Effort (EF) and Mental Demand (MD) relationship share a negative relationship, $r = -0.270$, such that increasing effort decreases mental demand (Table 2 and Fig. 2).

Table 2. Scoring Interpretation of NASA-TLX

Category	Average Score
Mental Demand	250.67
Physical Demand	276.33
Temporal Demand	338.17
Performance	217.5
Effort	176.17
Frustration	40.67
Average Score	**86.63**
Interpretation	Very High

5 Recommendations

The researcher's proposal advocates for a multifaceted approach to support Manila-based firefighters, recognizing the complex nature of their roles and the intrinsic stressors they face. Central to this approach is the recommendation to increase vacation days and bolster the workforce in fire stations by boosting recruitment and government funding efforts. These measures aim to provide firefighters with essential opportunities to rest and recharge while distributing workload pressures more evenly to mitigate the risk of burnout and injuries. The table below shows the current and ideal comparison of firefighter personnel.

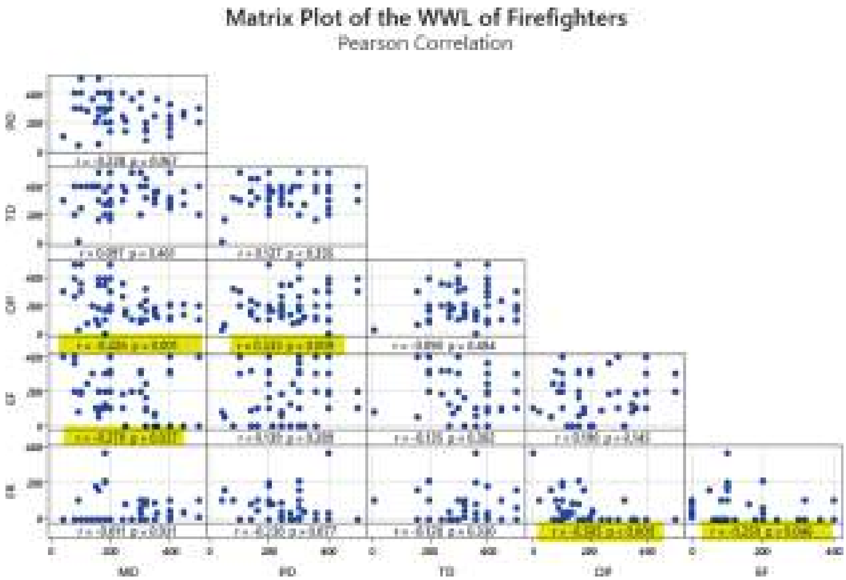

Fig. 2. Pearson Correlation of the Weighted Workload of Firefighters

The insufficient workforce was also attributed to the delayed response to the fire incident and traffic conditions in Manila City. As the Bureau of Fire Protection prescribes, the standard response time should be 5–7 min; however, their average response time is 11.51 min. This suggested that an increase in manpower should be made. Furthermore, a fire truck should be crewed by seven (7) fire personnel, with each personnel responsible for 2,000 persons in their area. This is greater than the average five (5) personnel crewing a fire truck when responding.

On the other hand, concerning the mental workload of firefighters, the proposal goes beyond addressing Physical Demand (PD) alone, emphasizing the importance of cultivating a holistic working environment that prioritizes firefighters' well-being. This involves implementing comprehensive support mechanisms, including ongoing training programs and access to mental health resources, to equip firefighters with the tools they need to manage stress and trauma effectively.

Moreover, proactive measures are proposed to mitigate the impact of time pressure on firefighters' mental workload. This entails promoting effective time management and decision-making strategies through scenario-based training exercises and regular debriefing sessions. This will further be augmented by strategies in modifying and upgrading cognitive workload management strategies, aside from NASA TLX, to do better assessments of the cognitive strains that firefighters face, thus informing better intervention strategies. This would foster a culture of open communication and psychological support, and firefighters can feel empowered to seek help and maintain their mental health resilience.

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Factors Associated with Heat Stress and Renal Changes Among Operators Working in Hot Indoor Environment at a Steel Manufacturing Industry in Selangor

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Abstract. Occupational heat exposure is an escalating concern in today's warming climate, particularly in tropical countries where temperatures routinely exceed 30 °C. For hot and humid tropical climates such as Malaysia, the association between indoor occupational heat stress levels and renal changes remains under studied, thus necessitating in-depth investigation. A study was carried out involving several study instruments, i.e., a self-administrated questionnaire, heat monitoring device, Thermal Work Limit calculator, and for urinalysis, the analyzer used to determine Urine Specific Gravity (USG) and Albumin to Creatinine Ratio (ACR) of the respondents. The findings suggest that steel manufacturing operators are prone to heat stress and renal alteration, based on the significant evidence reported in this study. Although the results from renal changes in this study cannot be conclusively used to indicate renal damage, the need for further study with a larger sample size and in-depth analysis is indicated to comprehensively establish the situation and, if necessary, preventive measures to protect employees exposed to heat in the workplace.

Keywords: Steel Industry · Indoor · Heat Stress · Renal Changes

1 Introduction

The steel industry consists of various work task that exposed to the heat sources [1]. For instance, welding and working close to controlled flames are vital activities, however does not just affect those directly involve with the work task, instead nearby employee is also affected by the heat. Operation of Computing Numerous Control (CNC) and injection molding machines, boilers producing steam, hydro-pyrolysis to reheat the acid, and annealing furnace are examples of machine and process that generate and release

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heat energy to the working area [2]. In addition, a high temperature of hot rolling coils around 1000 to 1650 °C that encourages the indoor natural cooling methods, which crucial to maintain the quality of the steel coils, but significantly rising the workplace temperature.

Previous studies including systematic reviews [1] has indicated that long term exposure to heat in the workplace alongside other factors are associated with chronic kidney diseases (CKD). Therefore, there is an urgent need to assess if there are manifestation of renal changes indicative of CKD based on the current level of heat exposure, and the corresponding sign and symptoms of heat strain among indoor steel manufacturing operators who are exposed to heat throughout their working hours. This study aid to provide better clarity on the potential factors of heat related illness and renal alteration so that mechanisms [3] can be instituted to prevent late onset of CKD.

2 Materials and Method

2.1 Study Design and Sampling Method

A cross-sectional study was conducted among 108 operators in a steel manufacturing plant located at Shah Alam, Selangor, Malaysia. The ethics clearance was obtained from Ethics Committee, Universiti Putra Malaysia (JKEUPM) with prior approval from the steel manufacturing company. A preliminary screening was held to recruit only Malaysian male respondents, aged between 18 to 60 years old who has exposed to heat for at least 6 months without pre-existing medical condition, such as but not limited to hypertension and chronic kidney disease.

2.2 Study Instrument

A set of self-administered questionnaires was used to collect information on sociodemographic background, occupational, health-related and medical history including Heat Strain Score Index (HSSI) [4] in Malay language. Calibrated QuesTemp^0 Heat Stress Monitors Model 36 (WBGT) and an anemometer (Kestrel Heat Stress Tracker 4400) were used to monitor heat exposure level at the workstation. The data obtained was computed using Thermal Work Limit Calculator [5]. For urinalysis, mid-stream morning urine were collected and analyzed using Clinical Refractometer to measure urine specific gravity (USG) whereas Biolis 24i Analyzer was used to measure urine protein to creatinine ratio (uPCR).

3 Results

3.1 Socio-demographic Background, Occupational Information, and Health-Related Info and Medical History

The mean and standard deviation of the subjects' age was 37.79 ± 11.53. A total of 88.9% of the respondents were Malay, followed by 9.3% Indian and 1.9% Chinese. The majority of respondents had secondary educational background (76.9%), followed by

21.3% of tertiary educational level. Out of 108 respondents, most were working at Cold Rolled Milling (CRM) (33.3%), followed by Continuous Pickling Line (CPL) (24.1%), Skinpass and Tension Leveller Line (STL) (12.0%), Batch Annealing Furnace (BAF) (8.3%), Maintenance and Electrician (ME) (7.4%), Acid Regenerated Process (ARP) (5.6%), Boiler (3.7%), Electro Cleaning Line (ECL) (2.8%) and Recoiling Yard Line (RCL) (2.8%).

Based on the respondents' self-assessment, most regard their metabolic workload to be medium (58.3%), heavy (33.3%), very heavy (6.5%) and light (1.9%). In terms of working experience, majority of them (68.5%) had worked for > 5 years with the mean and standard deviation of 12.88 ± 10.88. Most of the respondents (91.7%) worked for a minimum of 8 h, with the remaining (8.3%) > 8 h. The respondents reported an average of 7.94 ± 1.56 working hour and a rest period of 0.75 ± 0.29 h.

In terms of hydration, 68.5% of the respondents reported daily water intake of < 3.7L as compared to the remaining 31.5% who drank > 3.7L of water. Majority of them are smoker (63.9%), 36.1% were non-smoker, while 92.6% had never drank alcohol in contrast of 7.4% of them who self-reportedly consume alcoholic beverages. Self-reported medical history in this study revealed that 21.3% of the respondents were found to experience urinary difficulties, and the remaining 78.7% did not.

3.2 Thermal Work Limit (TWL) Level Across Production Plant

Based on Fig. 1, the TWL level of nine departments ranged from 107.5 W/m^2 in Batch Annealing Furnace (BAF) to 166.5 W/m^2 in Boiler. In BAF, the TWL was the lowest at 107.5 W/m^2, which can be classified as 'Very High Risk-Withdrawal Zone' and is safe for continuous self-paced light work with a work rest regime. In this category the TWL guide indicated the need for additional precaution to reduce heat stress [5].

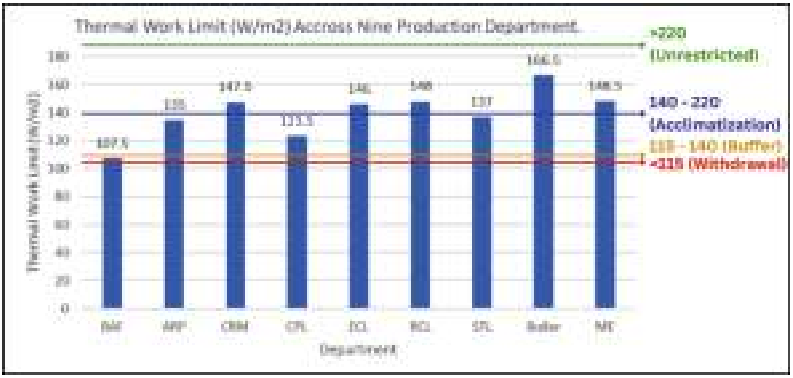

Fig. 1. Thermal Work Limit level across nine departments at the production plant.

3.3 Self-reported Heat Stress Level and Prevalence of Renal Changes

The mean and standard deviation for Heat Strain Score Index (HSSI) score was 15.8 ± 2.2. Out of 108 respondents, most of the respondents (82.4%) were categorized in the yellow zone, while the remaining (17.6%) of them were in the red zone of the HSSI.

For Urine Specific Gravity (USG) the mean and standard deviation of the specific-gravity were 1.022 ± 0.007, whereby 21.3% of the respondents were in the category of less than 1.02 (normal), the remaining 78.7% were in the range of 1.02 to 1.04 (dehydrated).

In terms of Albumin to Creatinine Ration (ACR), the mean and standard deviation in the unit of mg/dL were 26.3 ± 31.6. Half of the respondents (53.7%) had microalbuminuria, followed by (37.0%) being normal ACR, while (9.3%) had macroalbuminuria. The prevalence of renal changes was 65.7% (71 respondents) among the 108 respondents, and in comparison, 37 of the respondents (34.4%) did not.

3.4 Factors Associated with and Between Self-reported Heat Stress Level and Prevalence of Renal Changes

Bivariate analysis showed that there were significant association between age ($r = 0.197$), department ($\chi^2 = 5.783$), metabolic workload ($r = 0.213$), working history ($r = 0.296$), daily water intake ($\chi^2 = 12.666$), alcohol intake ($\chi^2 = 5.622$) and heat exposure level (TWL) at working area ($r = 0.624$) with the heat stress level. Prevalence of renal changes on the other hand showed significant association with working history ($\chi^2 = 2.518$) and daily water intake ($\chi^2 = 1.528$). Heat stress level and prevalence of renal changes reported in this study ($\chi^2 = 2.001$) showed significant association.

4 Discussion

Findings in this study reported TWL value which indicated the need for intervention for all the workstations monitored. Similarly, the heat level based on WBGT measurement in this study reported a maximum of 36.5 °C, although lower than a similar study among steel operators in India at coke oven area yielding 41.7 °C [2], the results has exceeded the threshold limit value [6]. Between the different methodologies, TWL appear to be a better suited approach to assess hot indoor environments which factors in the five environmental factors (as well as wind speed, atmospheric pressure, and clothing factors) in its calculation compared to WBGT which takes into consideration of only the five environmental factors [7].

As a parameter of interest in determining potential chronic kidney disease (CKD) attributed by heat strain, the results indicated that majority (65.7%) of the respondents in this study showed renal changes based on the parameters of urine investigated. Using HSSI, the results obtained in this study demonstrated concerns to a similar previous study among steel manufacturing workers [8] which reported 60% of the respondents in red zone (definitive heat strain), 30% in yellow zone (likelihood of heat strain) and 10% in green zone (no heat strain). In this study, none of the respondents were categorized in the green zone, a shared concern which was correspondingly reported in other industries where heat exposures are significant, i.e.: construction and agriculture [9, 10]. There are limited potential for direct comparison of the reported prevalence of heat stress illnesses attributed to the different questionnaire being used across different studies including the terminology (strain vs. stress). However, it is noteworthy that most methodologies utilize dehydration to indicate self-reported heat strain [11–13].

A systematic review [1] which analyzes 111 studies involving 21,721 workers, indicates that CKD affects 15% of individuals who typically worked under heat stress. The highest rates of CKD are observed among heat exposed group, where the prevalence of CKD is 18% among the respondents [14]. In this study the USG indicates the dehydration level, whereby, ACR reflects the reduction in renal function, raising concerns on the onset of irreversible CKD. This is why this study, despite being cross-sectional, aims to investigate the prevalence of renal changes in anticipation of potential CKD in the future.

As indicated by various studies in the literature, age has consistently been shown as significant factor of heat related illness [15, 16, 19]. As individuals age, their thermoregulatory capacity decline, increasing the risk of heat-related illnesses such as hyperthermia due to factors like decline in metabolic rate, and inefficient sweat glands [16]. Among different races, heat stress and renal changes were significantly linked to varies heat tolerance among ethnic groups likely due to body size, life history, and nutritional status rather than inherent traits [17].

In terms of working history, age and repeated episodes of dehydration are two major contributors prone the respondent to experience higher heat stress level as compared to younger and short employment duration [15, 18]. A study by Al-Bouwarthan (2020) among outdoor and indoor construction workers found that workers who performed their activities mostly at moderate to heavy intensity with poor hydration have a greater potential for developing heat stress, where dehydration recorded as the major factors [3]. Farag et al. (2020) found that farmers with >10 years of experiences were 4.7 times more likely to develop renal disease, and even worse, significant median difference of protein to creatinine ratio (uPCR) in urine of farmers group reported in their study.

This study also reported that respondents with higher metabolic workload were 0.213 times more likely to experience heat stress particularly those with continuous workload and limited self-pacing opportunities [10, 11]. Previous study by Venugopal et al. (2019) also reported the physical exertion, combined with a lack of automation and cooling intervention, exacerbates heat producing such high-risk hot working environments in many sectors.

5 Conclusion

Overall, the findings indicated valid concern which found potential renal change associated with dehydration amongst heat exposed workers in steel manufacturing industry and thus a call for a much robust in-depth study to establish the relationship and prevention.

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Determining the Effect of External Non-driving Factors on Long Distance Trucking: A Cognitive Study

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Abstract. Transportation is vital in daily life for goods transfer, often managed by trucking companies for long-distance haulage due to their efficient truck sizes and capabilities. However, these factors also increase their susceptibility to accidents. This study investigates external non-driving influences on truck drivers leading to accidents. Daily reports highlight the prevalence of truck-related accidents, impacting the company's reputation and financial stability. The research seeks to identify significant factors distressing drivers, assess associated risks, propose solutions, and anticipate improvements post-implementation. Survey data from 204 truck drivers were analyzed using Multivariate Analysis. Findings pinpoint crucial non-driving factors, aiding trucking companies and stakeholders in accident prevention strategies, thus mitigating further issues. Validation through interviews with respondents and a trucking company enhances the study's credibility. In summary, understanding and addressing these factors can improve road safety and operational efficiency within the trucking industry.

Keywords: External Non-Driving Factors · Long Distance Trucking · Multivariate Data Analysis

1 Introduction

Transportation plays a vital role in developing a country's economy. We need it to go to work, and goods and services will only be able to reach consumers if they pass through transportation channels, be it by land, water, or air [1]. Currently, land transportation is most widely used on the island of the Philippines. In 2023, land transportation contributed to approximately 60 percent of the total share of modes of transportation [2]. Having these data regarding land transportation, accidents related to trucking are also identified to gain a percentage of 8.21, which comprises the road crashes caused by trucks in the first half of 2022. The data stated above have occurred due to many reasons, namely:

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driver error, those who engage in drunk driving, the driver's loss of control, situations when the driver is inattentive whenever he is moving backward, or when he is turning wrongly when the driver had forgotten to do a maintenance check on his vehicle which could result to lost brakes, overheating and other malfunctions [3]. Most accidents also involve hitting a pedestrian when crossing the roads; sometimes, drivers overlook another vehicle [4]. Moreover, most accidents nowadays are due to drivers fond of overtaking, maybe because they are in a hurry or just getting bored of slow drivers, not realizing that it may lead them to such misfortune.

Truck drivers are usually the ones experiencing long-distance driving due to the different locations they need to come to deliver various goods and products. The longer they are on the roads, the higher the chance they are prone to road accidents. As stated by Shandhana Rashmi and Marisamynathan (2023), the impact of long hours driving in trucks decreases the overall performance of the drivers; some studies for non-driving activities show a significant decrease in the drivers' performance due to fatigue [5].

The trucking industry continues to have some of the highest work-related injury and illness rates and costs of any industry in the United States. Until recently, little focus has been placed on addressing non-motor vehicle collision-related injuries within the trucking industry. Drivers are exposed to multiple physical risk factors contributing to occupational injuries while completing their job duties, such as loading/unloading freight, decoupling trailers, strapping downloads, and ingress and egress from the cab and trailer. About one-fourth of all truck driver injuries in the United States are related to slips, trips, and falls near the truck [6]. Long-distance trucking can cause drivers ill health, stress, and some injuries; most of the respondents reported having a chronic injury they got from truck crashes or work-related injuries due to long hours of driving [7].

Therefore, the current study seeks to address the following research question: What are the significant factors that will affect the safety of truck drivers during non-driving activities in long-distance trucking? Thus, considering the escalating number of truck accidents on the road, trucking companies in the logistics industry are actively seeking solutions. Consequently, this study uses Multivariate Data Analysis to identify and analyze the critical non-driving factors influencing truck drivers' safety during long-distance trucking. Moreover, it aims to provide valuable insights into the effects of these factors on safety outcomes.

2 Methodology

2.1 Conceptual Framework

The conceptual framework illustrates the steps the researchers will take to obtain a conclusion for their research questions. The conceptual framework will also show the precedence of the needed concepts, which the researchers must pass through to gather information to formulate their conclusions accurately. The first part of the conceptual framework shows the gathering of data from the trucking industries. Once the needed data is gathered and assessed, the researchers will then analyze the data using the Multivariate Data Analysis (Fig. 1).

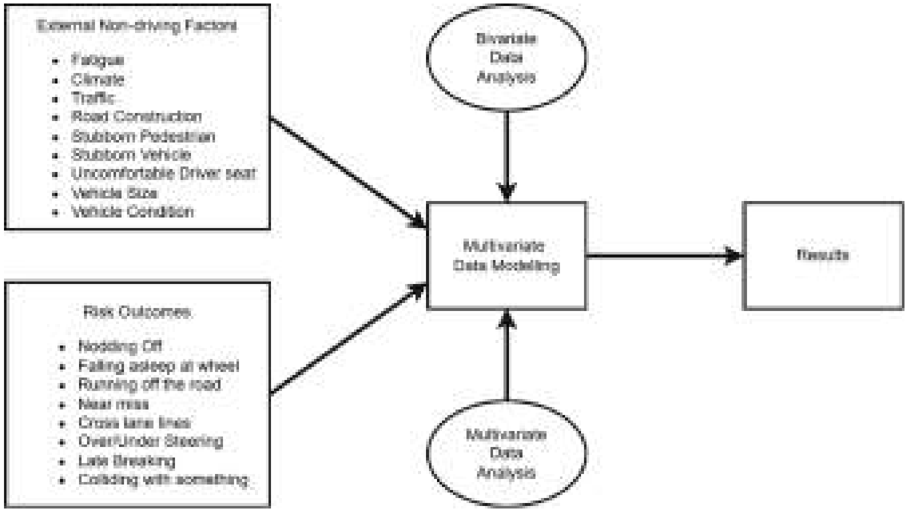

Fig. 1. The conceptual framework of the study.

2.2 Respondents

The research was carried out in the third region of Luzon, Philippines. This study was conducted from December 2023 to March 2014, focusing on a specific group of truck drivers. The criteria for participation included having at least one year of driving experience, engaging in long-haul journeys of 50 miles or more, and being employed in the trucking industry within Region 3 of the Philippines. A total of 204 truck drivers were selected for the study based on the sample size calculated using Slovin's formula. The study employed Purposive Sampling as its sampling strategy. Furthermore, the research was designed to be both survey-based and descriptive.

2.3 Questionnaire

The researchers developed the questionnaire to examine and identify the factors that will affect the safety of truck drivers during non-driving activities in long-distance trucking. The survey was conducted through a face-to-face approach, and they were required to complete four parts: demographics, driving experience, fatigue risk management of drivers, and the frequency of drivers' dangerous experiences during long-distance trucking.

2.4 Statistical Analysis

The researchers used the Statistical Package for Social Sciences (SPSS) 21 in determining the significant non-driving factors that affect the drivers using one of the functions of the SPSS through the Bivariate analysis in assessing the relation of the risk factors to the safety outcomes that a driver might experience during long-distance trips. Multivariate analysis is used to determine the significant factors that affect a driver during his trips, utilizing a logistic regression test.

3 Results and Discussion

3.1 Bivariate Data Analysis – Odds Ratio Summary of Safety Outcomes and External Factors

Table 1 shows that factors affecting safety outcomes among truck drivers were investigated. Fatigue emerged as a significant predictor, with odds ratios ranging from 0.02 to 6.39 and p-values indicating statistical significance. Moreover, climate conditions were found to have a noteworthy impact on safety, with odds ratios ranging from 0.05 to 8.05. Additionally, discomfort from the driver's seat was identified as another significant factor, highlighting the complex interplay of various elements in ensuring driver safety during long-distance trucking.

Table 1. Odds Ratio Safety outcomes and external factors

Safety Outcome	Factors	Odds Ratio (%)	p-value
Nodding off	Fatigue	6.39	0.001
	Climate	8.05	0.015
	Stubborn Pedestrian	0.09	0.005
	Stubborn Vehicles	0.11	0.003
Falling Asleep	Fatigue	0.06	0.001
	Climate	0.06	0.009
	Stubborn Vehicles	0.22	0.039
Running off the road	Fatigue	0.06	0.001
Near miss	Fatigue	0.07	0.001
	Climate	0.06	0.009
Cross lane lines	Fatigue	0.07	0.001
	Climate	0.05	0.006
	Uncomfortable driver's seat	7.21	0.038
Over or under steering	Fatigue	0.02	0.001
Late braking	Fatigue	0.04	0.001
Colliding with other vehicles	Fatigue	0.13	0.001
	Climate	0.04	0.004
	Uncomfortable driver's seat	8.46	0.026

3.2 Multivariate Data Analysis – Summary of Significant External Non-driving Factors and Risk Outcomes

Table 2 shows the significant external non-driving factors and their corresponding associated safety outcomes. The survey results were distributed to the truck drivers, and the data was analyzed using the Multivariate Analysis tool. It was found that falling asleep at the wheel, running off the road, and over or under steering are the most significant effects that drivers often experience. Falling asleep, running off the road, and over or under steering are the most significant effects [8, 9], with three non-driving factors because of the risk factors, namely Stubborn Pedestrians, Stubborn Vehicles, and Uncomfortable Driver's Seat.

Table 2. Summary of Significant External Non-Driving Factors and Risk Outcomes

Non-driving Factors	Risk Outcome	p-value
Uncomfortable Driver's Seat	Falling Asleep	0.001
	Running off the road	0.001
	Near Miss	0.005
	Cross Lane lines	0.004
	Over or under steering	0.005
	Late braking	0.010
	Colliding with other vehicle	0.028
Stubborn Pedestrian	Falling Asleep	0.047
	Running off the road	0.036
	Over or under steering	0.010
	Late braking	0.010
Stubborn Vehicle	Falling Asleep	0.001
	Running off the road	0.003
	Over or under steering	0.011
Fatigue	Nodding off	0.002
Road Construction	Nodding off	0.017
Vehicle Size	Cross Lane lines	0.011

4 Conclusion

Analyzing external factors influencing truck drivers' safety outcomes reveals several significant findings. Fatigue emerges as a critical predictor of various safety incidents, with notably high odds ratios and statistically significant p-values across multiple outcomes, including nodding off, falling asleep, and near misses. Additionally, climate conditions substantially impact driver safety, with substantial associations identified with nodding off, falling asleep, and colliding with other vehicles. Stubborn pedestrians and vehicles on the road also contribute to safety risks, albeit with lower odds ratios than fatigue and climate factors.

Furthermore, non-driving factors such as the uncomfortable driver's seat significantly increase the risk of falling asleep, running off the road, and colliding with other vehicles. The presence of stubborn pedestrians and vehicles further exacerbates the risk of falling asleep, running off the road, and experiencing over or under-steering incidents. These findings underscore the importance of addressing both driving and non-driving factors in enhancing truck driver safety. Implementing measures to mitigate driver fatigue, improving climate resilience, and addressing non-driving factors like uncomfortable seating arrangements could significantly reduce the occurrence of accidents and near misses, ultimately contributing to safer roadways for all users.

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Development and Ergonomic Evaluation of a Mobile Bath and Hygiene Chair: Health, Comfort and Safety

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Abstract. For patients with motor limitations (temporary or permanent) and/or the elderly, a shower chair is an Assistive Technology designed to optimize bathing and hygiene activities, both for the patient and for the caregiver or Healthcare Professional. However, there are ergonomic issues in the use of common shower chairs that can lead to risks for users, involving aspects such as comfort, efficiency, and safety in their use. The aim of this work is to develop the design of a mobile chair for bathing and sanitizing, focusing on the needs of direct users (patients) and indirect users (Healthcare Professionals), complemented by an ergonomic assessment of the final product, based on functional, structural, and anthropometric aspects. The research is of an applied nature and its development was divided into three phases: (Phase 1) Theoretical Basis, related to the relevant themes of the project and gathering of technical information; (Phase 2) Development of the Bath Chair Project, using the Orientation Guide for Project Development (GODP, MERINO, 2016), which has a human-centered approach, (Phase 3) Ergonomic Evaluation of the Final Product, considering functional, structural and anthropometric aspects. As a result, it was possible to design and manufacture, on a full scale and fully functional, a mobile chair for bathing and hygiene, using the principles of User-Centered Design.

Keywords: Design for All · Assistive Technology · Health

1 Problem Statement

The shower chair is an Assistive Technology Device (ATD) that facilitates Activities of Daily Living (ADL), used in various types of environments, such as hospitals, rehabilitation clinics, nursing homes, residences, and home care (Curimbaba; Ferreira; Thobias, 2014).

This ATD is usually used by people with motor limitations (temporary or permanent) and/or elderly people who find it difficult to sanitize themselves independently. Healthcare Professionals and caregivers also play a key role in this context, due to their direct

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contact with the device, and should therefore be considered direct users of the product. For this reason, this study considered two groups of users: patients and caregivers or Healthcare Professionals.

The project was developed at the Institute of Psychiatry - IPq, in the State of Santa Catarina (Brazil), with the collaboration of an interprofessional team made up of Designers, Nurses, Engineers, Occupational Therapists and Physiotherapists, aiming for a comprehensive approach to improve users' living conditions.

Based on the problems identified by Curimbaba, Ferreira and Thobias (2014) and Merino et al. (2016) in similar models available on the market, such as: types of materials unsuitable for the environment and activities carried out in the IPq; inadequate sizing of fabric support areas; inadequate material and dimensions of industrial castors making it difficult to move them in small spaces, brakes and bearings not suitable for wet environments); general weight of the structure among others, compromising its functionality and especially safety.

These aspects have an impact in product quality that affects comfort, efficiency, and safety in its use, resulting in risks to its users. In this scenario, an opportunity was identified to develop the design of a mobile chair for bathing and hygiene, using a User-Centered Design (UCD) methodology.

2 Objective

The objective of this article was to develop the design of a mobile chair for bathing and hygiene, focusing on the needs of direct users (patients) and indirect users (healthcare professionals), complemented by an ergonomic assessment of the final product, based on functional, structural, and anthropometric aspects.

3 Methodology

The research is of an applied nature and its development was divided into three phases. The first of these included the creation of the study's theoretical basis, conceptualizing topics relevant to the project, such as 'User-Centered Design', 'Technologies and Design', 'Ergonomics and Assistive Technologies', as well as a survey of technical information. For this article, this part has been removed in order to disclose only the practical results.

Phase 2 exposed the development of the bath chair project, based on a User-Centered Design approach called the Orientation Guide for Project Development (Merino, 2016), which places the user at the center of each phase of the development of a product or service, supported by the GODP Set of Procedures (Costa, Merino, Merino 2023), as shown in Fig. 1.

Phase 3 also included stages 5 and 6 of the GODP (Materialization and Final Check) through an Ergonomic Evaluation of the Final Product, considering functional, structural, and anthropometric aspects, taking into account the patient and the caregiver or health professional. Structural, functional, and anthropometric analyses were carried out using a functional prototype.

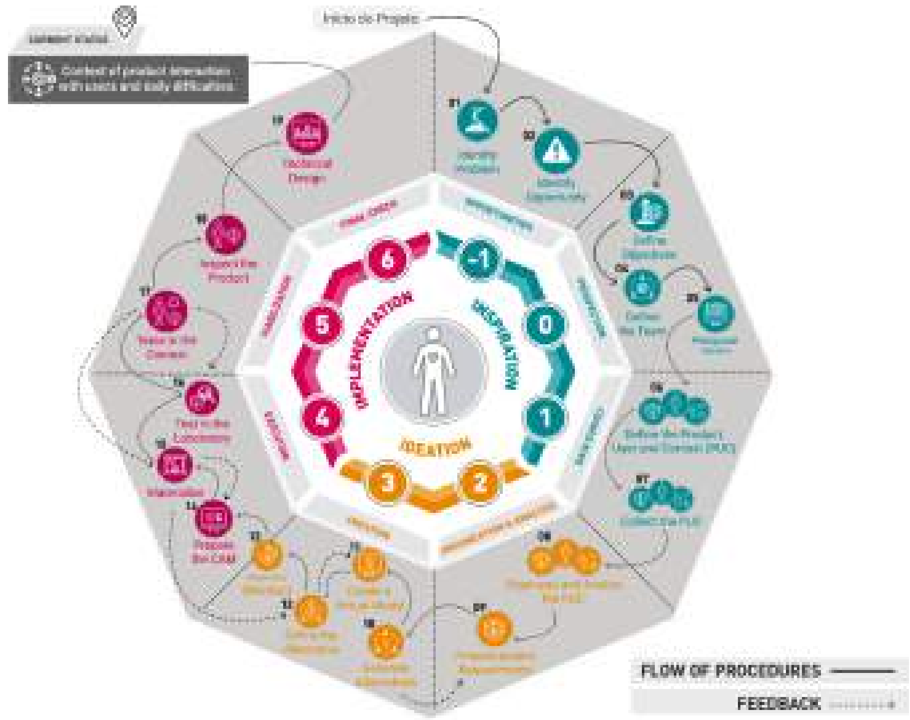

Fig. 1. Orientation Guide for Project Development (MERINO, 2016).

4 Results

4.1 Stage 2 – Organization and Analysis

Phase 2 – Development of the Bath Chair Project

As a principle for using the methodology, the Reference Blocks were first defined (see Fig. 2), which divided the project into three smaller parts, each containing specific information related to the Product, User and Context (PUC). With this tool, it is possible to analyze each of these aspects separately, thus obtaining greater depth and understanding of all the information that involves the product-user interaction, as well as the relationship that takes place in the environment.

Based on the research carried out in the Ideation Moment, project requirements were defined, which for a better understanding are presented in the form of Reference Blocks:

4.2 Stage 3 – Creation

Once the final prototype had been defined using the figure mentioned above, the virtual three-dimensional file was built using CAD software (SolidWorks®) for better visualization, analysis and planning of the product's materialization (see Fig. 4 – detail A). Next, a Virtual Ergonomic Simulation (VES) was carried out with the object, using Blender

Fig. 2. Project requirements.

software version 4.1.1 (see Fig. 4 – details B and C). To do this, two models of the Parametric Digital Human (HDP) were used, created in MakeHuman software version 1.2.0, the first corresponding to the 95th percentile of the user (health professional) – height 172 mm and 85 kg, while the second considered the dimensions of the patient (95th percentile) – height 195 mm and 110 kg (Fig. 3).

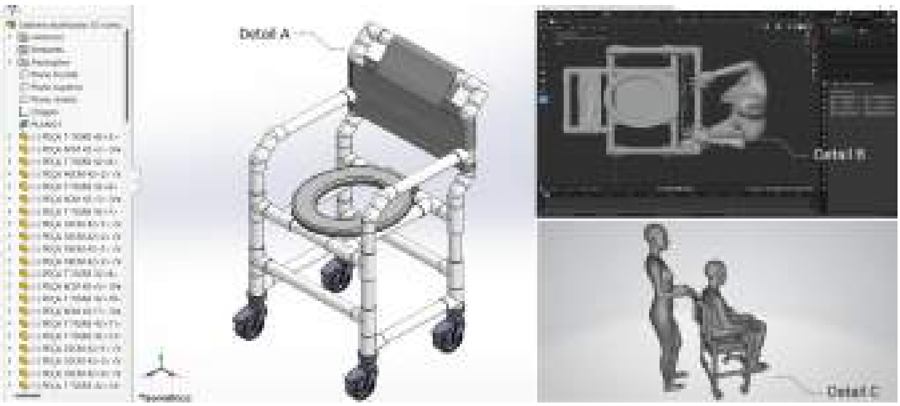

Fig. 3. Virtual file and virtual ergonomic simulation using CAD software.

The results of this simulation were satisfactory, as they corresponded to the expected design of the object, as well as meeting the previously defined requirements.

4.3 Stage 4 – Execution

The object's three-dimensional file was adjusted and organized to make production feasible. In addition, technical drawings of the mobile chair were made to obtain detailed dimensional information for each part. The first prototype was then produced in chlorinated polyvinyl chloride (CPVC) and taken for static and dynamic tests in the toilets of the Federal University of Santa Catarina (Florianópolis, Brazil).

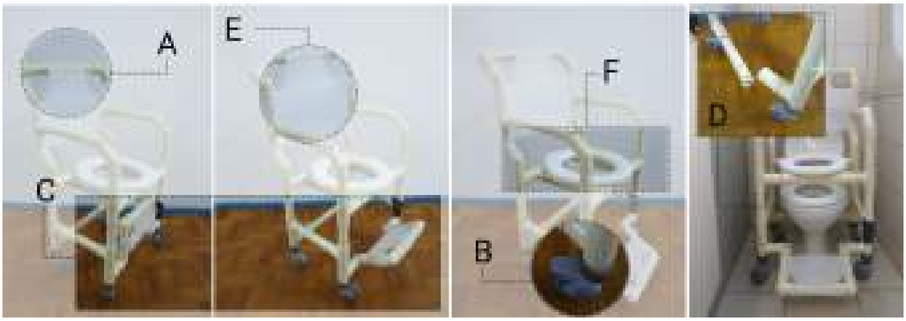

Fig. 4. Identification of adjustments to the first shower chair prototype.

In regards to the prototype, it is perceived to have a big advantage in relation to other models, because it is an object made up of pipes and fittings (through a partnership signed with a Brazilian multinational company that operates in the hydraulics segment), resulting in favorable characteristics such as: lightness, easy cleaning, modularity, impermeability and potential durability.

Furthermore, detail A favors the execution of user activities, and the caster model (specific for medical products) has significantly reduced the total weight of the product (detail B). In addition, the chair proved to be very stable and had no rolling noise in dynamic tests. No significant friction with the ground was identified either.

The footrest is articulated (130º) to suit the user's needs, as is a custom-made synthetic PVC support fabric. In addition, there is a removable structural rod (detail D), to make it easier for the user to attach the chair to a toilet to carry out their needs. On the other hand, it was identified the need to make adjustments to the footrest, as well as some fittings that made it difficult to use the object.

4.4 Stage 5 – Viabilization

Phase 3 – Ergonomic Evaluation of the Final Product

With a prototype that had already been corrected and optimized in the previous stage, a structural analysis was carried out to obtain a synthetic view of all the parts that make up the product, as well as a description of the materials used to make it and their quantities. It is possible to also access other information and details of the chair in the Qr-Code in Fig. 5.

After this, a second virtual ergonomic simulation was carried out, following the pattern of the previous one, considering the standards related to the 99th, 50th and 1st percentiles for both sexes (male and female), using the proportions measured by Tilley and Dreyfuss (2005). As a result, it was possible to conclude that the product was well-adapted to the different types of users (patient and caregiver or Healthcare Professional), since a variety of dimensional values were considered when simulating the product-user interaction.

The constitution by means of pipes and fittings was also positive and favorable to continued development, as it facilitates tests and adjustments that are identified as necessary by professionals and/or users.

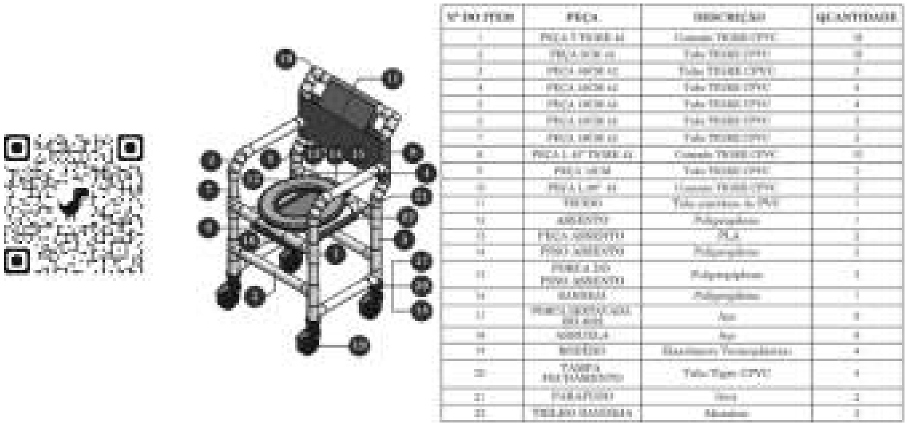

Fig. 5. Structural analysis of the prototype.

4.5 Stage 6 – Final Check

The product is currently at this stage, as it is still being developed and tested at the Design and Usability Laboratory of the Federal University of Santa Catarina (Florianópolis, Brazil).

5 Discussion

The new solution for the shower chair allows the patient to maintain proper and stable posture during static and dynamic procedures. This is because there have been changes to the handle; the total weight of the product; the type of castor, with locks; the footrest, with articulation; and the material (CPVC), which is more durable and easier to assemble.

The tests yielded satisfactory results, with the support of ergonomic evaluations of the final product, which confirmed potential in technical qualities such as: ease of cleaning and maintenance, as well as ergonomic qualities: good interaction between the product and the user (patient and caregiver or health professional), ease of handling, anthropometric adaptation, compatibility of movements, and items associated with comfort and safety.

6 Conclusion

One of the reasons for the satisfactory outcome of the project is related to the interinstitutional and interprofessional partnership signed between the project team, linked to the Federal University of Santa Catarina, specifically the Management and Design Center & Design and Usability Laboratory (NGD/LDU), with Healthcare Professionals from the IPQ, as well as collaboration with a Brazilian multinational company that operates in the hydraulics segment (for the pipes and fittings).

The project made it possible to develop a product that reduced and/or eliminated a series of problems found in existing products on the market, enhancing the health, comfort, and safety of its users (patients and professionals), demonstrating the potential of solutions that can be achieved through interprofessional teams.

It is important to note that there was a limitation in the evaluations of the prototype, since the development of the mobile chair took place in the midst of the COVID-19 pandemic context, most of the tests had to be conducted through virtual simulations.

As a result, the project is due to continue with tests in real life conditions of use at the Psychiatric Hospital, scheduled to begin in the first half of 2024, with the medical and design team continuous work to identify opportunities for improvement and consequently obtain an ergonomic product.

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Human Factors and Ergonomics in Human-Robot Interaction Design for Public Space Promote Perceived Safety

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Abstract. Still robots are more widespread in everyday working life than in public space. Favorable and humane implementation of robot systems in public space calls for concepts and findings in Human Factors and Ergonomics (HFE) for offering and promoting high-quality human-robot interactions (HRI) and perceived safety for passers-by and users. A systematic review of the international literature and discussions among experts identified HFE concepts, design principles and design factors of relevance. A system design concept is suggested for structuring results according application contexts. Some adaptations, specifications, and extensions seem necessary to support design of HRI in practice, especially for forming a basis for test and evaluation environments for future use of robotic systems in public space. Despite the design factors identified, more research is required for implementation of performance and safety improved HRI, facing the variability in public space, and evaluating design solutions in day-to-day environments.

Keywords: Human information processing · Work system design · Design principles · Literature Review · Human-robot interaction · Perceived safety

1 Introduction

Robots are not (yet) widely used in public space in European Union countries. Design requirements from occupational safety and health (OSH) as well as from Human Factors and Ergonomics (HFE) for human-robot interaction (HRI) in public space are largely unclear. Therefore, implications for practical implementation of HRI in public space are investigated, considering ethical, legal, performance, health, and safety aspects, informing a robotic system competence and interaction test cluster for HRI in public space [1]. With safety in HRI often limited to functional safety in industrial settings [2], in public space, an area of special interest for the design of HRI is perceived safety of users and passers-by to be addressed by prevention through design and presentation of design

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requirements of practical use. Encounter with robots may, for example, increase passers-by fear of approximation or collision even with built-in but invisible functional safety, or passers-by may be taken by surprise by sudden and extraordinary evasive movements of robots, to name but a few.

The given research is related to social robotics [3] but introduces robots in public space rather as agent or participant and is not intending robots to compensate for social behavior. Overlap is closer when robots in public space are designated for direct social interaction with users, e.g., when mobile robots act as city tour guide. Findings on the design of HRI according to HFE requirements in different settings suggest improvements in interaction performance and human perception of safety when working with technically and functionally safe robot systems (e.g., [4, 5]). Therefore, a review of HFE findings readily available or potentially relevant for HRI in public space is considered to inform about design requirements to prevent performance decrements and interferences with perceived safety.

2 Methods

A systematic literature review (EBSCOhost) in international databases (e.g., APA, IEEE, Medline, ScienceDirect) and effective from 2002 identified 371 peer-reviewed journal articles and conference papers referring to HFE and perceived safety in HRI. Exclusion of duplicates and review of titles left 52 papers for closer inspection of practical relevance for identification of HFE design requirements for HRI in public space.

Discussions in project workshops and among members of the work package on perceived safety suggested additional contributions to improve performance and perceived safety, i.e., the exploration of related standards on HFE related to machinery safety [6, 7] and related concepts such as work system design [8], extended safety [9], human trust in automated technical systems [10], and acceptance of robots [11].

Reviews and discussions provided identification and specification of suitable and robust characteristics of physical-technical performance as well as of perceived safety for robot systems in public space. The concept of work system design [8] is fundamental for designing according to HFE principles and consists of interdependent dimensions relevant in design [7]. In the given context, it served a structure to categorize design factors identified in the literature review and for feeding in a robot competence and interaction test cluster for HRI in public space.

3 Results

The literature review after text screening resulted in 43 papers informing about context relevant concepts (e.g., perceived safety, system design), measures (e.g., trust, acceptance), reviews (e.g., meta-analyses, topic summaries) and empirical investigations identifying design factors for HRI in public space. In the context of HRI, perceived safety is an interdisciplinary concept, internationally sometimes characterized by synonymous terms (e.g., perceived, psychological, mental safety) and for which classic approaches in OSH are a necessary, but not sufficient condition. Since perceived safety is associated both with the absence of accidents, diseases, and hazards and with the presence of safety and well-being, this points to a close relationship to extended concepts of occupational safety (e.g., [9, 12]). Such concepts build on familiar OSH processes and content, such as the hierarchy of controls based on risk assessments and place a stronger focus on risk assessments by directly involved and proactive actors in processes for action with potential risk at stake. The aim here is safety as freedom from unacceptable risk. Perceived safety may sometimes also conflict with risk classified as acceptable, as this may not always be perceived as safe.

Contributions of perceived safety for improving HRI quality suggest that HFE findings on human-centered automation design, such as trust in automation or robots (e.g., [10, 13]), should also be considered. In principle, performance characteristics (e.g., predictability of trajectories, [14]) and property characteristics (e.g., anthropomorphism, [15]) of robotic systems have an impact on trust and thus perceived safety in HRI, and in consequence, HRI quality. However, findings from human-automation interaction can only be partially transferred to HRI [16], since, for example, human tasks and thus trust in human-automation interaction tend to focus on results of interaction processes while the focus in HRI is on the interaction process itself. This in turn influences recording of trust in HRI to shape perceived safety.

Fig. 1. Inspection of functional performance testing of highly automated collection vehicle (Angsa Robotics GmbH, Germany) in rokit test scenario.

Contributions of HRI design for improving perceived safety suggest that suitable and robust characteristics of physical-technical performance with basic interactive features of functional performance of robotic systems should be integrated in the context of further development (e.g., robot stability, limited speed, see Fig. 1, [17]). In addition, consideration of HFE principles for the design of interfaces [18] foster HRI quality regarding interaction performance and human perception of safety. This refers to HFE design principles for task interfaces of a system with, e.g., provide feedback [19, 20], informing passers-by in public space about the purpose of a robot or reporting failure of task completion in service applications. HFE design principles for the interaction interface, e.g., conformity with expectations [6, 21], inspire that passers-by should negotiate mutual avoidance of collisions and sidestep to the right or left depending on the culture. HFE design principles for information interfaces, e.g., double coding for warnings [22, 23], propose signaling robot information in color as well as position coding. Use of HFE design principles likely positively affects perceived safety and results in improved quality of interactions of humans with robots in public space.

Enclosing the concept of (work) system design in HFE [8] advises to not only concentrating on a robot system alone to ensure improvements in interaction performance and human perception of safety. To ensure effective, healthy, and safe interaction, analysis, design, and evaluation should cover interdependent dimensions, such as tasks interplaying with conditions of a public space or weather conditions. This concept of system design is practical for structuring literature review findings from different sources to be categorized along interdependent dimensions of the concept referring to humans involved (e.g. passers-by, users), performing their tasks (e.g., using the walkway to a studio, e.g., [23]) affected by interacting conditions of action organization (e.g., being late for the appointment, e.g., [21]), space and place (e.g., crossing the greens in public parc, e.g., [4]), equipment and interfaces (e.g., facing a refuse collection robot, e.g., [15]) and environment (e.g., rainy dawn, e.g., [20]) of the system [7, 8]. This allows systematically to sort, present, and specify various design requirements identified in the review. In addition, results are readily available to be applied in contexts of use for future high-quality HRI design perceived as safe in public space.

4 Discussion and Conclusions

A review of international literature revealed findings for improvements of HRI quality and perception of safety and appeared suitable for structuring the application context. However, adaptations and extensions shall be carried out for HRI in public space in general and for the application context to be specified in scenarios in practice.

This broad range of HFE findings of proven relevance for improving HRI quality as well as perceived safety should not mask the fact that only little evidence is given for hands on design of high-quality HRI making passers-by and users feeling safe when coming across a mobile robot in public space. Apparently, there is urgent need for research, for implementation of results in practice and for further action. Limitations of practical knowledge for 'how to' is often due to explorative research still required for investigating potential factors of influence. There is a lack of evaluation studies investigating specific HRI designs in different contexts of use or with different populations, probably also due to missing requirements from practice.

For a long time, robotics is already applied in industrial settings, and this gives reason for elaborating about differences. HRI in public space is different from industrial settings, because of higher variability of conditions to be considered from a system perspective (e.g., types of tasks, unpredictable ground quality) with application contexts being less deterministic in public space (e.g., delivery indoors and outdoors). However, the main difference seems to be that variability of conditions is available across industries whereas in public space it always exists. Defining, specifying, and selecting public space seems to be helpful for approaching HRI design solutions.

HRI in public space is different from industrial settings, because of higher variability of the population of interest. Public space is rather open to all, e.g., passers-by and users, instead of limited to the working population and specifically qualified work forces. In common work contexts, HRI refers to occupationally trained personnel interacting with robot systems. However, in public space also general public with different age distribution interacts with robots and personnel related, i.e., may like to understand robots' function or requires negotiating about giving way. Research and design for HRI in public space face the challenge to consider additional or modified constraints and requirements for designing the robot system and its interaction modalities to fit to HFE design requirements, e.g., regarding human information processing, and anthropometrics, as compared to 'pure' labor conditions with OSH regulations in place.

Some of the results of the given research will be used for in field scenarios so that they can be investigated in public space with robot systems available in the project. To this end, design requirements are collected and specified, test environments are being developed, test methods derived, and test requirements evaluated. This will inform the robot competence and interaction test cluster for HRI in public space [1].

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Work Interruptions in Digital Information Work - A Scoping Review of Influencing Factors and Effects

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Abstract. Work interruptions are one of the most common stressors in the workplace and an increasing frequency of interruptions is, for example, associated with higher perceptions of strain and lower overall well-being. Although there is a large body of literature on the effects of work interruptions, an overview of the effects in the context of digital information work is still lacking. A systematic scoping review following the PRISMA-ScR Guideline was therefore carried out. The results show that previous research has taken a one-sided view of work interruptions, mainly analyzing the frequency of interruptions. However, different characteristics of interruptions may be associated with different effects and may even have positive effects. Given the constant presence of interruptions such as emails, text messages, calls and alerts in everyday working life, it seems unrealistic to avoid them altogether. It is therefore important to identify the characteristics of interruptions that are associated with both negative and positive effects in order to create a digital working environment that promotes productivity and reduces health risks.

Keywords: Scoping Review · Work interruptions · Information workers · Digital work environments

1 First Section

Digitalization is shaping almost all areas of work, leading to increasingly demanding and complex work tasks and processes [1]. In the work context, knowledge and service occupations are particularly affected by digitalization. Digital solutions in office work have become standard and the COVID-19 pandemic, during which many have switched to remote office work, has further accelerated the digital transformation of companies [2].

Whilst there are many benefits of the digitalization for both employers and employees, digital work also introduces new challenges. Emails, chat messages and phone calls are just a few of many possible interruptions of work. An interrupted task takes a third more time than an uninterrupted task, and an increasing frequency of interruptions is associated with higher subjective perceptions of stress and lower overall well-being [3,

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4]. In fact, Work interruptions are one of the most common stressors in the workplace [5]. Current research offers various definitions to describe work interruptions (for an overview, see [3]). In this article, the definition proposed by Brixey et al. [6] is adopted, according to which interruptions are characterized as unexpected, of internal or external origin that interrupt an ongoing primary task and involve a secondary task. However, it is crucial to recognize that external and internal interruptions have fundamentally different triggers, resulting in different characteristics [7]. This article focuses exclusively on external interruptions. Thereby, a clear distinction is made between the construct of work interruption and that of distraction (where one is not engaged in a secondary task) and multitasking (where one is engaged in several primary tasks), neither of which are the subject of the present review.

1.1 Research Questions

In the light of the accelerating digital transformation of work, it is important to explore the challenges and the effects of work interruptions and to develop appropriate strategies to protect employees from the short- and long-term negative consequences. With this aim, a systematic scoping review is presented that investigates external work interruptions in the context of digital information work and the effects they may have on workers.

2 Method

2.1 Review Protocol and Eligibility Criteria

The review protocol was developed based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR; [8]). To identify articles for the outlined research questions, the following four eligibility criteria were selected. Articles were required to report:

Concept: Definition of work interruptions as described above
Context: Digital information work as described by Tegtmeier [9]
Sample: Healthy, adult persons
Types of evidence sources: Peer-reviewed journal articles

As Rigotti [4] conducted a systematic scoping review on "disruptions and interruptions", which provides a comprehensive overview of the state of research up to 2016, this scoping review builds on and extends his findings. Firstly, the publications identified by Rigotti were screened and assessed according to the eligibility criteria, and only the relevant literature was used for this review. Secondly, a systematic scoping review encompassing literature from 2016 onwards was conducted in 2022. This publication focuses exclusively on the characteristics of the interruption and excludes characteristics of the person and the environment that may also influence the effects.

2.2 Search Strategy and Selection of Entries

The systematic literature search encompassed three databases: Web of Science, PsyIndex, and PubMed, utilizing a three-stage strategy. Initially, a limited search was conducted in two online databases to verify the defined search term's accuracy. Subsequently, all identified keywords and index terms were used in a comprehensive search across all databases. Finally, bibliographies of identified papers were examined for additional sources, adhering to the JBI guidelines. The following search term was used, in line with Rigotti [4]: ("interruption*" OR "distraction*" OR "intrusion*" OR "work interruption*" OR "regulation obstacle*" OR "regulation problem*" OR "distraction*" OR "disturbance*") AND ("work*" OR "task*").

3 Results

A total of 11,088 potentially relevant research papers were identified. After checking for duplicates, 372 of these hits were excluded. The titles and abstracts were then screened, followed by the full text. In the end, a total of 79 relevant research studies were identified. The identified publications date from 1989 to 2021, with the majority of the included research literature published since 2018. As described above, the results in this publication focus exclusively on the characteristics of the interruption and exclude the characteristics of the person and the environment, which were also analyzed as part of the full scoping review.

3.1 Analyzed Characteristics of Work Interruptions and Their Effects

Frequency. Research extensively examines the frequency of work interruptions, with 18 experimental and 15 field studies highlighting its impact. Increased interruption frequency correlates with negative outcomes: decreased general task performance [10–13], impaired working and long-term memory [14–16], lower perceived performance [12, 17], and prolonged task completion time [10, 18–20]. Additionally, frequent interruptions hinder action plan implementation [21], reduce accuracy [11, 15, 18, 19, 22, 23] although Kalgotra et al. [24] found no such effect. Moreover, interruption frequency positively correlates with general workload [25], lower job satisfaction [26, 27], increased stress [7, 28–30], emotional exhaustion [31, 32], and physical [28] and psychosomatic complaints [27], though Grebner et al. [33] reported no such effects. The impact on decision-making processes remains inconsistent [34, 35]. Fritz et al. [36] found that interruption frequency on Monday were positively associated with fatigue on Tuesday and indirectly with fatigue over the week.

Types, Content, and Format. Different content, different formats and different types of interruptions were analyzed in previous research. With regard to the content of interruptions, it has been shown that the content has an impact on performance, as incorrect information during an interruption leads to poorer performance [37]. Addas and Pinsonneault [38] show that work-related email interruptions are positively correlated with daily performance, but not with general perceived workload, which was also confirmed by Cheng et al. [31]. In contrast, the format of an email-interruption has no effect at least on the decision-making behavior [34]. Two studies have investigated the differences between interruptions by short messages and emails [39, 40]. The results show that while email-interruptions are related to negative effects for the working persons, IM-related interruptions are not. Further-more. Wilkes et al. [41], who focused on effortful versus restorative interruptions, showed only effortful interruptions are positively associated with physical and mental stress and cognitive fatigue.

Temporal Aspects. Interruptions' duration and timing were examined. Longer interruptions relate to higher error rates [42, 43], longer resumption lag [44–46], increased risk-taking [34], and more psychosomatic complaints [47]. Gillie et al. [48] explored factors characterizing disruptive interruptions, finding no correlation with interruption duration. Sykes [49] noted that office discussions were most time-consuming interruptions. Regarding the timing of interruptions, according to Jenkins et al. [50], the timing of an interruption has a strong influence on the interference that occurs in the brain. Interruptions during the course of the primary task generally lead to more errors and longer processing time (and not between subtasks or interruption tasks) [51], while end-task interruptions lead to poorer performance [52], although Wu et al. [53] found early-task interruptions critical for decision-making. Feldman and Greenway [54] analysed that the duration and timing of interruptions can have positive effects as long as they are deemed worthy, at 'good' times and short.

Similarity and Complexity. Research indicates that complex secondary tasks are associated with increased subjective strain [55], higher error rates [56], and longer resumption lags [57], but have no significant impact on long-term memory [58]. Furthermore, similarity between primary and secondary tasks hampers performance due to shared cognitive resources [15].

Further Characteristics. Gupta et al. [59] emphasize, that the interrupter can influence the outcome. Supervisor interruptions perceived as more disruptive. In addition, Brazzolotto and Michael [57] found that task enjoyment affects secondary task performance and resumption time, while Amaral [60] found that psychological distance to the tasks acts as a mediator. Stich et al. [61] found that email interruptions cause stress when they deviating from a preferred level. Perceived interruption over-load, which reflects feeling overwhelmed by interruptions, mediates mental stress effects in leisure time [62] and work contexts [26], however, Yin et al. [63] found no link to job satisfaction. In addition, Zoupanou et al. [64] emphasized that positive evaluations lead to less rumination and improved well-being.

4 Discussion

The literature search and synthesis conducted in this scoping review aimed to systematically gather existing research on work interruptions among employees performing digital information work. As already highlighted by Rigotti [4], work interruptions are not a new research topic. However, existing research in this area is still fragmented across disciplines, lacks integration and often focuses primarily on the frequency of interruptions. Other characteristics of interruptions have been investigated only to a limited extent and mostly in experimental studies. Although elaborate experimental designs and settings are used with ecologically valid tasks, most experimental studies leave a gap in transfer to occupational practice. In field studies, however, the investigation of interruption frequency dominates, with most field studies using cross-sectional questionnaires focusing on Likert scales or estimated numerical values of interruptions, although it has been shown that different interruption characteristics can be associated with different effects [10]. Furthermore, there are limitations to relying solely on subjective estimates, as perceived interruptions may not match actual occurrences. In fact, the perception of interruptions is emerging as a critical factor in understanding interruption effects as shown by Rick et al. [65]. The distinction is therefore essential for both research and practice in order to effectively analyze and mitigate the (negative) effects of work interruptions. In order to identify when and how interruptions lead to negative outcomes, it's essential to examine how interruptions are operationalized, taking into account both numerical and perceived frequency. In addition, the positive effects of work interruptions have been largely over-looked, although there is evidence of associations between certain characteristics or perceptions of interruptions and positive outcomes.

Like most scoping reviews, the one presented here has limitations that one should be aware of when interpreting the results. For one, the manual search and sorting processes are prone to error, particularly with such a large volume of literature. The articles reviewed also revealed incomplete definitions of work interruption and information work contexts, which may have led to both erroneous exclusions and inclusions of research. In this vein, building on Rigotti's [4] scoping review provided a good starting point for gaining an overview of interruption research, however, potential errors from Rigotti's work would also have been carried over in this review.

In summary, this scoping review highlights the predominance of negative out-comes in previous research, particularly in relation to the frequency of work interruptions, often assessed using experimental designs or subjective methods. Future re-search should broaden its focus to include different characteristics of interruptions, especially including those associated with positive outcomes. In addition, there's an urgent need to distinguish between objective and subjective interruption frequency in longitudinal field studies. Given the ubiquitous nature of interruptions such as emails, text messages, phone calls and push notifications in our daily work lives, avoiding interruptions altogether seems impractical. It is therefore important to identify the characteristics of interruptions that are associated with both negative as well as positive effects in order to design work environments that support our health in the long term.

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Utilising Digital Tools for Prevent Work-Related Musculoskeletal Disorders: A Systematic Application Review

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Abstract. Through a systematic review, this paper investigates digital and intelligent solutions in occupational safety and ergonomics, identifying 31 validated tools for preventing musculoskeletal disorders. It highlights integrating various technologies and functions, including checklists, workflow management, and collaboration support implemented in a multiplatform environment. The methodology adapts the PRISMA approach, focusing on digital solutions available in English or Hungarian, offering free licenses, and is compatible with Android, Windows, or iOS systems. Of 174 identified solutions, 31 met the criteria. The results showcase diverse functionalities such as record-keeping, compliance auditing, risk assessment, and data collection through desktop applications, mobile devices, and wearables. The discussion describes the identified functionality and presents the emerging trend of integrating digital methods into ergonomic assessments and occupational safety processes. The conclusion stresses the importance of validation and professional responsibility in applying these tools.

Keywords: Occupational Safety · Ergonomics · Digital Solutions · Musculoskeletal Disorders · Workplace Technology

1 Introduction

Work-related musculoskeletal disorders pose a significant threat to employees' well-being, necessitating effective preventive measures. This paper's importance lies in its exploration of digital occupational safety and ergonomics solutions, aiming to provide a comprehensive understanding of available tools. The identified and assessed digital solutions offer practical applications for MSD prevention and highlight the need for caution in their implementation.

Recent years have seen a shift in how we perceive work and the workplace, with occupational health emerging as a constantly evolving field [1]. Through a structured review, the paper seeks to identify, categorise, and showcase the characteristics of digital solutions. The primary objective is to offer insights into the functionalities of these tools, providing a foundation for understanding their role in preventing musculoskeletal disorders in the workplace. Additionally, the study emphasises the importance of responsible

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implementation in light of the occasional lack of validation, contributing to the discourse on best practices in workplace safety.

2 Methods

This paper is based on an adapted PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method [2] tailored for a safety, health, and ergonomics application review. This systematic approach ensured transparency and completeness in the review process.

The search aimed to identify relevant digital solutions meeting the criteria for inclusion in the systematic review, made by a Google search with the specified search term: "digital tool safety health ergonomics."

The inclusion criteria required scientific references to the identified digital tools, availability of information in English or Hungarian, provision of a free license, demo or trial period, compatibility with Android, Windows, or iOS systems, and an issuance date falling within the range of 2015 - 2023.

The selected systems have been installed, tested, and classified based on technological and functional characteristics.

3 Results

174 digital solutions were identified, of which 31 met the selection criteria. Regarding functionality, occupational health and workplace safety systems support various functions, e.g. record-keeping, compliance auditing, safety walks, checklist management, risk assessment, reporting, notification, and installed data collection systems. Desktop, responsive, mobile applications, wearables or installed data collection instrumentation, and data links are equally present.

Digital tools for occupational safety, which also serve ergonomic purposes, are available to support processes, reporting, documentation, and compliance. Key features of these tools include support for employee information provision and consultation and incident and accident reporting systems.

Assessment systems also incorporate augmented and virtual reality applications for training, integrating ergonomic assessment methods into computer-aided design systems, including virtual manufacturing planning and verification. Workflow management systems provide activity reminders, notifications, instant messages, and employee checks, allowing records of occupational safety and ergonomics activities, such as materials, equipment, employee competencies, occupational illnesses, accidents, exposures, and personal protective equipment, to be maintained.

Integration and data feeds from different systems and technological platforms, including machinery, workplace instrumentation, wearable devices, and occupational, professional, and legal databases, are also common. Furthermore, they can assess the risk of musculoskeletal disorders and provide user feedback based on wearable physiological data collection systems and visual posture analysis.

4 Discussions

The transition from traditional paper-and-pencil-based methods to digital solutions simplified the use of these tools and made them more accessible.

For example, the revised NIOSH lifting equation is accessible through various mediums, including Excel spreadsheets, online forms, and downloadable applications for mobile devices. Furthermore, incorporating the NIOSH lifting equation into complex evaluation systems underscores the versatility and adaptability of digital solutions in occupational health and ergonomics. [3].

The Rapid Entire Body Assessment (REBA) method [4] is another example of how traditional paper-based methods have been digitized. Initially, the REBA method was a paper-pencil tool and underwent digital adaptation to enhance its accessibility and functionality. This evolution is evident through creating web-based, Excel-based, and application-based versions of the REBA method.

Furthermore, the integration of the REBA method into video-based or inertia sensor-based motion capture systems showcases the practical application of digital technology in ergonomics evaluation. This integration allows advanced data capture techniques to conduct comprehensive ergonomic assessments in real-world settings.

Additionally, the incorporation of the REBA method into complex ergonomic evaluation frameworks underscores its versatility and adaptability in addressing a wide range of workplace challenges.

The diversity of technological functions extends within specific systems, facilitating seamless integration and adaptability to various tasks. For instance, web interfaces are designed to be responsive, accommodating both desktop and mobile devices, or separate mobile applications are developed alongside desktop versions. A prime example of this adaptability is ergo/IBV [5], whose structure aligns with the evaluation process, aiding in activity analysis, hazard assessment, selection of appropriate evaluation methods, execution of assessments, and documentation of intervention measures. This multifaceted approach ensures comprehensive support throughout the evaluation process, enhancing efficiency and effectiveness in occupational health and safety management.

Adopting cloud-based solutions for data storage and collaboration purposes facilitates seamless collaboration during evaluation, planning, and verification processes by enabling the archiving and sharing of data, documents, and videos related to assessments. For instance, the Vivelab [6] system utilizes cloud-based technology to allow professionals working at various sites to collaborate effectively with experts developing the evaluation system. This setup supports remote consultations for ergonomic assessments, ensuring that valuable insights and expertise are accessible regardless of geographic location.

Online checklists and applications, as well as checklists integrated into complex support systems, are traditionally used in ergonomics or occupational health and safety, serving multiple purposes such as hazard identification, compliance assessment, self-assessment, and training. Classic examples include the Egonomics Checkpoint 2.0, [7] which illustrates how well-structured checklists can effectively support self-assessment and training. Process management in occupational safety includes predefined tasks and processes, notifications, activity tracking, reporting, and alternative routes based on predefined conditions.

The primary limitation of this research was the initial identification of applications through a Google search, which may only capture some relevant tools available in the market. Additionally, the applications featured in this study are subject to frequent updates and changes, which can affect their functionality and relevance over time. Consequently, the findings of this research may not fully represent the current state of digital tools for occupational safety and ergonomics.

5 Conclusions

Numerous possibilities are available for addressing ergonomic tasks, enabling accessible and user-friendly evaluations, training, and implementing workplace ergonomic programs. The results also indicate that available solutions need more validation, making them applicable under professional responsibility. The limitation of the research is that, even with systematic data collection, the sample cannot be considered representative.

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Labor Reintegration: A Nonlinear Process-Since the Prescription to the Reality of the Labor Reintegration

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Abstract. *Problem statement.* From the ergonomics of activity, the central concept is the work activity, where there is a difference between the prescribed work and the real work. In this case, the prescription is by the law and the real is how the reality of the activity of the process of labor reintegration occurs.

The *aim* of this article is to present a reading of the phenomenon of the process of labor reintegration of people who have experienced long-term disability (common and work). *Method*: A qualitative study was carried out using the biographical method and the discursive interview technique with eleven participants. Narrative line was used analysis technique.

Results: Five ways of developing work reintegration were identified, which allowed us to understand that the phenomenon studied is complex due to its multidimensional and multitemporal nature; there are different processes depending on the experiences of those who live it, the contexts and organisations in which they develop; there is no single way of understanding it and intervening in it.

Discussion: This process is more than an administrative procedure that begins with the end of the period of incapacity for work. Instead, it begins from the moment of the occurrence of the event which of the event that alters the worker's state of health.

Conclusion: The phenomenon needs to be understood from a psychosocial and ergonomic point of view, going beyond the normative reading of health and safety at work. It must move from a model based on insurability to one based on the health of workers.

Keywords: Return to Work · Work conditions · Occupational Health · Process · Labor inability · Ergonomics of the Activity

1 Problem Statement

Returning to work after a period of disability is part of a complex, multidimensional phenomenon known as return to work (RT)[1], in which various actors and organizations are involved [2–5]. Return to work involves a constant exchange of information, expectations and meanings, along with agreements to be fulfilled and evaluated in order to promote what is useful for the employee and the employer [2].

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The RT process is influenced by personal characteristics, forms and conditions of work, which leads to the involvement of different actors and institutions [6, 7]. Research has shown that these factors relate to the physical and psychosocial characteristics of work, such as heavy work, physical work, repetitive and continuous effort, musculoskeletal strain, physical conditioning, uncomfortable working positions and exposure to noise, among other issues related to prolonged labor inability [3–9].

At the organizational level, there is extensive research on employer factors that predict the duration of labor inability, including a people-focused culture and an organization with a proactive return-to-work program with a positive safety climate and ergonomic design practices [10–12]. Other factors include early intervention activities such as case management, compensation coordination with the primary care provider, accommodation assessment, work modification, supportive exercise, and return to pre-injury activities assessed through motivational interviewing and cognitive behavioral interventions [13].

Other studies have shown that work is characterized as a necessity, a source of pleasure, recognition and socialization [14]. Work is seen as a guarantee of material subsistence and active participation in society. It is also a source of suffering due to feelings of exclusion and social segregation. Although work alludes to negative feelings, it is perceived as something positive, and health professionals should therefore facilitate a return to work [12–15].

Several studies have addressed aspects of RT related to the positive impact of work on people's health [16], the construction of expectations, and perceived uncertainty [12–17]. Regarding the RT process, a linear perspective has been found in the literature. In this way, there are some steps, first taking into account the worker's recovery period, a second contact with the worker, a third contact to evaluate the worker and work tasks, and a fourth contact to develop the return-to-work plan with accommodations, followed by the resumption of work and a final follow-up to determine the progress of reintegration [18, 19]. Due process must be followed because there are challenges for the individual, the organization, and co-workers; therefore, early contact should be made [20].

Finally, studies of RT have focused on workers before they return to work [21–23]. Other studies have focused on the opinions of health professionals regarding the facilitators who participate in the work reintegration process [24], and in other studies the interest has focused on workers who are active again after periods of work incapacity [7–12, 15–24].

On the other hand, from the point of view of activity ergonomics, the central concept is the work activity, in which there is a difference between the prescribed work (what the worker has to do, i.e. the task to be performed, i.e. the task defined in advance by the organizations) and the real work and the real work, which is how the worker carries out in practice the instructions given to him through the procedures and standards (which in themselves are the activity itself) [25]. In this case, the prescription is through the law and the real is how the activity of work reintegration takes place in reality.

In this sense, this article presents an approach to work reintegration as a multidimensional and multidirectional process, taking into account the voices [26, 27] of workers who have experienced long periods of labor inability and have returned to work.

2 Objective

The objective of this article is to present a reading of the phenomenon of the process of work reintegration of people who have experienced long-term labor inability (common and work).

3 Method

A qualitative study design that used the biographical method and the discursive interview technique [28, 29]; thus, the method is essentially narrative, its purpose is to understand the process of work reintegration from the worker's perspective. Eleven workers were enrolled as participants, the majority of the participants had been off work for more than 30 days, two participants had suffered traffic accidents and two participants had a common illness, six participants had experienced work-related accidents, and one participant had experienced two accidents, one common and one work-related.

Narrative lines were used as an analysis technique, it was an explanatory resource to show that the process of work reintegration is diverse and has different paths [30].

Ethical aspects: The Deontological and Bioethical Code of Psychology, Law 1090 of 2006, Title II, Article 2, paragraphs 6, 9 and Chapter IV, Articles 49, 50, 51 of Colombia were followed [31].

Accordingly, the following criteria were applied: An invitation to participate in this research was sent. Individuals interested in participating in the research signed an informed consent form, and their information was kept confidential. When interacting with participants, attitudes that conditioned participants' responses were avoided. Information collected was carefully stored, and participants were guaranteed the right to anonymity. Risk management was considered, taking into account the principles of nonmaleficence and beneficence established for conducting research with human subjects.

4 Results

5 Labor Reintegration Process and Its Bifurcations

In order to show the different ways of understanding the phenomenon, narrative lines have been used as an explanatory resource to demonstrate that the process of reintegration into work is diverse and has different paths. This understanding implies referring to reintegration as processes in the plural, since the phenomenon does not appear in a single way and is not always linear; each process depends on the development of another, on the experience of each person and on the social, organizational and administrative contexts [32]. Five types of the phenomenon have been identified:

Form 1 - Traditional-Linear Cases: Some participants (P1, P3, P5, P6, P8, P10, P11) had the experience of being disabled immediately after the occurrence of the health-illness event, ending the period of disability and returning to work with medical recommendations. Due to regulatory effects, some types of reintegration were presented as the norm, such as reintegration without modifications, reintegration with modifications, temporary work relocation, permanent work relocation, or manual reconversion of work, and these workers were not disabled again after their return. If we consider only these experiences, we might get the impression that the phenomenon is linear, i.e. the health event/illness - period of labor inability - termination of work - return to work. However, a second way of looking at the phenomenon shows how changes indicate that the experience is not so sequential for everyone who goes through it.[1].

Form 2 - Case with Interruption of the Incapacity to Work at the Beginning of the Event: A participant (P9) was disabled immediately after the onset of his health event. However, due to problems related to the delay in the approval by the health system, his period of work incapacity was interrupted; therefore, he had to return to work without medical support. Later, due to his health-illness process, he was again incapacitated and later returned to work; this process occurred several times.[1].

Form 3 - Case Without Initial Diagnosis: This case presented a different situation. P4 experienced a health-illness event but was not immediately incapacitated due to the lack of a diagnosis, which implied that the person was working while incapacitated. "Some clinicians view temporary disability as a marshy area where the same criteria cannot always be applied to the same people or situations. Proper management of temporary disability requires a proper diagnosis of health problems, knowledge of the law, and good doctor-patient communication" [1–33].

Form 4 - Case of Formal Labor Inability - Real Work: In P2's experience, the onset of the health event was immediately disabling. However, during the period of incapacity, P2 was able to work remotely, which does not happen in all cases. This possibility depends on the employee's position within the organization. In this case, the person is "disqualified" from working remotely because of the health condition.[1].

Form 5 - Case Between Real and Formal Work and Labor Inability: The complexity discussed at the beginning of this paper becomes much more apparent in this case; one participant (P7) was not immediately disabled. Despite his injury, he continued to work personally. Later, when he was incapacitated, he continued to work in some way. When the period of disability ended, he returned to work in person. However, after a period of time, due to his health-illness process, he again received medical disability benefits, thus starting a cycle of leaving and returning to work. Such an experience, in which there are parallel situations (health-illness-disability event and work; a period of labor inability-work during the period of work incapacity; return to work while the health-disease process continues), confirms the need to broaden the psychosocial and ergonomics reading of the phenomenon.[1].

6 Discussion

Health is not a state, it is dynamic because it is related to the changing reality: "reality in this case refers to the material, affective, relational, family and social environment" [32], which is also related to the social determinants of health [34].

This qualitative study highlighted the complexity of the work reintegration process. The process is multidimensional, multitemporal and nonlinear, with many nuances and characters or actors (organizations, companies providing care and economic services such as ARL and EPS, family and friends) that participate directly or indirectly and influence the recovery of those who experience a change in their health-disease process. [1].

The phenomenon becomes complex due to all the psychosocial and ergonomic implications. The worker changes his relationship with himself, work, family, colleagues, supervisors and companies, so it is important to study the phenomenon in its entirety. In addition, the results help us understand that there are changes in the very reading of the health process and in the economic and social aspects of work. [1].

Finally, the results of the research showed that the beginning of the process of reintegration to work occurs before what is proposed in the Colombian regulations (termination of labor inability, because the beginning is the occurrence of the health-illness event and this phenomenon is marked by different moments, such as the period of disability, the end of disability and return to work with medical recommendations, and reintegration planning). The first step should be to consider the worker's recovery period, the second step is the initial contact with the worker, the third step is the evaluation of the worker and work tasks, the fourth step is the development of return-to-work plans with accommodations, the fifth step is the resumption of work, and the sixth step is the follow-up after the individual returns to work [1, 2, 19, 20].

At times, employers tend to prioritize administrative issues with economic interests over workers' health care (EPS and ARL). This point is consistent with the following statement: "… the displacement they [workers] experience between home and health care facilities to attend medical appointments, surgeries, check-ups and the procedures of these activities, many of which are unnecessary due to lack of clear communication. These displacements are a source of economic wear and tear, loss of time, and worker fatigue…" [12] and the author's discussion of workers' perceptions: "… workers consider that health and occupational risk entities do not want to take their case, the costs related to their treatments and compensation, which affects their recovery and economic income…" [12].

Thus, in the reading of the processes of return to work, a broader vision of health should include the social determinants of health, ergonomics, psychological, biological, social and economic components due to the additional costs; findings on the research of the health-disease process [35] imply a call to broaden the reading from safety regulations to occupational health, shifting the focus of the model from insurability to workers' health.

7 Conclusions

Work reintegration is a complex, multidimensional, multitemporal and multidirectional phenomenon. It is not a single process. It can involve multiple processes that can be non-linear, depending on the experiences of those who undergo it and the situational contexts and organizations in which it occurs.

Importantly, this reading of labor reintegration in a context such as Colombia is possible in the context of employment that includes modalities such as informality, service provision, and independent work where social security is not guaranteed. In the future, it will be important to conduct studies in contexts and countries where the majority of the population is not fully employed, in order to consider public policies for the health of workers in all types of work.

The phenomenon requires an understanding based on the psychological, ergonomic, social and cultural factors involved, which is why it must be seen beyond purely regulatory administrative procedures that conceive it as a consequence of the end of the labor inability period; it is important to move from models focused on insurability to models focused on workers' health, broadening the reading of ergonomics and clinical and occupational psychology in the person-work relationship.

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Study on EEG Characteristics of Different Personality Errors Under Time Stress

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Abstract. This research explored how time pressure modulates human error generation and its neural correlates across personality dimensions. Using a dual-condition paradigm (pressure-free vs. time-pressured tasks), we analyzed subjective stress ratings, behavioral accuracy, and EEG recordings from 41 participants classified via the Big Five Personality Inventory. Results revealed that highly neurotic individuals exhibited amplified stress responses, marked by a pronounced Pe amplitude enhancement in error-related potentials, whereas error-related negativity (ERN) remained stable across conditions. Time-frequency decomposition showed suppressed alpha (8–12 Hz) and beta (13–30 Hz) oscillations during time-pressured tasks. Notably, openness levels significantly predicted beta-band energy variations under pressure, with high-openness individuals displaying distinct neural adaptability. These findings clarify the neurocognitive pathways linking time pressure to error monitoring and underscore the divergent roles of neuroticism (stress sensitivity) and openness (neural flexibility), offering an empirical basis for designing personalized training protocols to enhance cognitive resilience in time-critical scenarios.

Keywords: Time stress · Human error · Big-five Personality · EEG

1 Introduction

Human error is one of the major causes of accidents in the aerospace, nuclear, and military fields, which require the operator to respond correctly within a short time period (i.e., there is time pressure). Due to the modulation of personality and operators have certain individual differences. Therefore, it is of great significance to study the mechanism of human errors under time pressure, which can reduce the probability of human errors from the root, and improve the reliability of the human-computer system.

The term personality was first proposed in 1937 by Albert, who believed that personality is a unique internal dynamical system that determines an individual's successful adaptation to the environment, while personality traits are some enduring character traits

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of each individual based on his or her physiology [1]. Tappes proposed five relatively stable traits that can describe personality [2], which were validated by scholars and eventually formed the Big-five Personality factor model, namely, Openness, Conscientiousness, Extraversion, Pleasantness, and Neuroticism.

The research on human error was more common in nuclear industry, air traffic control, railway transportation and medical aid implementation [3]. Most of these macro-analytical methods start from human operational behavior and lack in understanding of human errors from a human cognitive perspective, thus failing to identify and solve the problem fundamentally.

It has been shown that in the case of psychological stress induced through time pressure, the load of early perceptual processing is increased and the speed of perceptual processing is slowed down, suggesting that more cognitive resources are taken up in the later stages of information processing [4]. Kong et al. pointed out that when the time pressure exceeded the operator's tolerable range, the operator's behavioral reliability increased as the pressure decreases, and they proposed to adopt the way of assigning tasks to reduce the operator's time pressure and improve the behavioral reliability [5]. Some researchers have since explained the double-edged effect of time pressure using a variety of theories [6], indicating that appropriate time pressure will improve performance and reduce human mistakes, the key is to find the most suitable level of time pressure for individuals.

In this study, we conducted an analysis of the psychological behaviors and EEG characteristics associated with human errors under time pressure. We aimed to clarify the specific EEG indicators related to human factor errors occurring in high-pressure situations and shed light on the cognitive effects of time on error processing. Additionally, we explored the correlation between each personality trait within the Big Five personality model and their respective associations with EEG indicators, thereby identifying which personalities are particularly sensitive to these indicators.

2 Method

2.1 Subjects

The study recruited 41 graduate students pursuing master's degrees from a university. Participants were instructed to maintain adequate sleep prior to the experiment, follow regular dietary habits on the test day, and refrain from consuming stimulant beverages, including but not limited to alcohol, caffeinated drinks, and energy-enhanced sodas.

2.2 Experimental Tasks

Participants were presented with a series of colored words, and there were both matches and mismatches between word meanings and colors. When there was a mismatch between word meaning and color, the participant was required to press the space bar as quickly as possible. When the words were repeated on two consecutive trials (repetitive NoGo) or when there was a match between the word meaning and the color (Consistent NoGo), subjects did not need to make any response.

2.3 Experimental Equipment

The hardware of the experimental system mainly consisted of one set of EEG acquisition equipment, one stimulation computer, and one EEG recording computer.

3 Experimental Results

3.1 Subjective Stress Data

Statistical analysis of the stress self-assessment scale revealed that participants exposed to time pressure reported significantly higher stress levels ($p < 0.001$) compared to those in the no-pressure condition, with separate calculations of mean and standard deviation for each experimental group.

3.2 Behavioral Performance Data

Under time pressure, participants exhibited markedly elevated error rates compared to without time pressure ($p < 0.001$). This pattern was observed across multiple metrics: the incidence of consistent and repetitive false reporting, frequency of incorrect keyboard inputs, and omission counts all demonstrated a substantial increase in the time-limited scenario ($p < 0.001$). While remaining measures also differed significantly between groups ($p < 0.05$), response latency analyses revealed an inverse relationship. Specifically, both accurate response times and erroneous response durations (including consistent and repetitive error subtypes) were prolonged in the non-pressured environment relative to the time-stressed condition ($p < 0.001$).

3.3 ERP Data

Neurophysiological analysis revealed distinct patterns between event-related potentials. Data presented in Table 1 demonstrate that error-related negativity (ERN) amplitude exhibited no statistically meaningful variation across experimental conditions ($p = 0.223$). In contrast, error positivity (Pe) amplitude displayed robust condition-dependent modulation, with effect size magnitudes reaching stringent significance thresholds ($p < 0.001$).

Table 1. Amplitude and P value of ERN and Pe (Average ± Standarddeviation, μv) (N = 31)

EEG index	No stress	Time stress	p
ERN	−1.41(±2.34)	−0.73(±2.41)	0.223
Pe	3.27(±4.08)	6.72(±2.84)	<0.001

Note: * $p < 0.05$,** $p < 0.01$

All participants were divided into high and low level groups according to the average of the each personality ratings. The results illustrated that there was significant difference in Pe amplitude between low levels of pleasantness personality and responsibility personality in the no-pressure condition, and that the high pleasantness group was higher than the low pleasantness group, while the high responsibility group was higher than the low responsibility group.

3.4 Time-Frequency Data of EEG

For each participant, β-ERD and α-ERD magnitudes were measured from ROI1 (FCz lead) and ROI2 (PO3 lead), respectively. Statistical comparisons of mean values and standard deviations under the two experimental conditions revealed distinct neural activation patterns. As presented in Table 2, both β-band ($p = 0.001$) and α-band ($p = 0.002$) energies exhibited statistically significant differences between conditions. Notably, the absence of pressure was associated with increased oscillatory activity in both frequency bands, suggesting enhanced cortical synchronization in the pressure-free environment.

Table 2. Energy 0f α-and alpha β-band(Average ± Standard deviation, $\mu V^2/Hz$)(N = 31)

EEG index	No stress	Time stress	p
β-ERD	0.062 (±0.030)	−0.057 (±0.019)	0.001**
α-ERD	0.007 (±0.058)	−0.159 (±0.035)	0.002**

Note: * $p < 0.05$,** $p < 0.01$

Based on the Big Five personality scores, all subjects were divided into high and low level groups according to the average of each personality score. Independent samples t-tests were performed on the β-band energies and α-band energies under the two experimental conditions with the groups being the high and low levels of each personality. The results showed that there was significant difference in β-ERDs between high and low levels of open personality in time pressure, and the high openness group was greater than the low openness group.

3.5 Correlation Analysis of Data

Correlation of Big Five Personality and Subjective Stress Correlation. Psychological trait correlations were examined by computing Pearson's coefficients between Big Five personality dimensions and stress ratings across experimental contexts. Analyses revealed context-dependent relationships: In the pressure-free paradigm, elevated neuroticism scores predicted higher self-reported stress levels ($\beta = 0.436$, $p < 0.01$), whereas agreeableness demonstrated a buffering effect against perceived stress ($\beta = -0.387$, $p = 0.013$). These patterns intensified under time-constrained scenarios, with neuroticism showing stronger positive associations ($\beta = 0.436$, $p = 0.004$) and agreeableness maintaining significant negative correlations ($\beta = -0.383$, $p = 0.014$) with time-pressure evaluations.

Correlation of Big Five Personality and Performance. The aggregate Big Five personality scores showed no statistically significant links to the total error rate across either experimental condition.Under time-pressure conditions, distinct patterns emerged. Neuroticism exhibited a positive association with consistent false report reaction times ($r = 0.323$, $p = 0.039$) but a negative correlation with general false report reaction times ($r = -0.346$, $p = 0.027$). Both consistent and repetitive false report reaction times were inversely related to neuroticism ($r = -0.342$, $p = 0.029$; $r = -0.331$, $p = 0.035$).Conscientiousness demonstrated a positive relationship with correct response reaction times ($r = 0.321$, $p = 0.041$). While negatively correlated with consistent false report reaction times ($r = -0.335$, $p = 0.032$), it showed a positive connection to general false report reaction times ($r = 0.337$, $p = 0.031$).

Time pressure uniquely modulated the behavioral impacts of neuroticism and conscientiousness, with opposing directional effects on error-related reaction times. No personality-performance associations were observed in other experimental contexts.

Correlation of Big Five Personality and ERP. A positive association was observed between Pe amplitude and neuroticism scores under time pressure, with statistical significance ($r = 0.420$, $p = 0.019$). No other Big Five traits exhibited significant relationships with Pe amplitude in this experimental context.

Correlation of Big Five Personality and ERSP. A statistically significant inverse relationship emerged between β-band energy levels and openness scores ($r = -0.368$, $p = 0.042$). This association was specific to the β-frequency range and the openness trait. No other personality dimensions within the Big Five framework showed significant links to spectral energy measures in this condition.

4 Discussion

Individuals with high neuroticism exhibit enhanced Pe amplitudes under time pressure, likely linked to their heightened emotional sensitivity and stress susceptibility. Mechanistically: 1) Stress-induced impulsivity may increase error rates, thereby amplifying Pe through heightened post-error awareness; 2) Stress amplifies this group's hypervigilance toward errors, exaggerating error perception due to self-doubt even during correct responses. Notably, the neuroticism-stress interaction primarily modulates late-stage error processing (Pe) rather than early error detection (ERN), aligning with the hierarchical dissociation of these neural markers in error monitoring.

Beta-band power decreased under time pressure, corresponding to weakened error-response inhibition. The typical association between stronger beta oscillations and enhanced inhibitory control was disrupted by stress, with reduced beta synchronization directly reflecting impaired regulation. These results identify beta attenuation as a neural indicator of stress-induced inhibitory deficits during error monitoring.

The ERN amplitude of the two experimental conditions showed an opposite trend, that is, the lower the total error rate, the greater the ERN amplitude, which is consistent with the results of previous studies [7]. It might be that the brain's ability to monitor errors was weakened under stress, which in turn led to a reduction in the magnitude of ERN [8].

Alpha-band oscillations demonstrated an inverse relationship with sustained vigilance, mental workload, and error monitoring. Elevated levels of internal alertness, task-related cognitive demands, and post-response error detection were linked to reduced α-band power and suppressed oscillatory activity. Under time-constrained conditions, α-band energy values significantly declined alongside diminished oscillation intensity. This pattern suggests that temporal stress heightened participants' focus on error identification and real-time performance monitoring. However, such hyper-attentional engagement concurrently depleted limited cognitive resources, leading to an overload effect that exacerbated task-processing inefficiencies.

In conditions of time pressure, individuals with high openness personality showed greater β-ERD amplitude compared to those with low openness personality. This revealed that individuals with higher levels of openness have stronger inhibitory control over erroneous responses, which may be related to the personality differences between high and low openness individuals. Those with high openness personality tended to prefer challenges and adventurous exploration, while those with low openness personality were more conservative.

In this study, it was found that under time pressure, the energy value of the alpha frequency band decreases and oscillations show attenuation, indicating that stress leads to an increase in participants' alertness level and awareness of errors. However, it also consumed excessive attention resources, resulting in increased cognitive load.

5 Conclusion

This study demonstrates how error-related ERP components and time-frequency dynamics can capture the impact of time pressure on human error modulation. Among the Big Five personality traits, individuals with high neuroticism displayed the strongest stress reactivity, whereas extraversion, openness, and conscientiousness showed selective sensitivity to isolated neural or behavioral markers. For practical implementation, organizations could integrate personality profiling (via the Big Five framework) with tailored interventions—such as resilience-building programs for neurotic individuals—while monitoring ERP and time-frequency metrics to refine stress-adaptation strategies. This dual approach may optimize both stress resilience and task performance precision in high-pressure environments.

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A Simulation Research on the Thermal Comfort of Pilots in Air Ventilation Clothing During High-Altitude and High-Temperature Operations

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Abstract. During the high-altitude operations, pilots would suffer from heat stress. The air ventilation clothing is usually utilized for promoting the comfort of the human-clothing microclimate. It is necessary to obtain accurate ventilation setting conditions and assess the cooling efficiency of clothing in such environments. A reasonable design of the pipeline layout and flow distribution of clothing could help improve the thermal comfort of the human body. In this study, A three-dimensional human body model with the air ventilation clothing was established, and the simulation of body temperature distribution was conducted with ANSYS FLUENT software. The temperature distribution on the surface of human body skin and the outer surface of clothing were compared when the ventilation temperature is 18 °C. In general, the distribution range of skin temperature was from 31 to 37 °C. Overall, the results of human body and clothing temperatures calculated were relatively uniform. In accordance with the calculation results, the wind temperature and flow rate which could maintain thermal comfort of the human body were suggested.

Keywords: Heat Stress · Thermal Comfort · Air Ventilation Clothing · High temperature

1 Introduction

Affected by ground high temperature, heat release from electronic equipment, solar radiation and other factors, pilots may experience heat stress phenomena such as reduced hypoxia tolerance and increased error rate during the operation process [1–3]. In a high-temperature environment, the normal thermal balance of human body would be disrupted, which will seriously affect the function of the body, specifically manifested as affecting the pilot's reaction time [4], cardiovascular function [5], hypoxia endurance, etc., and serious cases will lead to flight accidents.

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Cooling clothing could provide protection for high temperature operators and improve the comfort of the human microclimate zone. According to the cooling medium, cooling clothing could be categorized into gas cooling, liquid cooling and phase change cooling [6]. All three types of cooling suits play a role in improving thermal comfort and reducing heat stress [7–9]. Among them, ventilation clothing could inlet and homogenize air of appropriate temperature to the body. Air ventilation clothing uses cold air to be discharged into the clothing, allowing the flowing cold air to dissipate heat and cool the human body [10–12]. A reasonable design of the pipeline layout and flow distribution of clothing could help improve the thermal comfort of the human body.

Since the implementation of the Apollo program, the U.S. has conducted a large number of modeling and simulation studies of thermal management within clothing (space suits). Since the 1990s, related research were also begun in China. In the early stage, most of the human thermal models were one-dimensional 10-segment models [13], while the geometrical refinement of the human thermal models has been improved, which mainly focused on the increase in the model segments and the improvement of the model dimensions [14]. Nowadays, more detailed segmentation of the human thermal model has been used, such as 15-segment human thermal model based on the Wissler model [15] and the Fiala model [16]. Currently, computational flow dynamics (CFD) were focused on anatomical and geometrical combinations of thermoregulatory models, solving accurate heat exchange in non-uniform environments and during dynamic activities [17–20]. However, there are few studies on the relationship between heat transfer between air ventilation clothing and the human body, especially in the high-temperature environments.

2 Model Description

In this study, Solidworks and ANSYS ICEM software were used to establish the human body model with the air ventilation clothing, mesh and set initial boundary conditions. ANSYS FLUENT software was used to complete the thermal simulation.

2.1 Clothed Human Model

The three-dimension human body was modeled in accordance with the Standard GB 10000-1988. The clothing was composed of inner layer, airtight layer, constraint layer and outer fabric, and the dimensions were established on the basis of human body dimensions. The inner layer was set to keep close to the human body, while the outer layer, constraint layer and airtight layer were regarded as one. As the pressure difference between the inside of the garment and the outside environment is about 35 kPa [21], the clothing would not be fully inflated, and the gap between the clothing and the human body was set to be 20 mm. The folds of the clothing were treated as the roughness of the heat transfer surface, indicating an increasee of the airflow turbulence solved by the turbulence model. In addition, the head ventilation is fed from the top of the helmet.

The human body model consisted of a core layer and a tissue layer wrapped around the core, which integrated human skin, muscle, fat and blood flow together as a layer of equivalent body surface tissues. The model was set with a thickness of 20 mm, and the thermal conductivity was the equivalent thermal conductivity of the all tissues fit together, taking into account the enhancement of the effect of blood flow on the heat transfer. The computational domain is the gap between the garment and the human body, with a mesh number of about 4 million.

Ventilation would be provided along 6 pipelines leading to the head, back, both wrists and both ankles, with the outlet set at the abdomen. Each air supply inlet was set directly in the model without constructing the ventilation pipes physically. The air inlet at the wrists, ankles and head positions were set to the gap between each segment and the cuff of clothing or helmet.

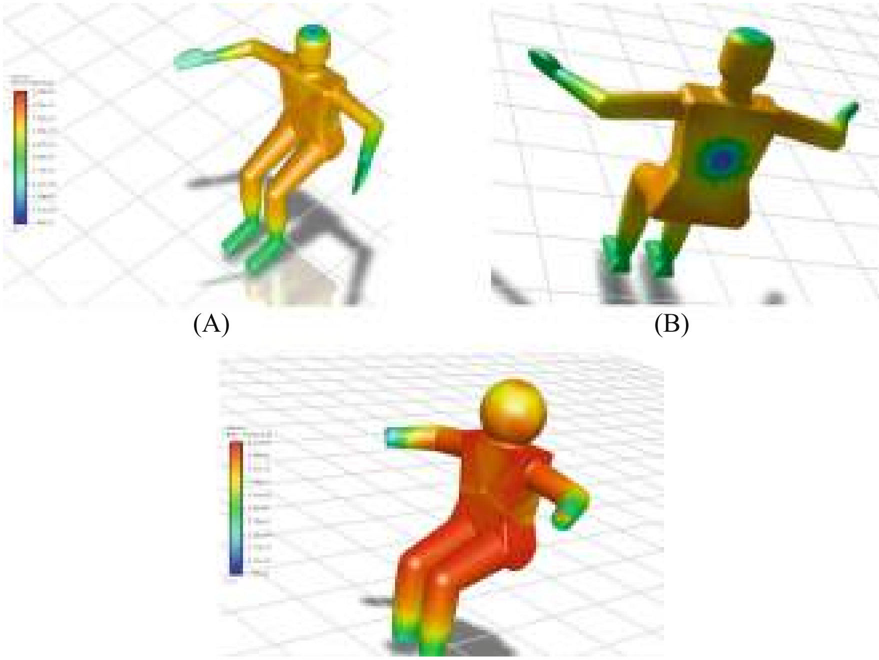
2.2 Configuration of Calculation Model and Parameters

Due to the small thickness of the clothing material, the lateral heat conduction of the garment material was not considered. As the temperature of the cockpit could increase to approximately 40–45 °C [22], existing a temperature difference with the clothed human body model, the radiant heat transfer was considered in the calculation of heat dissipation within the clothing. The outside surface of the clothing was set as a constant temperature boundary, with the average value of 42.5 °C. The gaps between the two wrists and ankles and the clothing were set as ventilation inlets, so as the air inlets on the top of the head and the back, with a total flow rate of 6.5 g/s (300 L/min) and a ventilation pressure of 40 kPa. The metabolic rate of the human body was set to 300 W, assuming as uniform distribution, taking into account the high-temperature environment outside. The helmet is treated as the spherical shape and is set as a radiative heat transfer boundary condition together with the clothing. It was assumed that the heat flow of the body surface is uniform everywhere. Ventilation air were treated as ideal gas. The body was wrapped by the clothing (except for the hands and feet segments) and the gap between the body and the clothing kept uniform. The parameter settings given were all for the working condition of 18 °C air supply temperature. As the details of heat transfer on the wall boundary were focused on, the SST k-ω turbulence model was used for the solution.

3 Results and Discussion

Considering the air tightness and heat insulation of the clothing, the heat generated by the human body mainly relies on the internal ventilation to dissipate. Therefore, convection is the main form of heat transfer within the clothing. The heat transfer on the surface of the limbs could be regarded as the unidirectional flow in the tube from the wrists and ankles, while the heat transfer in the head could be regarded as the convective heat transfer in the disturbed cylinder from the top of the head. The air flow in the torso segment was more complicated, as the cooling gas from the limbs would be pooled in the torso and discharged from the abdomen. The temperature distribution over the body surface can be obtained by modeling calculations to determine the maximum body surface temperature.

In this study, the human thermoregulatory mechanisms was not investigated, only considering the ability of ventilated air to dissipate the heat generated by the human body. Regularly in a steady state, the heat flow heat generation on the surface of the human body is equal to the heat flow through the inner layer inside the clothing, which would be carried away by the ventilation airflow between the inner comfort layer and the airtight layer. Therefore, the heat transfer and thermal comfort problem could be simplified to convective heat transfer between the inner layer and the outer layer of the air ventilation clothing. The temperature distributions of the human body surface and the outer surface of the clothing at a ventilation temperature of 18 °C were exhibited in Fig. 1. The comparison showed that the temperature of the human body surface is more uniform, ranging from 31 to 37 °C. The temperature of the extremities is slightly lower than that of the torso, which is due to the fact that the airflow first exchanges heat with the limbs and the head. The cooling ability would decrease when it flows to the torso segment, resulting in relatively higher temperature near the torso.



(A) (B)

(C)

Fig. 1. Surface temperature distribution of human body and clothing calculated at a ventilation temperature of 18 °C. (A) and (B) exhibited front and back view, respectively. (C) exhibited outer surface temperature distribution

From the calculation results of different segments, the surface temperatures of the upper arm, forearm and calf were low, in the range from 31.9 to 32.2 °C, and 34.6 to 36.7 °C, respectively. The temperature in the middle part of the torso near the air supply outlet on the back was in the range from 36.2 to 36.5 °C, which was a little bit lower compared to that of the other parts of the torso (i.e. near the shoulders and chest) in the range from 36.7 to 36.9 °C. This may be because these segments are close to the air supply outlets of the limbs. Besides, the temperature very close to the outlet which was about 21 °C, Indicating a localized deviation from the overall thermal comfort.

The hip and thigh segments had the highest calculated range of results, from 36.8 to 37.0 °C., which is related to the high value of tissue thickness, heat capacity, and heat production. Meanwhile, due to the sitting posture of the model, the folding of the knees and hips limits the airflow inside the clothing. However, the temperature of the head (except for the temperature at the parietal bone) was also in a high range from 36.7 to 36.9 °C, despite with a separate air supply line, indicating the high level of heat accumulation at pilots' head during high-altitude operations, and its heat dissipation needs special attention.

Due to the complexity of the human body structures and the clothing surface, the limbs were simplified as cylinders with cross-sectional diameters varying along the axial direction, the head was simplified as a cylinder, and the torso is simplified as a column with a rounded rectangular cross-section. In future research, more specific human body could be developed for the heat transfer calculation in details, such as fingers and face. Besides, the metabolism in each segment of human body would be added in the human-clothing model, while the heat transfer process within the human body should be developed for more accurate outcomes. Moreover, the hands and feet should be taken in account separately.

4 Conclusion

The simulation results showed that in accordance with the ventilation temperature of 18 °C, ventilation pressure of 40 kPa and the specified ventilation volume (1.95 g/s at the entrance of limbs and 1.3 g/s at the back and the head), the surface temperature of the human body would be distributed more uniformly, with a distribution range of 31–37°C, and the temperature of the end of the limbs and the head slightly lower than that of the torso segment. In general, the design of the garment thermal control system of the air ventilation clothing could meet the balance of human metabolic heat production and heat dissipation of ventilation, realizing thermal comfort needs.

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Slips (I)

Recognition of Physiological Patterns During Activities of Daily Living Using Wearable Biosignal Sensors

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Abstract. A key aspect of developing fall prevention systems is the early prediction of a fall before it occurs. This paper presents a statistical overview of results obtained by analyzing 22 activities of daily living to recognize physiological patterns and estimate the risk of an imminent fall. The results demonstrate distinctive patterns between high-intensity and low-intensity activity using EMG, ECG, and respiration sensors, also indicating the presence of a proportional trend between movement velocity and muscle activity. These outcomes highlight the potential benefits of using these sensors in the future to direct the development of an activity recognition and risk prediction framework for physiological phenomena that can cause fall injuries.

Keywords: Physiological Patterns · Activities of Daily Living · Biosignals

1 Introduction

Falling causes severe injuries with significant consequences for the entire healthcare and economic system. According to the World Health Organization (WHO), 684,000 people die, and 172 million suffer disability from falls each year. In addition, the total medical cost resulting from falls of the elderly is $50 million annually in the US alone [1, 2]. A key aspect of developing fall prevention systems is the early prediction and/or detection of fall events. While a fall detection and ground impact estimation system can rely solely on the use of inertial sensors [2–4], prediction of a loss of balance [5], heart failure [6], or fainting [7] can be made solely based on the person's biomedical signals and patterns. To predict the subsequent fall, monitoring the causes (physiological changes) and not the consequences (fall) is necessary. However, this is challenging due to the quantity, quality, and heterogeneity of data and processing time requirements [3, 4]. The literature lacks data sets based on biomedical and IMU signals that can be useful in falling analysis and used to train and validate algorithms for falling detection and

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prediction. This paper evaluates these considerations and presents preliminary results obtained by analyzing 22 Activities of Daily Living (ADLs) performed by ten subjects (five females and five males) to recognize physiological patterns and use them in the future to direct the development of a framework to predict the risk of physiological phenomena that may cause fall injures. Once the patterns of ADLs are identified, it is possible to recognize the activity performed by the subject and identify abnormal changes that may be early symptoms of unconsciousness.

2 Methodology

A series of experiments with subjects equipped with wearable biosignal sensors was organized to evaluate physiological patterns during Activities of Daily Living. The study was carried out according to the Declaration of Helsinki and approved by the Ethics Committee of Liguria (protocol reference number: CER Liguria 001/2019) on 28 October 2019.

2.1 Activities

Subjects were required to perform ADLs and dynamic activities during the experiments, but no falls. The primary criterion for selecting dynamic activities was to test the fall prediction algorithms' robustness, a future work, in tasks involving motions where controlled falls are performed, such as jumping, which do not result in injuries. Table 1 describes the 22 activities the subjects participated in, sorted by chronological execution order. During the activity sequence, there are four calibration phases to measure the Maximal Voluntary Contraction (MVC) of the femoral muscles: the subject is asked to push 3 times with the heel up toward a hard surface, such as the base of the treadmill, to measure the MVC of the posterior femoral muscle and to sit on a chair and push 3 times with the leg toward each other with a resistance imposed by an outside person to measure the MVC of the anterior femoral muscle. This procedure is repeated for each foot and is used to evaluate the variation in MVC as the experiments continue and to normalize the muscle data (i.e., EMGs) properly. All experiments were preceded by a 5-min warm-up session on the treadmill at a constant speed of 3.5 km/h to safeguard the subjects' health and limit the risk of possible contractures and injuries. The time required to record all trials was approximately 1–1.5 h for each subject.

2.2 Participants

For data collection, 10 subjects (five females and five males) were invited to participate. The participants' ages ranged from 25 to 42 years, their height from 1.55 to 1.91 m, and their weight from 44 to 83 kg, with generally higher male values than female values. The group of participants consists of healthy affiliates of the Istituto Italiano di Tecnologia (IIT).

Table 1. Types of activities carried out during the experiments.

	Activity	N. of Repetitions
Calibrate	MAX EMG 80%, Standing 10s	1
Walking	4 km/h for 30s + 10s rest (treadmill)	1
	5 km/h for 30s + 10s rest (treadmill)	1
	Walking at own pace	1
Jogging	6 km/h for 30s + 10s rest (treadmill)	1
	7 km/h for 30s + 10s rest (treadmill)	1
	Jogging at own pace	1
Running	10 km/h for 30s (treadmill)	1
	11 km/h for 30s (treadmill)	1
	Running at own pace	1
Re-calibrate	MAX EMG 80%, Standing 10s	1
Stairs	~2 stairs fast + 10s rest	2
	~2 stairs + 10s rest	2
	~2 stairs + 10s rest	2
Re-calibrate	MAX EMG 80%, Standing 10s	1
Ladder	Ladder climbing (up & down) 5 steps 3s stop	3
	Ladder climbing (up & down) 5 steps no stop + after the last repetition a jump off	3
Jumping	Vertical jump	4
	Leap (2 tiles)	4
Workouts	Squats	5
	Jump squats	5
	Push-ups	5
	Burpees	5
Re-calibrate	MAX EMG 80%, Standing 10s	1
Sitting/getting up	From a chair	3
	From the floor	3

2.3 Sensors

Data were collected with the wearable multi-sensor platform biosignalsplux, PLUX wireless biosignals S.A. (Lisbon, Portugal) using four electromyography (EMG) sensors, an electrocardiography (ECG) sensor, and a piezoelectric respiration (PZT) sensor. The four EMG sensors were placed on the anterior and posterior femoral muscles; the ECG sensor was fixed near the heart, and the PZT sensor was attached frontally under the nipple line. All tests were performed with a sampling frequency of 300 Hz.

3 Results

Muscle activation (MA), heart rate (HR), and respiratory rate (RR) were calculated from biomedical signals to assess the variation of these physiological indices according to the activities.

3.1 Analysis of Activity-Related EMG Signals

The EMG signals were initially treated with the same process described in [8], i.e., rectification and low-pass filtering. Then, the data were normalized with Maximum Voluntary Contraction (MVC) values to make them comparable. In particular, they were divided regarding the 95th percentile of muscle activation during the antecedent calibration phase. After normalizing the data, the median was calculated to evaluate the signal trend. Then, these values were compared for each muscle in which the EMGs were placed for the various activities. The bar graph in Fig. 1 shows the results obtained considering all subjects. The numerical value on the ordinate has been voluntarily removed to give more meaning to the qualitative differences that can be found.

3.2 Analysis of Activity-Related ECG Signals

Heart rate (HR) was estimated using the following frequency method based on ECG signals. Initially, the signals were filtered with a band pass filter with cutoff frequencies of 0.9 Hz (55 bpm) and 3.7 Hz (220 bpm). Subsequently, the filtered signal's Fast Fourier Transform (FFT) was calculated, and the subject's HR during the activity was defined as the sinusoidal frequency with the highest amplitude. Cutoff frequencies were established considering the following considerations presented in the literature. The normal range for resting heart rate is 50–90 beats per minute (bpm) [9], and the maximum heart rate is loosely estimated as 220 minus one's age [10, 11]. Figure 2 shows the HR thus calculated for the activities studied considering all subjects.

3.3 Analysis of Activity-Related Respiration Band Signals

Similar to the method used to analyze ECG signals and estimate heart rate, respiratory rate (RR) was calculated from the signals of the piezoelectric respiratory band. In this case, the signals were filtered with a band pass filter with cutoff frequencies 0.2 Hz (12 Bpm) and 1 Hz (60 Bpm), given that the regular respiratory rate for an adult at rest is 12 to 18 breaths per minute (Bpm) [12]. The breathing increases to about 40–60 times a minute during exercise [13]. In Fig. 3, the RRs calculated for the activities studied considering all the subjects are reported.

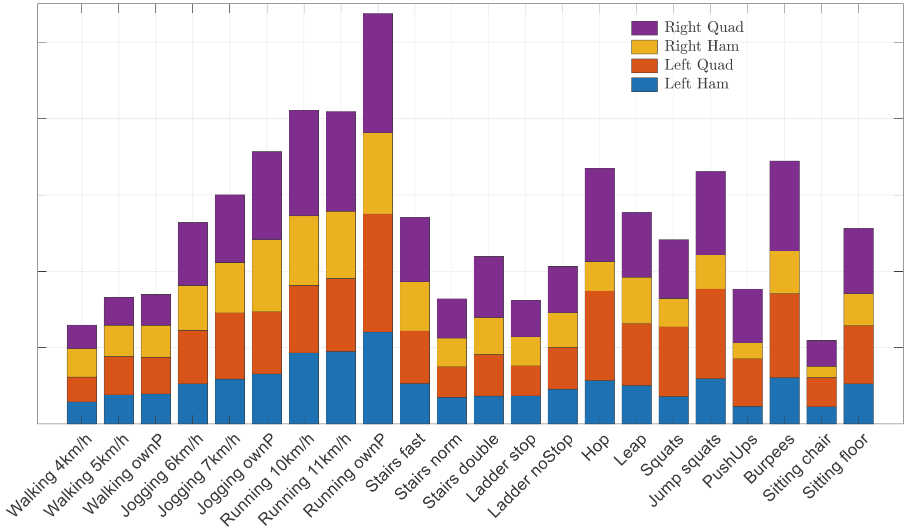

Fig. 1. EMG median value for activities. Ham stands for hamstring, and quad for quadriceps.

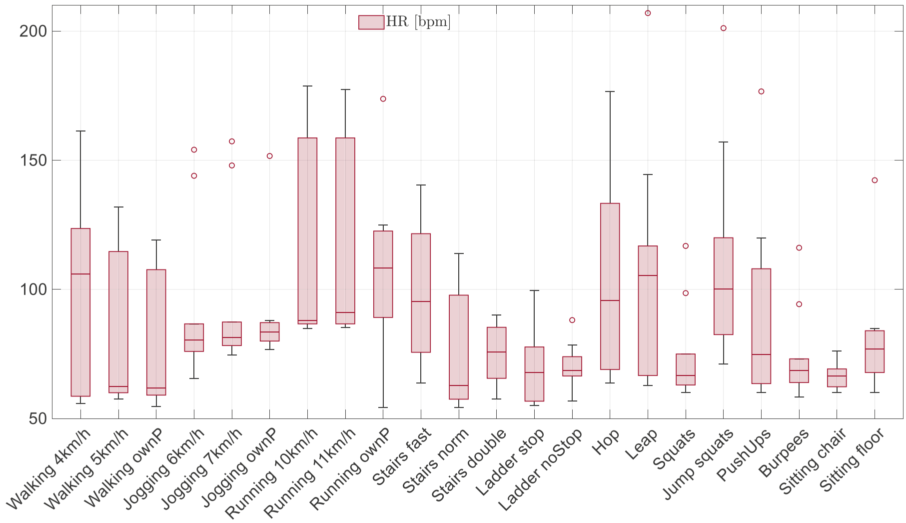

Fig. 2. Heart Rate (HR) for activities.

4 Discussion

By analyzing these indices, it is possible to recognize certain physiological patterns with respect to each activity and to discriminate those heavier and more strenuous, involving, for example, greater muscle activation, increased heart rate, or respiratory rate. Activities that are less strenuous and at lower risk of falling are identified.

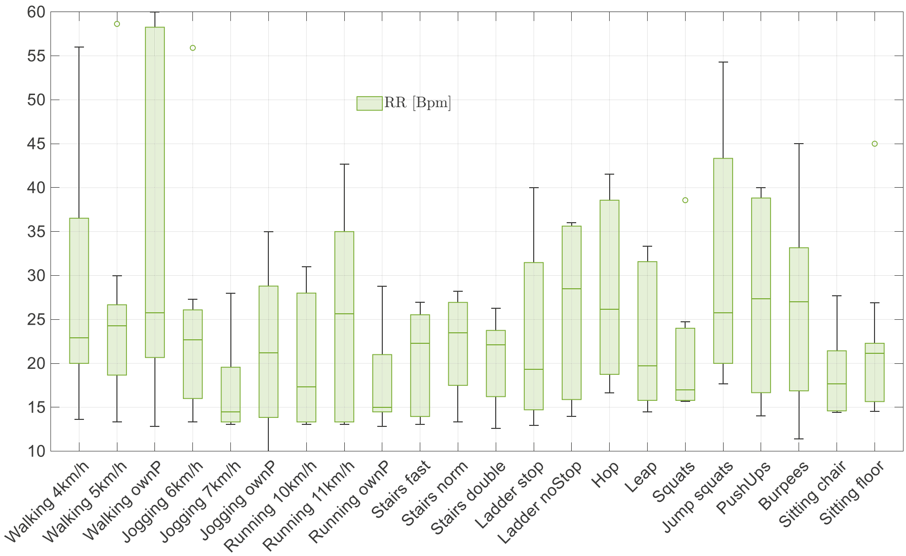

Fig. 3. Respiration Rate (RR) for activities.

As the required walking, jogging, and running speed increases, the median for the four muscles seems to increase with a linear profile. Walking at 5 km/h causes a higher average activation than walking at 4 km/h; jogging at 7 km/h causes a higher average activation than jogging at 8 km/h and is similar to running. In addition, the muscle activation of running is greater than that of walking and jogging. In vertical jumping and leaping, it was found that the quadriceps muscles have a higher average activation than the front leg muscles. In contrast, a lower median of muscle activation is observed between subjects in ladder activities than in more explosive activities such as jumping or jumping squats.

As previously noted with EMGs, HR increases with the speed imposed on subjects. Furthermore, the highest HR was found for the first activity performed (walking at 4 km/h), running, and jumping. These are also the activities with the most variable HR. Walking and going up and down stairs, as well as stairs, are the activities with the lowest HR, probably also because they are the most carried out by the subjects taken as a sample.

The highest RR is found for jumps, squats, and push-ups, while the activities with the lowest are jumping, squatting, and sitting. The results obtained while walking at one's own pace seem anomalous and present a high variability between subjects. A cause could be found in the frequency with which subjects walk calmly (walking cadence), which could fall within the bandpass filter range (0.2–1Hz) and influence the results.

5 Conclusions and Future Works

This work introduces a new dataset where 10 subjects of different characteristics are equipped with various biosignal sensors while performing a series of ADL and dynamic activities. The aim is to investigate how biological signals can be used as predictors of falling and fill the gap in the literature that lacks datasets with such signals. The results demonstrate distinctive patterns between high-intensity and low-intensity activities in the heart rate and respiration rate, indicating the presence of distinctive and characteristic patterns and the potential benefits of using such sensors to study a person's physiological patterns. In addition, the more the speed of movement increases, the more muscle activation increases, following a profile similar to the linear one. These results suggest that these data can also be used in the development of biomedical-based activity recognition. In future work, this dataset will serve as a basis for developing reactive and proactive algorithms for defining and estimating muscular fatigue, cognitive fatigue, and stress levels that could induce a fall, which will result in assessing the risk of an imminent fall before it happens.

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Berg Balance Test for Predicting a Fall Risk in Older Adults Living at Home: A Preliminary Study on the Effect of Pre-Existing Health Conditions on Postural Balance

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Abstract. Elderly people worldwide have been facing a high risk of fall, which impact their health and quality of life. Once fall, it becomes difficult for elderlies to get back to their active lives. This presented study aims to assess postural balance of elderly individuals using the Berg balance test and to determine the correlation between the Berg balance score (BBS) with the individual's health-related conditions. This research involved people aged over 40 years, living at home in Montreal metropolitan area. Participants were recruited via a variety of channels including associations working with elderlies, a university community and through a snowball sampling. Our balance tests were collected at participant's home, the university's laboratory as well as public locations within the community. To find the relationship between the BBS and the participant's pre-existing medical conditions, Chi-square tests, with the level of significance of 0.90, were used. The results show the significant correlation between fall history and low BBS, and between vision disorders and low BBS, thereby highlight the importance of these factors to prevent falls in the elderly. From our study among active community-dwelling elderlies, BBS proved to be valuable for assessing balance by identifying those at high risk of falling based on their history of falls and probably vision disorders. This informs stakeholders to create appropriate preventive interventions to reduce the incidences of falls among the elderlies living independently at home.

Keywords: postural balance · Berg balance scale · fall · elderly people

1 Introduction

Elderly people are at a very high risk of fall and many of them have already experienced a fall in their life. In 2014, nearly 30% of older adults in the United States reported falling at least once in the past year, and among those who fell, 37.5% needed medical treatment or had restricted mobility for at least one day [1]. The consequence of fall treatment could then greatly lower the quality of life as reported by over half of the elderly women fallers in Korea in 2019 [2]. Postural balance, being important for daily activities, may depend on several factors from the individual's medical history like having previously fallen [3], to their physiology like advancing age, female gender, visual impairments, declined cognitive functions as well as the environment they live [4].

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It is crucial to have ways, applicable easily in a large scale, to predict the risk of falls in order to prevent it. A recent systematic review identified numerous tests that were commonly used [5]. Gait speed test, the most common one, offered a simple protocol practical for various settings but had a limited reliability [6]. The second most common method was Timed Up and Go (TUG) test. In a cross-sectional epidemiological study [7] applying the TUG test, sex had no significant impact on balance among elderly people, but age and diabetes mellitus did. Still, the TUG test also had weak validity [8]. Berg Balance Scale (BBS), the third most used one, requiring one minimally trained person, could be relevant. The BBS score was found to decline after a person reached 70 years old [9]. Furthermore, BBS was useful in predicting the fall risk in multiple sclerosis patients [10]. In stroke patients, BBS was valid and reliable in assessing postural balance change [11] and performed better than quiet standing on a force plate [12].

This paper presents the application of the BBS test to determine individual's health conditions that may affect the loss of balance.

2 Methodology

2.1 Participant Recruitment

This project recruited healthy persons, aged 45 years and older, living at home within Montreal metropolitan area. The protocol was approved by the Institutional Review Board of the École de technologie supérieure (Reference H20221103). The participants were volunteers who did not use assistive tools to walk and were autonomy in moving from places to places. The participants did not experience a fall in the past six months before the study (September–December 2023) but might have experienced falls in the past. We asked the participants to neither fast nor consume caffeine on the study day.

The recruitment was done through associations who collaborated with elderlies. We were invited to participate in a cultural event to share information. If a person expresses their interest, we verified their eligibility criteria and let them choose the place of experiment. Some invited us to conduct the study at their home, others came to the university, and the rest chose to perform the test in a public place. Even though the places were different, we used exactly the same equipment.

2.2 Data Collection Procedure

Upon the participant's consent, we collected their demographic and pre-existing health conditions. The participants then performed BBS test with the following tasks: (1) changing from sitting to standing, (2) standing unsupported, (3) sitting unsupported, (4) changing from standing to sitting, (5) transferring from one chair with armrest to another chair without armrest, (6) standing with eyes closed, (7) standing with feet together, (8) reaching forward and outstretching arms while standing, (9) grabbing an object from the floor from standing position, (10) turning to look behind while standing, (11) turning around 360 degrees, (12) placing alternating foot on a step or stool while standing unsupported, (13) standing with one foot, and (14) standing with two feet in tandem, i.e., placing one foot in front of the other.

The test took about 15 min per participant and was administered by two trained researchers, who independently rated the score then compared the results.

2.3 Statistical Analysis

To find a relationship between pre-existing medical conditions and postural balance, we used a chi-square (x^2) test with significance level (1–α) of 0.90. Our initial hypothesis was no relationship between balance and medical conditions. Then we conducted a post hoc power analysis and determine a priori sample size for future study under a desired power (1–β) of 0.80. We used R programming language, version 4.3.2.

3 Results

3.1 Participant Characteristics

Fifteen participants' physical characteristics and pre-existing conditions are presented in Tables 1 and 2, respectively.

Table 1. Participant's physical characteristics by sex, Mean ± standard deviation.

	Women (N = 6)	Men (N = 9)
Age (year)	64.8 ± 12.5	55.1 ± 7.2
Height (cm)	163.8 ± 9.1	175.5 ± 5.8
Weight (kg)	64.5 ± 12.5	82.2 ± 12.0
BMI	23.9 ± 3.3	26.7 ± 4.4

Table 2. Participant's pre-existing medical-related conditions.

	Women (N = 6)	Men (N = 9)	Total (%)
Parkinson's	0	0	0 (0%)
Vision problem	5	3	8 (53%)
Heart diseases	1	0	1 (6.7%)
Hypotension	0	0	0 (0%)
Hypertension	0	3	3 (20%)
Stroke	0	0	0 (0%)
Diabetes	1	0	1 (6.7%)
Thyroid	1	1	2 (13%)
Past fall incidence	3	1	4 (27%)

3.2 Relationship Between Berg Balance Score and Pre-Existing Conditions

With the small sample size, only the effects of vision problem and past fall incidence on the BBS score were analyzed and presented in Tables 3 and 4, respectively.

BBS and Fall History. From the x^2 test for the independence between the two variables, we found p-value = 0.044. Under the α = 0.10, we rejected the null hypothesis and concluded that the BBS and the past fall incidence were dependent. Also, the statistical power was 70.4%. If we were to set β = 0.20, we would have to conduct the test for 19 participants.

Table 3. Relationship between BBS score and fall history.

BBS score	Non-faller	Faller	Total
0 – 20	0	0	0
21 – 40	0	1	1
41 – 55	4	3	7
56	7	0	7
Total	11	4	15

BBS and Vision Disorders. Similarly, according to the x^2 test for the independence between BBS and vision disorder, the p-value of 0.060 was found. This suggested us that, using α = 0.10, BBS and vision disorders were dependent. However, our post hoc power analysis was only 46.7%. For the β = 0.20, we would need 34 participants.

Table 4. Relationship between BBS score and vision problem.

BBS score	No vision problem	Having vision problem	Total
0 – 20	0	0	0
21 – 40	0	1	1
41 – 55	2	5	7
56	5	2	7
Total	7	8	15

3.3 Difficulty of Tasks in Berg Balance Test

There were tasks that participants found more difficult. Three outstandingly challenging tasks were no.11, 13 and 14, as presented in Table 5.

Once the BBS scores from these three tasks were evaluated for their independence from the pre-existing conditions including fall history and vision problem, the results gave mostly similar tendency for the former but rather opposite for the latter.

BBS and Fall History. We found that the BBS score and the fall history were dependent for the task of pivoting 360 degrees and standing with two feet in tandem, but not for the standing on one foot (p-values = 0.0089, 0.015 and 0.15).

Table 5. BBS by tasks.

BBS score	Task 11	Task 13	Task 14
0	0	0	1
1	1	2	1
2	2	1	1
3	3	2	2
4	9	10	10

BBS and Vision Disorders. We did not find that BBS score and vision problem were dependent for any tasks (p-values = 0.23, 0.18 and 0.57).

4 Discussion

4.1 Interpretations of the Results

Postural balance disorders in the elderly very often leads to a fall. This is normal as we age and with the decrease in functional capacity due to illness [4]. Among our sample, we observed other factors that influenced this balance.

Individuals who had already fallen in the past and those with a vision problem had the worst BBS scores, all participants who had already experienced a fall had BBS lower than 56, and this phenomenon was the same for those suffering from a visual problem. The BBS test was designed to be able to identify people who could be classified as fallers if their score is less than 45, and non-fallers if it is greater than 45. This makes it possible to determine if the person needs help in walking in order to avoid a possible fall. In our sample, we did not have any subjects with a score falling in the range of 0–20; that is, the person requiring a wheelchair. This is due to the targeted population that we recruited were more or less independent and living alone or at home.

We noticed that certain tasks were more complicated for certain participants than others, particularly those with previous experience of falling or vision problems. The tasks in question were task 11 which consists of rotating 360 degrees. It required a pause and an increased supervision by researchers to prevent the participants from falling due to dizziness when rotating. The other two problematic tasks were task 13 and 14 which consisted of standing for one minute with one foot in front of the other and with only one foot, respectively. It was complicated for individuals with fall experience to stand with one foot, or with one foot in front of the other without leaning to the side, or even without supervision.

We deduced that the balance depends on several parameters. Among these, the history of falling could have caused fears of falling which ended up affecting postural balance. Also, visual problems would mean a more involvement of the vestibular system, i.e., an intact vestibule-ocular reflex. This is essential for maintaining stable vision during head movements; an impaired vestibular system means reduced visual acuity which can compromise balance and postural control, increasing the risk of falls [4].

4.2 Comparisons with Previous Studies

Postural balance can be affected by several parameters. First, increasing age may generally be associated with one's fall incidences due to a reduction in physical abilities including balance and thus lower BBS [13]. This was not found in our study among older adults living in metropolitan area in contrast to those living in rural area [14].

According to our results, female participants had poorer balance than male counterparts. Precisely, three out of six women had already had an experience of falling while for men except one man out of nine had already fallen. These sex-differences are similar to ones found in the previous study [14] regardless of the person's physical activities.

Medical history are also very important factors influencing balance. This was also reported by several studies carried out on a population suffering from Parkinson's [15], multiple sclerosis [16] and those suffering from stroke [17]. Notwithstanding, among our sampling frame, we were not able to recruit any persons having these conditions.

Our results corresponded to previous studies that BBS were different between the elderlies who had already fallen and those who had not [18], and that postural balance could be affected by fall history [19] and vision problem [20, 21].

In this regard, a previous study [18] also claimed that the combination of the BBS score and this history of fall was the best predictor of falls in elderly people. In contrast, another study [22] noted that the BBS did not necessarily predict future falls.

Vision could play a vital role in maintaining postural balance. This relationship was also reported by previous studies [4, 23] showing that a decreas in vision, decreased balance control in the elderly. This corresponds to our overall BBS results, yet is different when specific tasks were evaluated separately.

4.3 Limitations

To generalize the results, we must be careful and take into account the limitations of our study. First, we had a small sample size, and we decided to use the 90% significance level to be able to point out the relationship between the BBS and the independent factors in which we were interested. If we had changed the significance level to the commonly-used 95%, the results would not have been statistically significant. Furthermore, it is important to note that most participants generally had good balance. This is because we approached people who were actively engaged in their community and tend to be also physically active. With the absence of information on some medical conditions such as post-stroke and Parkinson's diseases, we could not verify their impact on the BBS. These are the two medical conditions known to have the risk of losing balance.

Notwithstanding, this pilot study gives an assessment result that can be used for a future study. The variance of the data collected can be used for calculating appropriate sample size for further data collection.

4.4 Recommendations

Future research would be better with a larger sample and a more detailed questionnaire on people's history of falls as well as its recurrence and severity. For Parkinson's and multiple sclerosis patients, it is also recommended to use the Berg balance test with other assessment methods. Mini-BESTest was found to be more effective than BBS to rate the severity of Parkinson's [24] and a better predictor of falls among people with multiple sclerosis who were independently mobile [25].

It is recommended to follow up after collecting the data and obtaining the results on the scores and performance of the participants. With 12-month follow up, a previous study was able to identify that the predicted fallers had higher incidence of falls [26]. This would help us know if those identified as potential fallers ended up falling in the future or if they chose to adopt any preventive measures such as exercise and mental health treatment, which were proven to mitigate the recurrent fall risks [27].

5 Conclusions

The BBS appeared to be useful for assessing postural balance in the elderly to identify people at high risk of falling in various contexts regardless whether the person is healthy or has illnesses. In this study, we carried out the BBS test with elderly people who were independently living at home, and found that their BBS score was correlated with the history of falls and vision problems. These findings help practitioners identify those with higher risk with losing balance and put an intervention to prevent it.

In summary, falls in the elderly are hardly inevitable, for this reason the use of BBS is interesting for assessing their balance before the fall occurs or re-occurs. Its use could help identify people who seem healthy and active but have minor balance disorders. This makes possible to apply interventions to minimize the risks of fall incidence.

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Application of Harmonic Ratio in Stair of the House

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Abstract. In 1964, Howard Gage reported on the harmonic ratio in accelerometer analysis of human gait. Although this index was used in gait analysis with a flat surface, it was necessary to examine the possibility of evaluating gait on stairs due to the hazardous areas of slips, trips, and falls. The aim was to develop a simple gait index for stair climbing up and down, and the application of harmonic ratio in stair movement was expected to indicate different values between up and down. It was well known that there was a significant difference between walking on a flat surface and stairs down, and this could be applied to the evaluation of indoor walking hazardous areas.

Keywords: Accelerometer · Stair Walking · Harmonic Ratio

1 Introduction

The walking were extensively analyzed quantitatively in the 1980s using instrumented systems for gait analysis based in motion capture, force platforms, electromyography [1]. It was widespread expensive experimental systems for analyzing human gait. Typical gait analysis provides a huge quantity of data, usually focused on hip, knee, and ankle angular kinematics and kinetics, but it is also expensive and time-consuming in clinical settings. More recently, many researchers have started to use less-expensive wearable and optoelectronic devices [2, 3], devoting more attention to the entire locomotor system, including the whole body. Stable gait may refer to the repeatability of walking, gait resilience to perturbations, or the ability to maintain upright balance during walking. Then, balance instability is a common condition in older people. It is one of the most important ones for old people because of their high risk of falls. Falls are a major determinant of poor quality of life, immobilization, and reduced life expectancy in people affected by older adults more generally [4, 5]. However, the full-floor reaction force measurement device is expensive and has many signal sources, and it is difficult to evaluate the front-back, left-right, and up-down sway of the posture. Furthermore, while normalization of gait speed is important in assessing walking on stairs, it is difficult to standardize a strict optimal walking speed.

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To observe actual house indoor walking conditions, there was currently no standard to evaluate whether the behavior was safe for stairs and steps as well as flat surfaces. The harmonic ratio of gait is calculated by the acceleration of the trunk in rhythmic accelerated movements of the left and right legs. [2, 3]. It was necessary to verify the harmonic ratio of walking up and down stairs, which has only been evaluated in the plane, rather than comparing the difficult walking condition with the healthy condition.

There were no data available on any method other than flat gait that could be used to evaluate gait using only accelerometer measurements.

Most houses in Japan are two-story structures, and most have stairs. Japanese houses are built of wood and they catch well-ventilated building. Therefore, stair falling accidents the multiple, interacting environmental and human factors involved. Among the environmental factors are properties of the walking-in the house (such as small steps and stairs). Within building standards law, stairways come in a variety of shapes, not just one product, and are one of the places where accidents occur in the home. Therefore, stair design and environ-mental conditions may play a role in slip and falls accidents. The purpose of this study was to examine the applicability of the harmonic ratio as an indicator for evaluating residential staircases.

2 Materials and Methods

2.1 Participants

After obtaining approval for the protocol from the local ethical committee of Jissen Women's University (H2022-23), ten healthy student were recruited (4 male and 6 female, average high 163 cm ± 5.3, average weight 54.6 kg ± 8.3), no need for a walking aid for daily activities, no known problems with visual, auditory or vestibular systems. All participants came to our accommodation with flat corridors and stairs and provided signed informed consent.

2.2 Experimental Protocol

Participants' body height and body mass were measured with clothes and shoes off. Participants were asked to walk the straight corridor about 15 m and go up 20 stairs and go down 20 stairs in the two-story house (Fig. 1). A tri-axial (X,Y,Z axis) accelerometer (LP-WSD1215, Logical Product, Japan) was fixed to their lower trunk at the level of L5 with an elastic belt, sampling frequency: 200 Hz. It was performed experimental procedure was repeated their preferred speeds. Measurements were started when the treadmill and participant were at a comfortable speed and each trial lasted for five minutes to ensure collection of sufficient strides. Participants were allowed to rest between trials and the next trial was started only after the participant indicated to be fully rested.

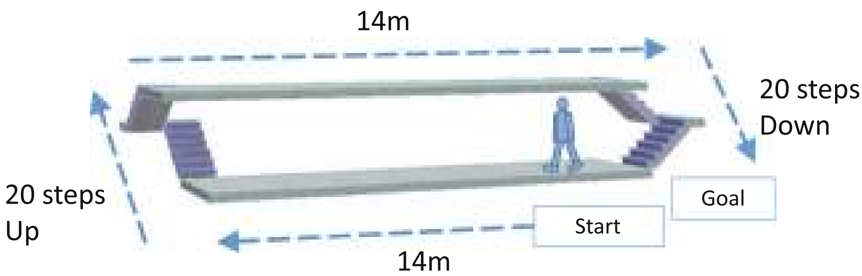

Fig. 1. Experimental procedure, walking a flat corridor, up a flight of stairs, walking again on a flat, and down a flight of stairs respatedly.

2.3 Data Processing

After all raw trunk acceleration data was collected, MATLAB (Mathworks, USA) was used for filtration and HR analysis for each conditions, walking flat corridor, stair up/down. First, the acceleration data were converted from g to m/s^2. Subsequently, the raw accelerations were realigned with the anatomical axes using the sensor's orientation with respect to gravity and an optimization of the left-right symmetry. The resulting data were used to calculate the following gait characteristics: harmonic ratio as a measure of gait symmetry, index of three directional harmonicity as a measure of gait smoothness.

2.4 Statistical Analyses

Normality was checked by visual inspection of the data. The mean and standard deviation of all the described parameters were computed. Analysis of variance (ANOVA) was first applied for assessing in healthy subjects the differences among the three waling conditions (comfortable flat walking, up stair, down stairs). All tests were conducted using SAS (SAS Institute, USA) and the statistical significance was accepted at p-value less than 0.05.

3 Result

Figure 2 show the typical data collection of raw data. From the acceleration data, one walking cycle was cut out and each HR was calculated and averaged under each condition. For stair ascent and descent, HRs were calculated for the left foot, right foot, and left foot, respectively, as in plane walking, as well as for one gait cycle, and the mean was calculated.

Harmonic ratio were plane, upstairs and down stairs, smaller respectively.

Figure 3 was illustrated that the mean and standard deviation of the x-, y-, and z-axis calculations of the harmonic ratio for each of the three walking environments: flat walking, stair climbing, and stair descent.

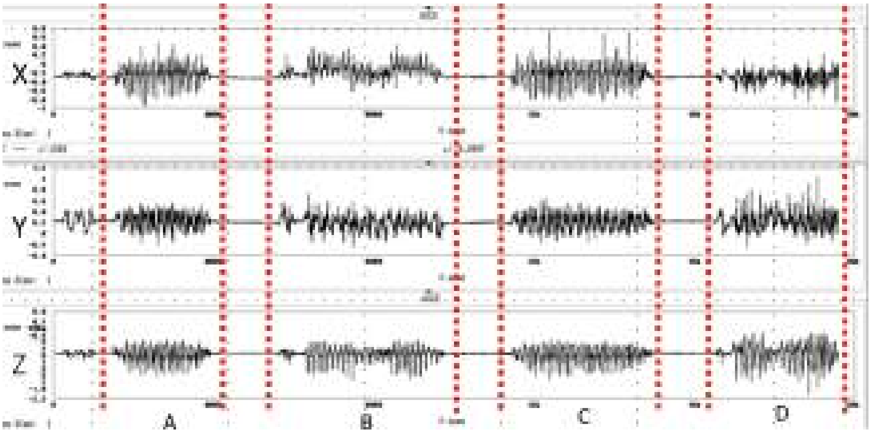

Fig. 2. Typical accelerations data, A: flat walking, B: up stair walking, C: flat walking, D: down stair walking. By visual inspection, several walking cycle were calculated for HR.

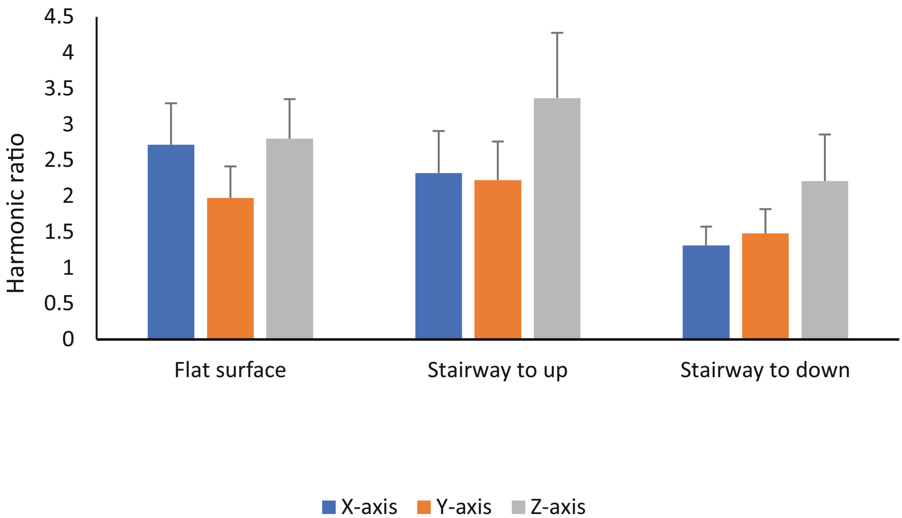

Fig. 3. Average harmonic ratio in three conditions, X-axis forward direction, Y-axis left-right direction, Z-axis Vertical direction

There were significant differences in means value in X-axis between walking on a flat surface and walking down stairs, and between walking up stairs and walking down stairs (Fig. 4). On the other harmonic ratio of Y and Z axis were no significant difference, respectively.

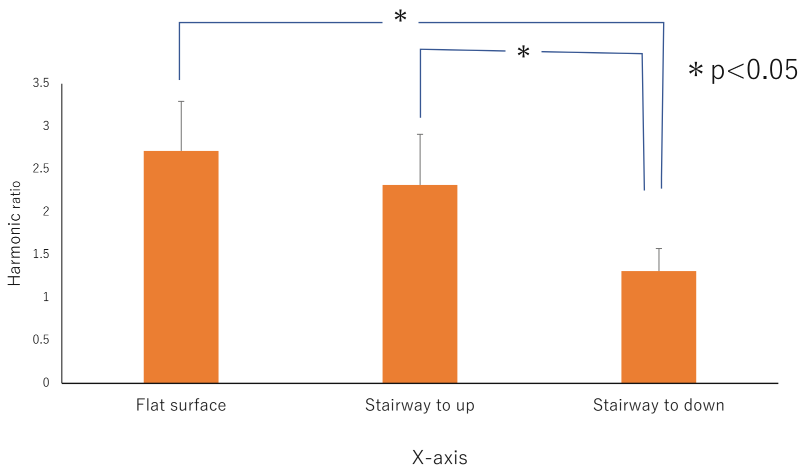

Fig. 4. Average harmonic ratio test in three conditions of X-axis forward direction

4 Discussion

The harmonic ratio was calculated using the same procedure as in previous studies [1] and could be calculated from steps obtained while ascending or descending stairs as well as from planes. The higher the value of the harmonic ratio, the more synchronized and rhythmic the gait [2]. Thus, on average, the walking in house was more stable on a flat surface and more unstable on stairs than on a flat surface. Subjectively felt like they were taking lighter steps down stairs than up steps, however, the harmonic ratio values were significantly lower than for stairway descents (see Fig. 4). This means that the known hazards of descending stairs are more dangerous than ascending stairs, consistent with the known.

5 Conclusion

The method utilized for determining the harmonic ratio in the previous study could also be applied to calculate the ratio for step movements obtained through accelerometers during stair ascent and descent. In ascending and descending indoor stairs, it was found that the harmonic ratio was significantly lower for descending stairs, and the hazards associated with descending stairs were higher. Therefore, calculating the harmonic ratio is considered a valuable evaluation item for stair geometry in buildings. Stairs in residences for toned elderly persons who have difficulty walking should be designed with ergonomic dimensions, handrails, treads, and kicks, depending on the physical characteristics of the user.

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Postural Stability in Functional Reach Test with a Passive Lower Extremity Exoskeleton

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Abstract. The postural stability on a passive lower extremity exoskeleton is important in preventing the falls at workplaces. The aim of this study was to assess the maximal reaching distances (functional reach test) and the weight distributions while reaching forward, backward, and side directions with and without the Chairless Exoskeleton (CEX) at different height settings (NO CEX, CEX HIGH, and CEX LOW). Twenty participants engaged in randomized tasks, and kinematic and ground reaction force (GRF) data were collected. CEX use showed no impact on anterior reaching but significantly reduced posterior ($p = 0.001$) and lateral ($p < 0.001$) reaching distances. CEX height had no significant effect. Anterior reaching GRF on the feet was 76% and 75% of body weight with CEX HIGH and CEX LOW. In posterior reaching, GRF on the feet was 19% and 24%, and in lateral reaching, it was 42% and 48%. In conclusion, even without CEX, posterior reaching is limited, and the CEX exacerbates this limitation, primarily due to restricted knee motion. This underscores the need for design enhancements and cautionary measures for workers before exoskeletons are deployed in the workplace.

Keywords: Passive Exoskeleton · Functional Reach Test · Postural Stability

1 Introduction

1.1 Squatting and Work-Related Back and Knee Problems

Work-related musculoskeletal disorders (WRMSDs) typically develop gradually, arising from prolonged exposure to risk factors like awkward postures, forceful exertions, or repetitive motions [1]. Squatting is a major cause of WRMSDs in the US [2] and one of the ergonomic risk factors on osteoarthritis from the World Health Organization (WHO) and the International Labour Organization (ILO) Joint Estimates of the Work-related Burden of Disease and Injury [3].

A meta-analysis on knee osteoarthritis found that exposure to kneeling or squatting at work elevated the risk with odds ratios 1.70 with a 95% CI of 1.35–2.13 [4]. The early onset and severity of osteoarthritis in certain occupations suggested an urgent need for studies for the prevention and intervention of work-related knee osteoarthritis [5]. A comprehensive cross-sectional population study conducted in Korea [6] discovered a high prevalence of the degenerative osteoarthritis in the knee, particularly among

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females. The cumulative squatting time (>10,000 h) increase the risk of radiographic knee OA among Korean farmers [7]. The joint contact forces at the knee during the squatting is 3.73 times of the body weight [8].

1.2 Exoskeletons

Introducing passive exoskeletons aims to offer mechanical support to workers enduring prolonged standing or squatting positions. Implementing the exoskeletons improve the balance between physical work demands and individual capacity [9]. Various exoskeletons were developed for different tasks and they can be roughly categorized by the supporting body part(s), such as the upper extremity [10–16], lower extremity [10, 17–19], or full body [19] devices. Passive lower extremity exoskeletons, often referred to as 'walking chairs' or 'chairless chairs' [20], specifically support the upper body weight while squatting or crouching by fix the knee joint at the preset angle. Passive exoskeletons for the lower extremities have demonstrated the ability to provide support for up to 60% of the body weight, thereby reducing the burden on the lower limbs [21]. A critical area for future research lies in identifying exoskeleton designs that are most suitable for varying task demands [22].

Current research on exoskeletons primarily focuses on the physical demands and user receptivity [5, 13, 22–26]. However, the amount of literature that has explored the impact of passive lower exoskeletons on postural stability is meager. Postural stability is important in the prevention of injuries related to loss of balance [27]. Luger et al. (2019) and Steinhilber et al. (2020) reported that the postural stability when using the exoskeleton did not significantly decrease during a simulated repetitive task. Nevertheless, the tasks assigned did not adequately challenge the boundaries of postural stability, as in the functional reach test.

1.3 Postural Stability with Exoskeleton

A stable posture is described as the body's center of gravity (COG) being within the base of support (BOS) [29]. The postural stability is greater when the COG is lower and the BOS is wider. The functional stability limit represents the area within which the body's COG can be controlled [27]. The functional stability limit reached only about 60% of the distance to the maximum base of support when allowing only the ankle motion and standing with the feet fully in contact with the floor. The functional reach test assesses the anteroposterior stability by measuring the maximum distance that a person can reach forward beyond arm's length while standing over a fixed base of support. The functional reach test is quick, simple, reliable, valid, sensitive and widely used in the hospitals to evaluate the patients with unstable balance [30–32]. The functional reach is much greater than the functional stability limit because the hip and knee joint motions are allowed [30, 33, 34].

Sitting on an exoskeleton moves the COG posteriorly and inferiorly [21]. This COG shift was corroborated with a decreased the range of the center of pressure (COP) displacement and, as a result, decreased velocity of the COP compared to standing without an exoskeleton. The risk of falling with a passive lower exoskeleton found to be low when reaching laterally for an object of up to 3 kg [28]. However, Steinhilber and his colleagues found the Chairless Chair® (Noonee AG, Switzerland) is not recommendable because people can fall backward when the external tilting moment was than 30 Nm.

This study aimed to evaluate the maximal reaching distance (functional reach test) and the trajectory of the center of mass and weight distribution in forward, backward, and sideways directions with a passive lower extremity exoskeleton at different sitting heights (NO CEX, CEX HIGH, and CEX LOW).

2 Method

2.1 Participants

Twenty (10 females and 10 males) young voluntary participants without any pain during the past month or musculoskeletal disorders in the lower extremities were recruited. All participants were read and signed the Hoseo University Institutional Review Board approved consent form (1041231-210830-HR-130). The characteristics of participants are summarized in Table 1.

Table 1. Characteristics of participants.

Characteristics	Male (n = 10)	Female (n = 10)	All (n = 20)
Age (years)	23.2 ± 3.1	20.8 ± 1.4	22.2 ± 2.7
Height (cm)	174.4 ± 4.2	158.3 ± 3.3	167.2 ± 9.0
Weight (kg)	75.1 ± 8.5	53.6 ± 10.6	65.5 ± 14.3
BMI (kg^2/m)	24.7 ± 2.9	21.4 ± 4.5	23.2 ± 3.9

2.2 Exoskeleton

The Chair-type Exoskeleton (CEX), a passive lower extremity exoskeleton weighing 1.6 kg, was utilized in this study. Developed by Hyundai Motors® (Hyundai Motor Group, Seoul, Korea), CEX provides support to the knee joint during squatting or crouching, enabling horizontal weight shifting without altering foot position. The device is secured to the lower leg and thigh, featuring a knee joint with three notches to fix at preset angles (55°, 70°, and 85°; 70° was not used in this study). The experimental conditions included the following: NO CEX, which involved reaching while standing on both feet with the CEX worn but not in contact with the floor; CEX HIGH, where participants sat on the CEX notch with an 85° knee angle; and CEX LOW, where participants sat on the CEX notch with a 55° knee angle.

2.3 Testing Procedure

Prior to the experiment, the experiment, participants received detailed information about the study's objectives, procedures, and the correct method for donning the exoskeleton.

Following this, participants were instructed with demonstration to try weight shifting and reaching in all testing directions under each CEX condition for a duration of five minutes. Participants were strongly encouraged to promptly report any physical discomfort experienced during any stage of the experiment, including prior to data collection and at the completion of each task (Fig. 1).

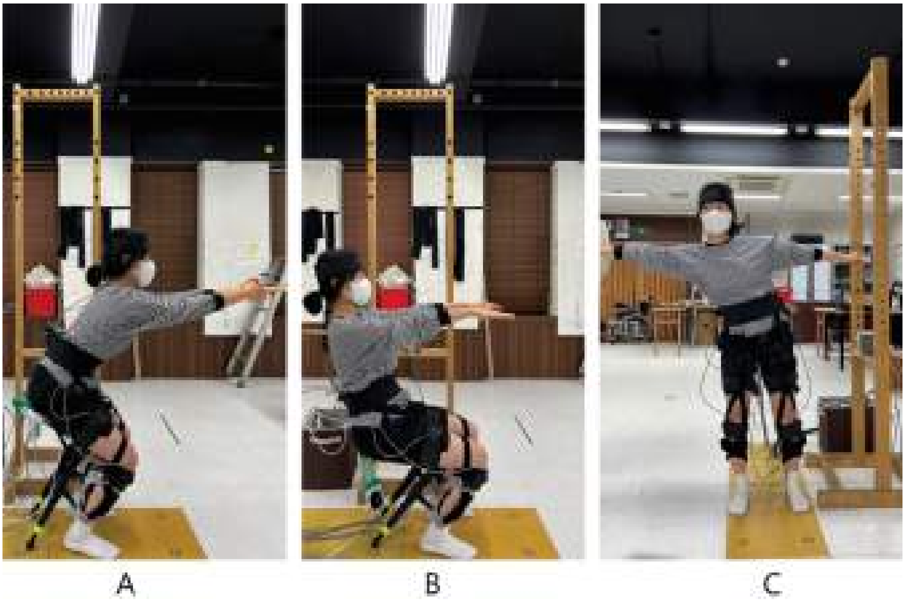

Fig. 1. Functional reach test was performed forward (A), backward (B), and toward dominant side (C) in NO CEX (C), CEX HIGH (A), and CEX LOW (B) conditions.

Each participant conducted the functional reach test in forward, backward, and toward their dominant side directions in a randomized order, under three conditions: NO CEX, CEX HIGH, and CEX LOW (Fig. 2). Participants took off the shoes and positioned on a force plate with their feet parallel and fixed at a distance of 35 cm apart.

For the anterior reach test, participants flexed their shoulders to 90º with fully extended elbows, clasped their hands together. A centimeter-marked yardstick, held horizontally by a custom-made wooden frame, was positioned in front of the hands at the level of the acromion. With trunk flexion, they were instructed to push the stick forward as much as possible. During the posterior reach test, the tip of the stick was aligned with the spinous process of T4 when participants were seated upright and the arms stretched forward for postural stability. In the lateral reach, both shoulders were abducted to 90º with fully extended elbows, and participants formed fisted hands. Participants were directed to reach as far as possible while keeping both feet on the floor, holding the end position until instructed to stop by the tester. Subjects performed at least one practice before each trial, following the starting position and verbal instructions akin to those utilized by Duncan and colleagues [32]. If a toe or heel lifted off the floor, the trial was repeated. Each task was repeated twice, and the maximal reaching distance (cm) was averaged.

2.4 Data Collection

Kinematic data of head, trunk, pelvis, and bilateral lower extremities were collected at a rate of 240 Hz using an electromagnetic 3-dimentional motion capture system (Polhemus Liberty®, Colchester, VT, USA). Seven active sensors were attached to occipital protuberance, C7, S1, bilateral thighs, and shanks. Center of mass (CoM) for the entire body was estimated based on the geographical distribution of all body segments excluding upper extremities and feet. The upper extremities and feet were not included in the center of mass estimation since all the tasks were systematical and the proportional mass was relatively small.

Two non-conductive force plates (Bertec® FP4060-NC, Columbus, OH, USA) sampling at 1,000 Hz were used to measure the ground reaction force (GRF). In CEX HIGH, and CEX LOW conditions, the supporting tips of CEX were on the force plate 2 to measure the ground reaction force of the exoskeleton independently: the magnitudes of GRF for the foot on force plate 1 and the supporting tips of the exoskeleton on force plate 2. In the NO CEX condition, participants still wore the CEX, but the grounding tips were suspended in the air, not contacting the force plate 2. The kinematics and GRF data were collected and time synchronized with the MotionMonitor xGen® (Innsport®, Chicago, IL, USA) software.

2.5 Data Analysis

The independent variables encompassed the exoskeleton condition (CEX LOW, CEX HIGH, and NO CEX) and reaching direction (anterior, posterior, and lateral). A two-way analysis of variance (ANOVA) was employed to examine the main and interactive effects of exoskeleton condition and reaching direction on the dependent variables. Given the significant interactions between exoskeleton condition and reaching direction, the impact of exoskeleton condition was assessed separately at each reaching direction using one-way ANOVA. Pairwise comparisons were conducted using Tukey's test. The significance level for all tests was set at $p < 0.05$. Statistical analyses were carried out using SPSS 20 (SPSS Inc, Chicago, IL, USA).

3 Result

3.1 Reaching Distance

The reaching distance (Fig. 2) was found to be the longest in the anterior direction and the shortest in the posterior direction ($F = 339.85$, $p < 0.01$). The anterior reaching distance was not significantly influenced ($F = 2.57$, $p = 0.09$) by the use of CEX. However, the utilization of CEX resulted in decreased posterior ($F = 7.8$, $p < 0.01$) and lateral ($F = 10.44$, $p < 0.01$) reaching distances. Notably, there was no significant difference between CEX HIGH and CEX LOW.

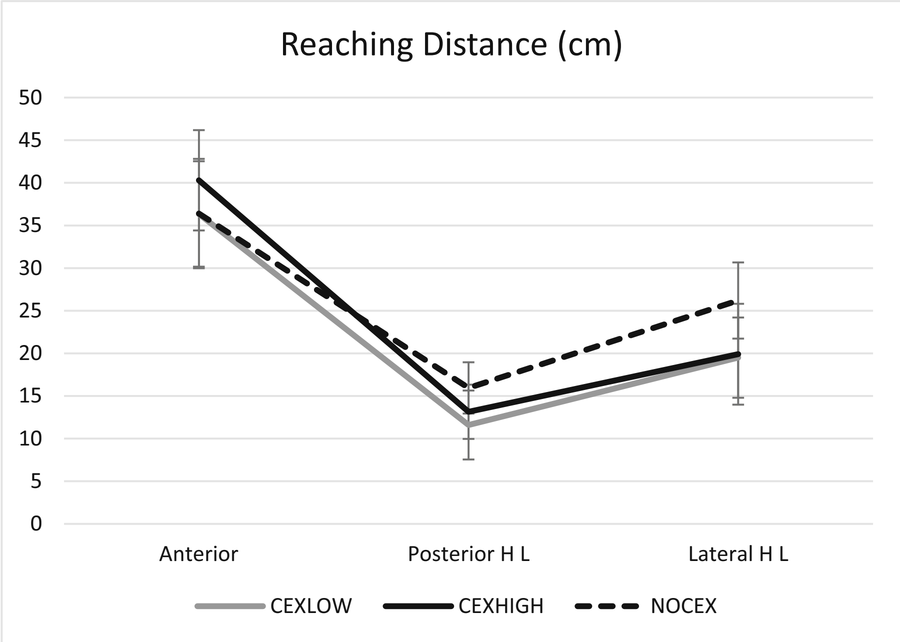

Fig. 2. Reaching distance (cm) by direction and exoskeleton condition. Black dashed line is for NO CEX, black line is for CEX HIGH, and grey line is for CEX LOW. H (CEX HIGH) and L (CEX LOW) means a significant difference from NO CEX ($p < 0.05$, Tukey's post hoc test). (Color figure online)

3.2 Center of Mass Dislocation

The Center of Mass (CoM) exhibited significant anterior movement in the anterior reach ($F = 165.99$, $p < 0.01$) and lateral movement in the lateral reach ($F = 307.96$, $p < 0.01$), with relatively limited posterior displacement in the posterior reach (Fig. 3). During the anterior reach, both CEX HIGH and CEX LOW further increased ($F = 12.02$, $p < 0.01$) the anterior dislocation of CoM compared to NO CEX. Conversely, during the lateral reach, both CEX HIGH and CEX LOW decreased ($F = 6.68$, $p < 0.01$) the lateral dislocation of CoM compared to NO CEX. The use of CEX did not have a significant effect on the CoM dislocation in the posterior reach. No significant effect of a specific CEX notch was observed on the dislocation of CoM in all reaching directions.

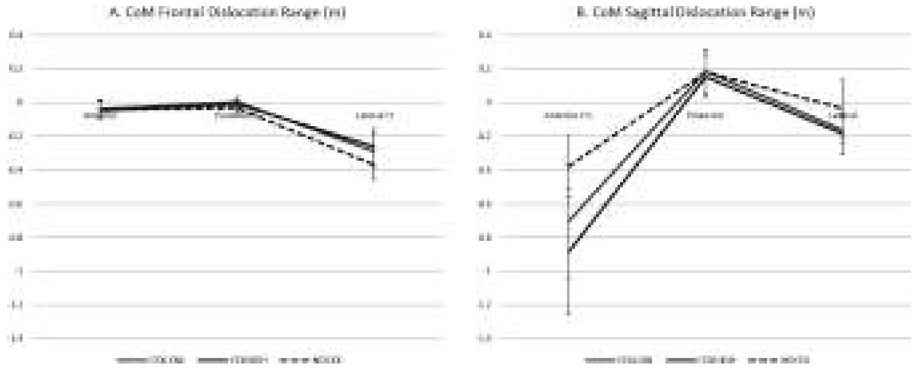

Fig. 3. Center of mass dislocation range (m) in frontal (A) and sagittal (B) plains by reaching direction and exoskeleton condition. Black dashed line is for NO CEX, black line is for CEX HIGH, and grey line is for CEX LOW. H (CEX HIGH) and L (CEX LOW) means a significant difference from NO CEX ($p < 0.05$, Tukey's post hoc test). (Color figure online)

3.3 Weight Distribution

The distribution of weight between the foot and CEX was significantly influenced by the reaching direction ($F = 58.93$, $p < 0.01$) (Fig. 4). In the anterior reach, there was an increase in the weight distribution on the foot coupled with a decrease on the CEX, while in the posterior reach, there was a decrease on the foot and an increase on the CEX. The weight distribution on the CEX decreased ($F = 26.07$, $p < 0.01$) during anterior reach and increased ($F = 522.18$, $p < 0.01$) during posterior reach. In the lateral reach, the weight distribution was relatively balanced between the foot and CEX. Specifically, during the anterior reach, the weight distribution on the foot was 96%, 76%, and 75% of body weight with NO CEX, CEX HIGH, and CEX LOW, respectively. In the posterior reach, the corresponding values were 94%, 19%, and 24% with NO CEX, CEX HIGH, and CEX LOW, respectively. For the lateral reach, the weight distribution on the foot was 96%, 42%, and 48% with NO CEX, CEX HIGH, and CEX LOW, respectively.

4 Discussion

The primary aim of this experiment was to evaluate the functional reach in forward, backward, and sideways directions with a passive lower extremity exoskeleton at different CEX conditions. The functional reach test, known for its quick, simple, reliable, valid, and sensitive attributes, is widely employed in hospitals to assess patients with unstable balance [30–32]. Postural stability plays a crucial role in preventing injuries associated with balance loss, particularly in the posterior direction where there is limited space for the Center of Mass (CoM) to move. The complexity of postural stability can be influenced by the intricate interaction of personal [37] and workplace factors, such as handling external loads [27]. Introducing a passive exoskeleton in various workplaces necessitates careful consideration of its impact on postural stability, ensuring informed decisions for workers to prevent falls and providing valuable insights for product designers to enhance the safety features of the exoskeleton.

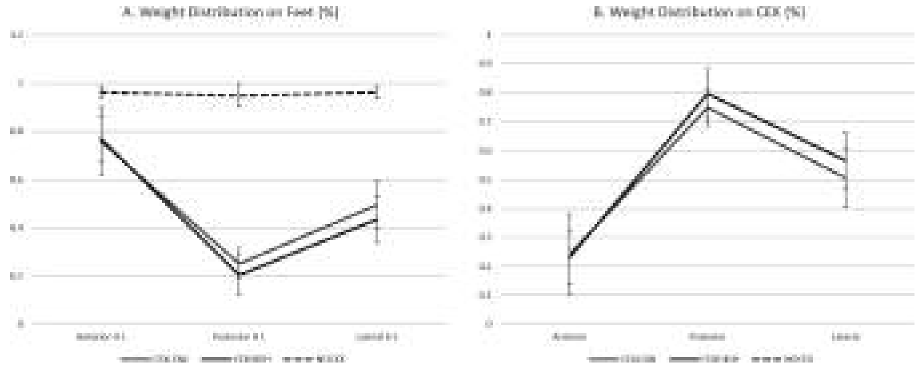

Fig. 4. Weigh distribution (%) on feet (A) and on CEX (B) by reaching direction and exoskeleton condition. Black dashed line is for NO CEX, black line is for CEX HIGH, and grey line is for CEX LOW. H (CEX HIGH) and L (CEX LOW) means a significant difference from NO CEX ($p < 0.05$, Tukey's post hoc test). (Color figure online)

4.1 Anterior Reach with CEX

In this study, it was observed that the distances covered in anterior reaching were significantly greater compared to posterior and lateral reaches in the absence of CEX, aligning with findings from a prior study on postural stability [27]. Anterior reach is functionally more important than other directions at many workplaces and it is most frequently tested in clinical setting as an assessment of the balance and postural stability. In quiet standing, the line of gravity (projection of center of whole-body mass) passes posterior to hip joint and anterior to knee and ankle joints [38]. As one reaches further anteriorly, there is an increased demand on the muscles attached to the posterior side of the joints (such as the soleus, gastrocnemius, hamstrings, gluteus, and erector spinae muscles) to contract and maintain balance.

The introduction of CEX did not impact anterior reaching distance but led to an increased anterior displacement of the Center of Mass (CoM). Both CEX HIGH and CEX LOW conditions resulted in participants shifting their weight towards the foot, reducing the weight on the CEX. When reaching forward, the use of CEX provided a broader base of support, a lower CoM, restricted movement in the lower extremities, and induced greater anterior trajectory of the CoM. This suggests that, for tasks involving anterior reaches, the utilization of CEX can potentially enhance workers' productivity by promoting good postural stability and reducing discomfort and fatigue.

4.2 Posterior Reach with CEX

Reaching distance was most limited posteriorly in this study, as seen in previous studies [27, 39, 40]. The standing position inherently provides a smaller base of support in the posterior direction compared to the anterior direction, resulting in limited postural sway at the ankle joint [27]. When reaching posteriorly from standing position, a person flexes the knee joint and extends the hip joint until the knee extensors and hip flexors are able to hold the postural loads and the CoM is within the limited base of support. Falling backward is more frequent and dangerous due to lack of protective reflexes and more challenging to brace for impact [41]. Studies [42, 43] on falls highlight that backward falls significantly increase the risk of head and spinal injuries, contributing to the severity of fall-related consequences.

With CEX, the already limited posterior reaching distance was further decreased with fixed knee joints and posteriorly shifted CoM. In CEX HIGH and CEX LOW, participants shifted their weight towards CEX, reducing the weight on the feet, and increasing pressure on the thigh pads compared to anterior reach. In previous studies [21, 28] have emphasized a significant decline in postural stability when sitting on a passive lower extremity exoskeleton, particularly in the posterior direction. The supporting tip of CEX contacts the floor roughly 15 cm behind the heels and extends the base of support posteriorly. However, the CoM also shifts posteriorly when sitting on CEX and the trajectory of CoM becomes shorter and slower compared to anterior reach. With a similar exoskeleton, Lugar and her colleagues [21] found a decreased velocity of the center of pressure on the force plates in the posterior direction during various simulated work tasks. Caution is warranted, especially in occupations involving posterior reaches, the utilization of CEX can potentially reduce the postural stability and increase the risk of fall. Precise caution for the workers is advisable when undertaking pulling tasks with CEX in certain workplaces.

4.3 Lateral Reach with CEX

Without CEX, the lateral reach was 28% shorter compared to the anterior reach. Introducing CEX further reduced the lateral reach distance, characterized by a shorter frontal trajectory of CoM. The weight distribution between feet and CEX was nearly even, and pressure on thigh pads was not influenced by the exoskeleton height condition. The flexed hip and knee positions with sitting on CEX limited lower extremity muscle engagement, probably relying more on relatively weaker trunk muscles to sustain lateral reach. The far boundary of the work area led to higher muscle activity in the lower back and increased discomfort, as observed in previous research [21]. Additionally, it's important to consider feet width, which was fixed at 35 cm apart in this study, as it can significantly impact the lateral reach distance and the frontal trajectory of CoM when sitting on CEX.

4.4 Limitation of Study

This study has several limitations. Firstly, it was conducted exclusively in a laboratory setting with young adult participants who had no prior experience with any exoskeleton. To generalize the findings across different age groups, skill levels, and workplaces, future research should include a more diverse participant pool. Additionally, the study focused on simulated tasks, and investigating actual occupational activities like drilling, using hand tools, and manual material handling on CEX is crucial to understanding its impact on postural stability and productivity. Secondly, the pressure on the thigh pad showed considerably large standard deviations, leading to statistical insignificance. The pressure data were normalized for each participant with their upper body weight in sitting with holding the one leg up in the air in CEX LOW condition in this study. The posture of normalization was unstable and some of participant required considerable external support to maintain the posture. Thirdly, the muscle recruitment data were not collected because the straps and pads of CEX already covers the surface area for electrodes of electromyography (EMG). However, there are already many previous passive exoskeletal studies reporting the efficacy (up to 60% in some muscles) of exoskeleton with EMG [10, 13, 14, 17, 19]. Despite these limitations, the study contributes valuable insights for introducing passive exoskeletons and enhancing the design of both passive and potentially active lower extremity exoskeletons. Despite these limitations, the study contributes valuable insights for introducing passive exoskeletons and enhancing the design of both passive and potentially active lower extremity exoskeletons.

5 Conclusions

This study examined the impact of a chair-type wearable exoskeleton (CEX) at different height settings (NO CEX, CEX HIGH, and CEX LOW) on functional reach distances and weight distribution. Results showed that CEX had no effect on anterior reaching but significantly reduced posterior and lateral reaching distances. Ground reaction force on the feet varied across reaching directions. Overall, limitations in posterior reaching were exacerbated by CEX, emphasizing the need for design improvements and worker awareness when deploying exoskeletons in workplaces.

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Sustainable Development (I)

Factors Affecting Filipinos' Perception of Purchasing Life Insurance: An Integration of the Theory of Planned Behavior

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Abstract. Life insurance is recognized as a vital tool for financial protection and risk management as it assists in minimizing financial risks related to unexpected occurrences. However, the number of people insured in the Philippines remains low. The study aims to provide information about the variables influencing the perceived purchasing of life insurance among Filipinos integrating the Theory of Planned Behavior. 514 participating respondents answered the online survey questionnaire with 53 questions. Structural equation modeling determined that media (M) affects generational cohort (GC); external influences (EI), personal experience and knowledge (PKE), and financial health (FH) affect social norms (SN); FH and GC affect attitude towards behavior (AB); and SN as well as AB affects perceived behavioral control (PBC) which have a statistically significant outcome on the perception on purchasing life insurance (PL). Moreover, most of the respondents, Generation Z, tend to be more exposed to life insurance information posted in the media given their ability to access information instantly. The study's results will contribute a new perspective in investigating the behavior of consumers who buy life insurance policies in the Philippines.

Keywords: Life insurance purchasing · Theory of planned behavior · Structural equation modeling

1 Introduction

Insurance has been considered a vital tool for financial protection and risk management in the Philippines as it helps individuals and businesses manage financial risks from unanticipated events, such as natural disasters, mishaps, ailments, and other unforeseen circumstances [1]. Lack of public information, inadequate understanding of insurance benefits, adverse attitudes of people, racial values, and small distribution channels contribute to various reasons affecting low insurance penetration [2]. Despite the continuous effort to improve the percentage of insurance penetration, shifting towards digitalization also had adverse effects, including the rise in fraudulent concerns.

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The Philippines' central bank revealed that the main reason why Filipinos do not enroll in insurance is due to their lack of money [3]. The high cost of insurance premiums has made Filipinos opt for microinsurance, resulting in a rise in contribution in 2022, with a 15.50% increase compared to the observed amount in 2021 [4]. Many perceive insurance as a non-compulsory expense rather than a necessity for survival, and there is still a negative perception of insurance related to death and accidents [5].

This research aimed to identify statistically significant variables influencing the insurance enrollment acceptance of Filipinos incorporating the Theory of Planned Behavior. Structural Equation Modeling was utilized to determine the interrelationships between the latent variables and played a fundamental role in examining the behavior and decisions of Filipinos when purchasing life insurance in the country.

2 Research Model

The study used the Theory of Planned Behavior variables to connect the hypothesized factors affecting insurance enrollment acceptance. It used these to determine the significant variables influencing the decision of insurance buyers in purchasing or not purchasing insurance (see Fig. 1) [6]. Determining the factors that affect a customer's purchasing behavior among Filipinos is crucial in making improvements in government insurance policies and programs and for insurance companies to adjust their strategies and products according to the most common needs of the people.

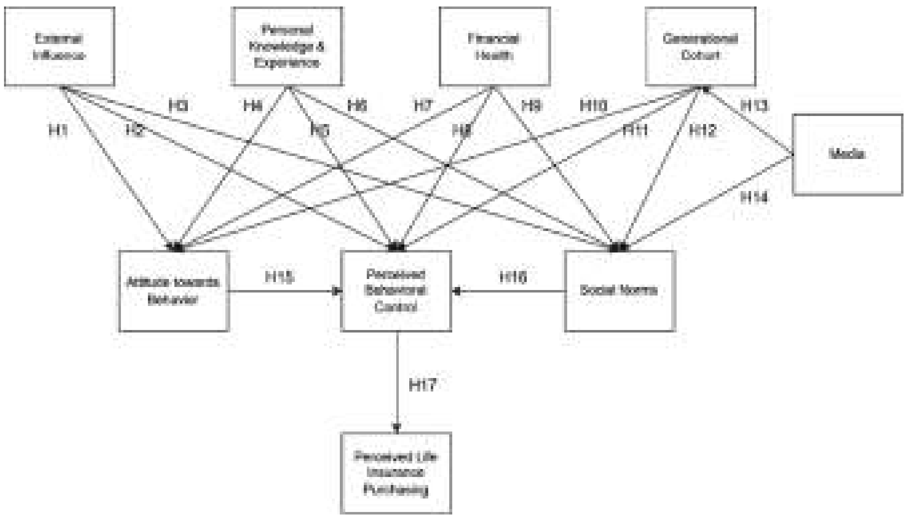

Fig. 1. Theoretical framework.

3 Methodology

The study utilized self-administered survey questionnaires (SAQ) as it reduces potential social desirability bias [7]. In developing the questions, findings from the literature reviews were used as the basis, and the respondents will answer the questions using a 5-point Likert scale assessment.

Filipino individuals currently or previously enrolled in life insurance policies were eligible to participate in the study. Specifically, male, and female individuals who are at least 23 years old, employed, have purchased life insurance policies before, and currently reside in the Philippines [8].

4 Results and Discussion

The initial SEM model (see Fig. 2) integrates the Theory of Planned Behavior, connecting the hypothesized factors influencing the perceived life insurance purchasing: external influence, personal knowledge & experience, financial health, generational cohort, and media. These were hypothesized to determine the effect on a person's generational cohort and social norms. Meanwhile, Fig. 3 shows the final SEM model for Filipinos' perception of purchasing life insurance.

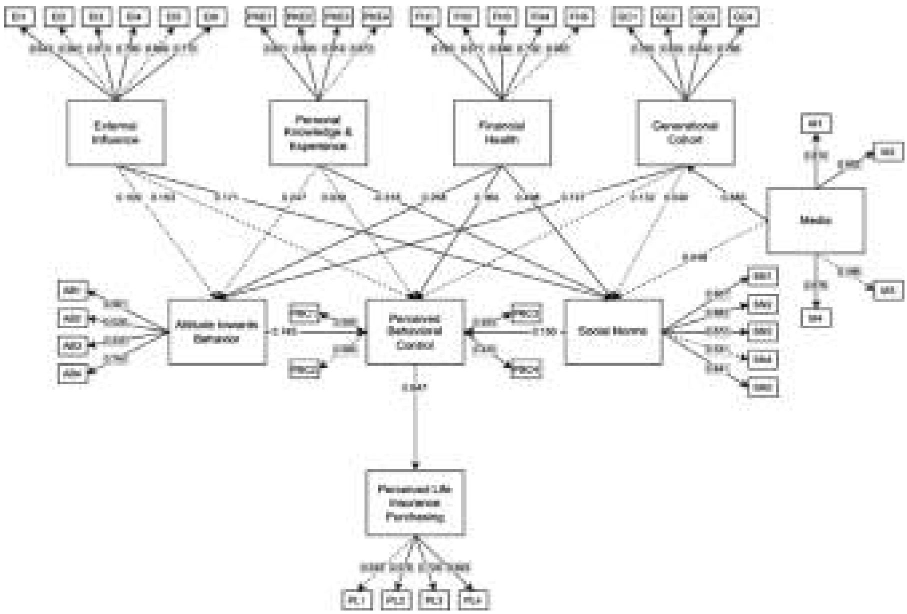

Fig. 2. Initial SEM model.

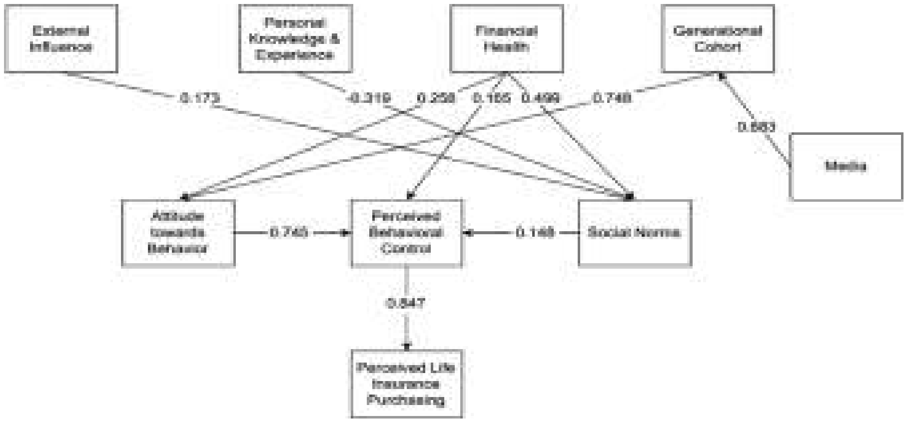

Fig. 3. Final SEM model.

4.1 Discussion and Measurement Evaluation

First, Media was proven to have a direct positive relationship with generational cohort (ß: 0.960; p-value = 0.002), implying that media use influences different generations when it comes to purchasing insurance and having up-to-date information used in advertisements as it influences a person's purchasing decisions [9, 10].

Second, Perceived Behavioral Control is directly related to perceived life insurance purchasing (ß: 0.876; p-value = 0.002). The fewer obstacles a person perceives and with a more stable future behavior, the more people understand how insurance works and its significance, and the lesser the resistance to purchasing life insurance [11].

Third, Financial Health has a direct and positive relationship with social norms (ß: 0.763; p-value = 0.002). Individuals with strong financial health have the means to follow social norms related to insurance, while those with weaker financial health struggle [12]. Next, the Generational Cohort was found to have a direct connection with attitude toward behavior (ß: 0.738; p-value = 0.002), as age categories have different factors motivating consumers to purchase life insurance [13]. Most respondents are from Generation Z; however, 61.95% of the respondents from this group have life insurance. This shows that younger people are more exposed to amusement programs and less to informative media, which influences their risk perception and, in return, also affects their perception of purchasing life insurance [14].

Fourth, Attitude toward Behavior was also found to have a direct positive association with perceived behavioral control (ß: 0.716; p-value = 0.001). Buyers are more inclined to buy insurance when they perceive it as a tool to keep them safe, lessening their anxiety when faced with unforeseen events [15]. Consumers compare costs and have various information about insurance, as most respondents (74.9%) felt that having a positive attitude towards purchasing life insurance made them more willing to buy one [16].

Lastly, Personal Knowledge and Experience have an inverse relationship with social norms (ß: −0.768; p-value = 0.001). The more a person has knowledge and understanding of insurance policies, the less they find the need to conform to social norms. Having sufficient knowledge about insurance purchasing benefits would make a person want to acquire. Hence, they are less likely to seek others' feedback [17].

Table 1 shows the reliability and validity outcome for each construct and latent variable used in the study. A Cronbach's alpha within the range of 0.6 to 0.7 depicts an acceptable reliability level, whereas an alpha of 0.8 or higher shows an excellent level [18]. The results demonstrate that Cronbach's alpha values fall in the acceptable range, indicating the model's validity and reliability.

Table 1. Composite reliability.

Variable	Cronbach's Alpha	Average	Composite Reliability
External Influence	0.776	0.475	0.779
Personal Knowledge & Experience	0.803	0.611	0.822
Financial Health	0.841	0.530	0.851
Generational Cohort	0.841	0.548	0.827
Media	0.784	0.432	0.690
Attitude Toward the Behavior	0.771	0..455	0.764
Social Norms	0.902	0.699	0.903
Perceived Behavioral Control	0.710	0.366	0.633
Perceived Life Insurance Purchasing	0.803	0.578	0.803

Table 2 shows the model fit based on several indices. A recommended minimum value of 0.80 is considered reasonable [19, 21]. The Adjusted Goodness of Fit Index, Tucker-Lewis Index, Incremental Fit Index, and Comparative Fit Index adhere to the minimum cutoff of greater than 0.80. Meanwhile, the root square mean error of approximation must be less than 0.07, whereas the model resulted in a value of 0.068, indicating that the model is a good fit [20, 21].

Table 2. Model fit indices.

Goodness of Fit Measures	Parameter Estimates	Minimum Cutoff	Suggested by
Incremental Fit Index	0.897	>0.80	[19, 21]
Tucker-Lewis Index	0.882	>0.80	[19, 21]
Comparative Fit Index	0.897	>0.80	[19, 21]
Adjusted Goodness of Fit Index	0.804	>0.80	[19, 21]
Root Mean Square Error Approximation	0.068	<0.07	[20, 21]

5 Conclusion

Perceived behavioral control is the latent variable that has the most significance in one's perception of buying life insurance of consumers towards life insurance. With Filipinos' personal knowledge and experience alongside one's financial health, standards on quality of life can be improved. In addition, media has different effects depending on the generation cohort that one is part of, thus also influencing one's attitude and behavior towards life insurance. The same can be said for financial health since having good financial health would mean that one could have a positive attitude when purchasing a policy, and thus, there is ease in making decisions.

This study presents a reliable model for experts and academicians to delve deeper into assessing Filipinos' perception of purchasing life insurance and to create effective programs and policies for promoting life insurance to Filipinos.

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Developing Safe Work Activities in the Metal Additive Manufacturing Industries of the Future by Analyzing Work Activity and Occupational Exposure. Methodological Development and Industrial Application

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Abstract. Development of work and prevention in the context of metal additive manufacturing industry faces new challenges with the integration of the production process, from design to manufacturing within a collaborative organization. The paper presents preliminary results of a research program about industries of the future. The methodology relies on building of the approach with the companies and occupational health and safety specialists, work activities observation, interviews, measurements (real time monitoring of heart rate and inhalation exposure to aerosols, and sampling), feedback meetings and transfers of the method. The challenge is to characterize the risks to human health and the possibilities for developing work activities to mitigate them. In this perspective, the project seeks to design a transferable method for use by preventionists and companies, to foster a safe and sustainable work.

Keywords: occupational exposure · method design · future of work · innovation · metal additive manufacturing

1 Introduction

The rise of metal additive manufacturing processes in connection with Industry 4.0 or more recently industry 5.0 (European Commission 2021) may generate risks to human health of chemical origin (Leso et al. 2021). Besides, the meaning of work and management are being renewed, and the organization of work and production are being transformed, as is the underlying economic model (Galey et al. 2022; Barcellini et al. 2023). This paper focuses on the additive manufacturing model to take account of and

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illustrate these transformations in the links between the technical and organizational dimensions, articulated by workers through their activities. In this context of innovation, these characteristics of the industry are under construction, providing an opportunity to act on its design process.

One of the contributions of this work is to integrate approaches from the technical sciences (engineering sciences and industrial hygiene) and the human sciences (activity-based ergonomics (Daniellou 2005), psychology and organizational modelling) into a multidisciplinary method. The objective and subjective characteristics of human work and risks, as well as the micro (work situation) and macroscopic (operation of the company in relation to services) levels of analysis constitute resources.

These proceedings objectives are to present the project (and first results) on the following themes:

1) Understand human work in the additive manufacturing industries as a case of industries of the future by characterizing the new forms of activity, prescription and organization of work.
2) Describe how these new forms of work make it possible to mitigate occupational risks, whether of organizational origin (e.g. autonomy) or technical (e.g. exposure to toxic products).
3) Supporting the transfer of the multidisciplinary method, for companies in order to characterize human work, and for preventionists in order to characterize occupational risks.

2 Methodology

Companies in the metallurgy sector are involved in the project to implement the method and ensure its transfer.

2.1 Understanding and Supporting the Development of Human Work in Industry 4.0

In order to build up a representation of the multi-scale organization of work, several approaches will be mobilized. The characterization of work activity in the 4.0 organization will adopt a modelling-based approach in order to structure and understand the structure and conduct of a production system while situating the inherent risks. More specifically, business modelling approaches will be used in combination with an analysis of work situations in relation to time, as proposed by ergonomics (Chizallet et al. 2023).

2.2 Identifying and Contributing to Risk Reduction

The 'safety' analysis will be based on documents relating to safety issues produced by the company, semi-structured interviews with company players involved in health and safety matters, as well as questionnaires to identified psychological risks and representations of risks.

Next, measurements will be used to describe occupational exposure to micro- and nanoparticles during these work activities. An analysis of physical intensity will be carried out for each of these activity stages using CAPTIV software. Finally, the collective analysis of exposure situations, during interviews with the workers previously observed and the members of the management team, should make it possible to understand the determinants of exposure while seeking to change the working conditions and the activity. Acting on these exposures should become possible through the design of the industry and the integration of indicators of exposure to organizational or technical factors.

2.3 Developing a Method for Sustainable and Safe Work Within Innovation

Developing the method described above involves understanding the practices of the players and their resources, as well as consolidating the method's transfer mechanism. This reflection on the design of the method is a further stage in the understanding of intervention techniques and methods for the players involved in the work and whose knowledge of the work constitutes resources (designer, preventionist, etc.).

3 Results

The results identified for scientific use will relate to the multidisciplinary method produced and the conditions for its development, knowledge about human work in these 4.0 additive manufacturing industries, knowledge about risks and how to protect against them.

At least two companies will be involved in the project to implement the method and ensure its transfer. The companies from various sectors as aeronautics, automotive and biomedical, have around 300 employees and carry out all the stages in the production of parts using metal additive manufacturing, from digital design to post-production finishing. An overview of the method under construction is presented in Fig. 1.

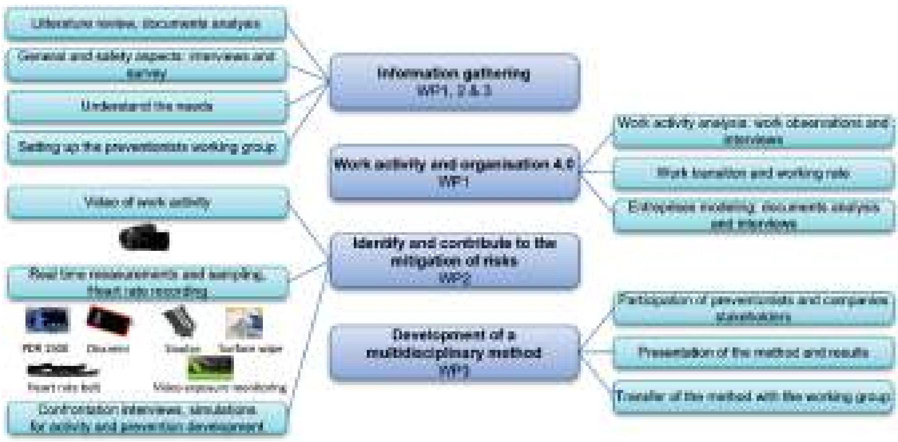

Fig. 1. Overview of the steps in the general method for metal additive manufacturing sites

We plan to carry out around 30 interviews, 300 questionnaires and 15 in-depth work observations. In addition, the creation of a working group involving company and institutional OSH specialists should help to develop a method that meets their needs, as well as contributing to the transfer of the method.

In companies, the deployment of the method will involve social construction with the stakeholders (management, trade unions, operators, occupational health services, etc.), participation on a voluntary basis in a participative and constructive approach, feedback of the results to the stakeholders, and the development of requirements for design to support the deployment of the Industry of the Future. The confidentiality of data from companies will be systematically ensured. The project, which meets the requirements of research in the humanities and social sciences, has been approved by a research ethics committee.

4 Discussion

One hypothesis is that the design of the industry of the future centred on metal additive manufacturing is mainly technocentric, leading to occupational exposure (to metal powders, to physically intense work, to a change in the meaning of work, to a cognitive load, for example). In order to design sustainable work, these limits need to be taken into account upstream of technological innovation.

The limitation of this project may be its qualitative dimension, which limits the generalisation of the results. The challenge of focusing on the development of methods and their transfer appears to be a response to these limitations.

5 Conclusion

This exploratory work based on a case of Industry of the Future seeks to bring together researchers and industrial to bring knowledges, criteria and sharing work practices. The challenge is to characterize the risks to human health associated with certain metal additive manufacturing processes (PBF and DED) and the possibilities for developing work activities to protect against them. The industry based on these means of production is leading to new professions and new ways of organizing production and work. With this in mind, the project is devising a transferable multidisciplinary method.

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Navigating the 5.0 Transitions: Strategic Management Insights from the HF/E Perspective

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Abstract. This study addresses the necessity for strategic management in transitioning towards Industry 5.0 and Society 5.0. Currently employed key performance indicators (KPIs) are insufficient for these new paradigmatic transitions. The objective of this study is to align the metrics associated to these transitions with the goals of human factors and ergonomics (HF/E). This multi-source review complies the variety of national and international institutional sources of KPI data relevant to employee well-being and productivity, particularly in Finland. The findings reveal that while numerous KPIs exist, they often reflect past conditions and lack a comprehensive sociotechnical approach. To conclude, existing KPIs and policy frameworks are inadequate when examined from the HF/E perspective, advocating for a new strategic orientation to better manage the anticipated changes in work and societal patterns.

Keywords: Industry 5.0 · Key performance indicator · Macroergonomics

1 Introduction

Digitalization and the related rapid development of technologies is at the same time a challenge and an opportunity. From a historical industry development perspective, currently experienced rapid technologization through digitalization is often referred as to the phenomenon of Industry 4.0. To enhance the human perspective, concepts like Industry 5.0 and Society 5.0 have been proposed to complement and expand the predominantly business-focused Industry 4.0 paradigm. These new future visions aim to foster a shift towards better sociotechnical understanding, with the ultimate goal of creating a sustainable, human-centric, and resilient industry [1, 2]. From the Human factors and ergonomics (HF/E) perspective, these 5.0 visions open a wide array of topics to join in with our expertise. In this article, we have selected to keep our focus on the business perspective, hence we focus on Industry 5.0 in our analysis.

Industry 5.0 specifically points out the need to 1) have a human-centric approach for digital technologies, 2) consider up-skilling and re-skilling worker skills and competences, and 3) aim for modern, resource-efficient and sustainable industries, with the

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overall objective for a revolutionary paradigmatic change [3]. From the HF/E perspective, Industry 5.0 should also be seen as an eye-opener. Those things being targeted in Industry 5.0 visions share many similarities with those we commonly associate as the ultimate goals for HF/E [e.g., 4]. In HF/E we also highlight human-centricity and strive for optimized system performance without harnessing human health and safety. Hence, we see it natural for HF/E to take its' part in these transitions and related academic discussion.

To achieve the Industry 5.0 vision, we need totally new policies, tools, partnerships, and objectives for industries [3]. Achieving this vision demands dedicated management across multiple levels, from individual organizations to society as a whole. From a strategic management perspective, it is crucial to track the progress toward the goals using key performance indicators (KPIs). These KPIs will help monitor development and make necessary adjustments. [e.g., 5]. As the Industry 5.0 vision alignments claim, the applicability of the "traditional" headline KPIs of competitiveness can be questioned in this context. For instance, a commonly used economic indicator, Gross Domestic Product (GDP) has been criticized for its adequacies to understand the development of welfare and well-being in the digitalized world [6]. Hence, there is need for more appropriate measures reflecting the contemporary economics thinking that values more profoundly human and natural capital [3].

HF/E has always had a keen interest in measuring work and turning the data collected and knowledge generated into design standards, yet we often face difficulties when trying to shift this knowledge into larger sociotechnical system entities and their optimization [e.g., 7]. Various authors have discussed the complexities for defining a system in the context of HF/E, reaching the discussion all the way to human-nature systems and sustainability [8, 9]. Neville Moray [8] claimed how all the challenges we confront, globally or locally, always require understanding of human behavior, shaping of human interaction with other humans and with the environment (both human-made and natural). Supplementing these macro level system considerations, we take in this article a broad perspective on systems, as we intend to focus on Finland as the unit of analysis. We emphasize how such a large system can't be considered an isolated entity, but it is influenced by various driving forces, like climate change, geopolitical turmoil, globalization, ageing population, and technologization. Further, we agree that nations may have significant differences internally for example through their regional business structures [e.g., 10], but we also highlight the potential strategic management research has in this national context [11].

2 Methodology

We take the general, yet not mutually agreed Industry 5.0 vision by the European Union [3] as a backbone for our analysis. We expand our systems' thinking to broad national-level systems as we examine how currently used metrics can be used for HF/E purposes. In our multi-source review, we are especially interested in investigating the spectrum of KPIs available for monitoring the national level development when considered from the dualistic goals of HF/E, i.e., human well-being and system performance. We emphasize how various kinds of national and international level KPIs and statistics databases provided by different institutional stakeholders can be used for that purpose [e.g., 12–17]. First, we jointly identified the most important international sources for information based on our existing understanding in this area. Second, we examined the webpages of those selected sources and examined the databases they provided and third, these KPIs were discussed in-depth in researcher meetings.

Before going into the KPIs, it is important to describe some basics of Finland to allow understanding the contextual perspective. Among the first countries in the world, Finland has created a national strategy that boosts digitalization in the Industry 4.0 context. At the same time, Finland has constantly been awarded as the happiest country in the world [18]. Among various other objectives, Finland [19] aims to increase our competitiveness and well-being through digitalization and within better working life that promotes the development of work ability and well-being at work. Despite these shiny views, we also see grey clouds on the horizon. An ongoing national level research project [20] has argued that employees' experiences on their work ability and employee well-being have decreased during the last years and mental health-related sickness absences have even started to increase. Further, there has also been insufficient development in the cases of musculoskeletal disorders and occupational accidents. At the same time, there is clear evidence how Finnish labor productivity has not kept its' pace and we are significantly lagging the positive productivity development seen in our key competitor countries in the Nordic countries and elsewhere in Europe [21]. In national debate, it has been argued how strengthening competitiveness would require—among other measures—paying attention to the better allocation of production factors, i.e., to the interplay between physical (technology, production facilities) and human (employees, know-how, etc.) capital. This, to our judgement, seems to be something where HF/E could contribute.

3 Findings and Discussion

Based on our multi-source review the most important sources for indicator data that allows comparing Finland to other countries were: 1) International Labour Organization [ILO], 2) World Bank, 3) International Monetary Fund [IMF], 4) Organisation for Economic Co-operation and Development [OECD], 5) Statistical Office of the European Union (EUROSTAT], and 6) European Agency for Safety and Health at Work [EU OSHA]. The indicators for which these institutions collect national level data potentially relevant to HF/E are compiled in Table 1. The indicators included those measuring labor productivity and those measuring employee well-being, with the latter one especially focusing on OHS indicators describing past issues. In addition, employee well-being data collected e.g., through surveys by EU OSHA and EUROFOUND, and their survey scores can be used for country level comparison. For simplicity these have been left out from Table 1.

Supplementing the above data there are also national data sources relevant to our study. Statistics Finland is the official statistics institution in Finland. It collects and masters data referable to the data sources presented in Table 1. The Finnish Workers' Compensation Center collects nation-wide data on occupational accidents of which compensations have been paid. Finnish Institute of Occupational Health has recently

Table 1. Indicators followed by the institutional stakeholders.

		OECD	World Bank	IMF	EUROSTAT	ILO	EU OSHA
Productivity indicators	GDP per hour worked	X	X	X		X	
	Employment/ unemployment rate	X	X	X	X	X	
	Annual hours worked per employee	X			X	X	X
	Labour force participation rate	X	X		X		
	Labour productivity - volume of output produced per unit of labor input	X			X	X	
	Labour costs					X	
	Total factor productivity	X					
	Multifactor productivity	X					
	Educational attainment level	X	X			X	
Well-being indicators	Occupational accident and injuries[a]	X			X	X	X
	Occupational diseases	X			X	X	
	Inspectors per 10 000 employed persons/Inspector visits					X	X
	Time pressure						X
	Vibrations, loud noise and temperature						X

(*continued*)

Table 1. (*continued*)

		OECD	World Bank	IMF	EUROSTAT	ILO	EU OSHA
	Exposure to dangerous substances						X
	Ergonomics risks						X

[a]This is purposedly a wide term, including a variety of lagging indicators describing occupational accidents by total numbers, frequencies, days lost and cases per different variables (like sex, age, economics activity).

established a Work-Life Knowledge Service (W-LKSD) website [22] aiming to collect reliable, up-to-date work life data in Finland. When examined from the HF/E perspective, the database is insufficient and partially old when it comes to ergonomics issues and it does not include data on productivity. Then for instance ETLA Economic Research collects and publishes data [23] on productivity but not on well-being related matters.

Likewise in Industry 4.0 [24], businesses would benefit from national strategies for Industry 5.0. These strategies must be equipped with suitable KPIs. The indicators listed in Table 1 provide reliable and useful information of the country level performance, yet they seem rather traditional when it comes to the Industry 5.0 visions. They do not acknowledge technological developments, nor do they measure resilience. For the starters—to supplement them with the perspectives of digitalization and employee skills—these indicators could be considered side by side with indicators available describing employees' digital skills and competences [25] leading potentially new indicators where for instance the rates and severities for occupational accidents or diseases or labor productivity are compared to the levels of employees' digital skills. From the resilience perspective—as a macroergonomics indicator—the ability of industries to maintain their operations during disruptions. These indicators could be compared to the levels of digitalization, like measured through the Digital Economy and Society Index by the European Union [26].

4 Conclusions

Paradigmatic transitions towards human-centric 5.0 visions require bold new initiatives in strategic management. To drive this change effectively, it is crucial to have the capability to collect diverse data and measure progress accurately. Based on our multi-source review, we argue that current policy systems and KPIs are not mature enough for this when examined based on the dualistic goals for HF/E, i.e. to simultaneously optimize wellbeing and system performance. Our analysis indicates that we are too strongly guided by traditional thinking that follows classical headline KPIs. We are especially worried whether changes in work, intangible capital changes and changing service patterns can be managed with currently available data. We recommend finding a new strategic orientation that guides in the shift towards the forecasted 5.0 visions. As these 5.0 visions aim for a human-centric future, we see here a moment for HF/E to lift its role in this paradigmatic change).

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Training Education (I)

Factors Affecting Perceived Career Decision-Making of Filipinos Across Generational Cohorts: A Structural Equation Modeling Approach

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Abstract. Choosing a career is an integral factor in life fulfillment. It is a complex process that requires an individual's intention, knowledge, and readiness with the help of proper guidance and counseling. Despite its significance, some individuals feel pressure and difficulty as they face their independence in their career choices. Although one's interest, perception, and judgment may be influenced by career knowledge, perceived benefits, and culture, this may result in hesitation and uncertainty in their chosen career. These variables are integrated into the Generational Cohort Theory (GCT) and Theory of Planned Behavior (TPB) to discover the significant variables that affect the career decision-making of Filipinos. Self-administered questionnaires were used to collect data and analyzed it by structural equation modeling using IBM SPSS AMOS. It was discovered that perceived benefits (PB) and career knowledge (CK) have a relationship with attitude toward the behavior (ATB), while Culture (C) is directly related to Social Norms (SN). Furthermore, ATB and SN have a significant relationship with behavioral intention (BI), as BI refers to the perception of correct decision (PCD). Through analysis of variance, results show that generational cohorts (GC) have a direct significance with PB and CK.

Keywords: Career decision-making · Generational cohort theory · Structural equation modeling

1 Introduction

About 1.2 million college graduates face employment difficulties due to the continued growth of education mismatch rates in countries like the Philippines. With the increasing number of job and organizational changes, millennials are likelier to make more job

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and organizational changes than previous generations. This led to a growing number of individuals engaging in newer forms of the labor market despite skills, education, and job mismatches due to the evident growth of globalization in how individuals perceive their careers [1]. Despite the profound impact of career choices, the career decision-making process was often overlooked or approached randomly by individuals. Extensive research over the past several decades examined the factors that influenced career decision-making, including individual interests, abilities, values, and external factors like labor market trends and availability of opportunities [2].

However, a gap persisted in understanding how career decision-making varied across generational cohorts, whose unique experiences were hypothesized to develop distinct perspectives and priorities around careers. While generational differences have been studied in various contexts, few studies analyzed their effects on career perceptions and choices within the specific Philippine cultural context. This study aims to identify and analyze the factors influencing the perceived career decision-making of Filipinos across generational cohorts. The expected outcomes include increased understanding regarding career decision-making, improved career guidance strategies, informed policies and programs, enhanced career satisfaction, and positive cultural and societal impacts by empowering Filipinos to make informed career choices, leading to better career outcomes and more fulfilling work lives.

2 Research Model and Methodology

The researchers disseminated a self-administered survey questionnaire through online platforms utilizing a 5-point Likert scale to measure the latent variables. The figure below shows the theoretical framework of the study (Fig. 1).

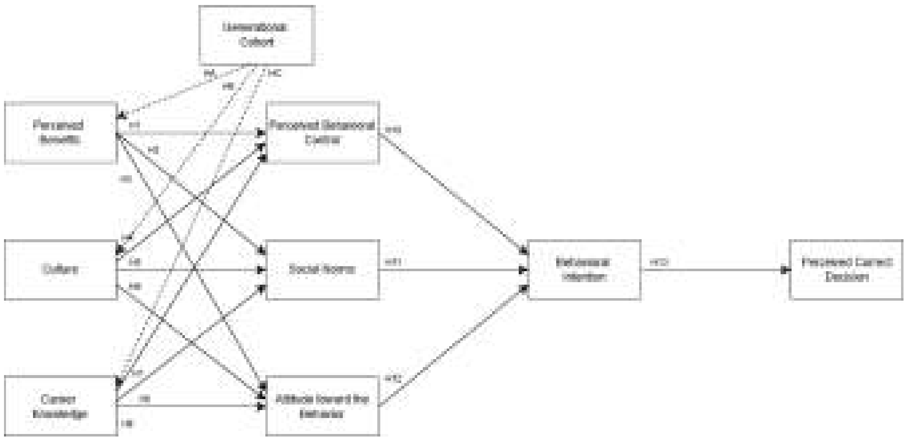

Fig. 1. Theoretical framework.

The theoretical framework examines the relationships between the latent variables such as perceived benefits, culture, career knowledge, perceived behavioral control, social norms, attitude toward behavior, and generational cohorts from the Generational Cohort Theory. It aims to determine their importance to behavioral intention and perceived correct decision through hypotheses H1 to H13. The study investigates how generational differences affect these variables and their relationship based on the two applied theories.

Results were analyzed through structural equation modeling to analyze complex structural relationships of constructs such as perceived benefits, culture, career knowledge, perceived behavioral control, social norms, attitude toward the behavior, behavioral intention, and perceived correct decision.

3 Results and Discussion

The initial framework constructed in the study consists of eight (8) latent variables. The variables and their significant indicators are presented in the model. Moreover, it is hypothesized in the initial SEM model that every latent variable has only one significant effect on either social norms or attitudes toward behavior. Insignificant hypotheses found were Perceived benefits and Perceived behavioral control, Perceived benefits and Social norms, Culture and Perceived behavioral control, Culture and Attitude toward the behavior, Career knowledge and Perceived behavioral control, and Career knowledge and Social norms (see Fig. 2).

It is also demonstrated that variables such as perceived behavioral control, social norms, and attitudes toward the behavior significantly influence behavioral intention based on the initial SEM model. Moreover, the final SEM model (see Fig. 3) shows the revised model by excluding insignificant hypotheses.

SEM results showed a positive connection between Perceived benefits and attitude toward the behavior (β: 0.571; p-value = 0.002), indicating that career benefits influence individuals' choices. Inner positivity significantly impacts employment success, while benefits enhance job satisfaction and well-being [3, 4]. Second, Perceived benefits directly affect behavioral intention (β = 0.484; p-value = 0.002). Job aspects such as salary and work-life balance impact Filipinos' career decisions, while external factors such as family support and education influence intentions [5]. Moreover, family involvement, education quality, and personal traits affect career intentions, incredibly motivating women's aspirations in higher education [6].

Third, Culture directly influences social norms (β: 0.554, p-value = 0.002), particularly in Filipino society, where collectivism prevails, prioritizing family and shared responsibilities [7]. This collective focus often supersedes individual interests. During upbringing, individuals are shaped by family, community, and peers, influencing choices, behaviors, and career interests [8].

Lastly, Career Knowledge positively affects attitude toward the behavior (β:0.421, p-value = 0.002). This suggests that those with more knowledge tend to hold favorable attitudes toward career-related behaviors [9]. It also highlights the crucial role of deep career insights in shaping positive attitudes and informed decision-making [10].

While the generation strongly correlated with perceived benefits and career knowledge, culture did not. Culture may shape one's perspective, but it does not appear to be a critical factor in generational career perception differences. As technology and

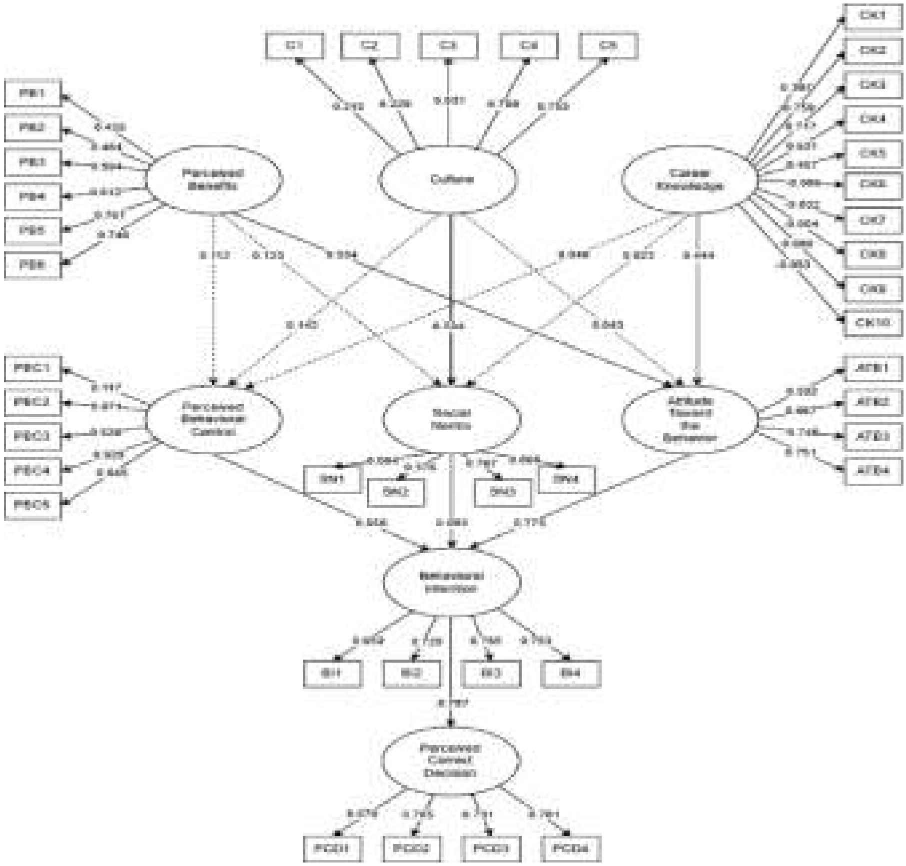

Fig. 2. Initial SEM model.

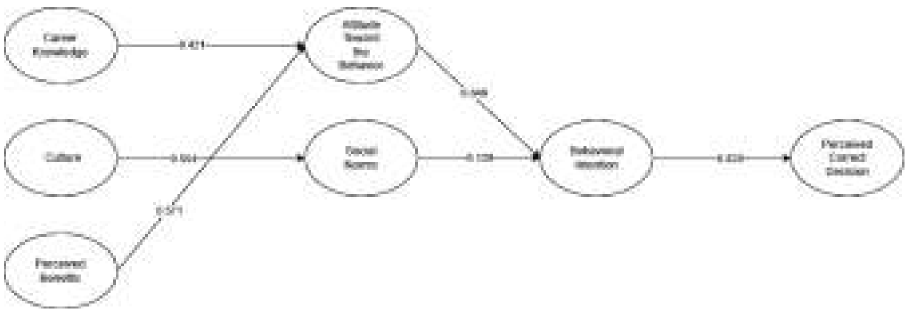

Fig. 3. Final SEM model.

society rapidly evolved, opportunities and job advantages shifted. Younger generations with different experiences perceive careers differently than older generations. However, cultural values do not significantly impact these generational career perceptions and knowledge gaps. It highlights how career pursuits and knowledge have adapted more across generations than cultures.

3.1 Model Fit Indices

This paper assessed the structural model through the measured values of the model fit indices. The indicated measures (see Table 1) are commonly used to evaluate the compliance of a constructed model. The Incremental Fit Index, Tucker-Lewis Index, Comparative Fit Index, Goodness of Fit Index, and Adjusted Goodness of Fit Index indicate a parameter estimation higher than the minimum cut-off of 0.80, demonstrating a good fit [11, 13]. In the Root Mean Square Error, the parameter is less than the minimum cut-off of 0.07, suggesting an acceptable fit [12, 13].

Table 1. Model fit indices.

Goodness of Fit Measures	Index Value	Cut-off Value	Suggested by
Incremental Fit Index (IFI)	0.868	>0.80	[11, 13]
Tucker-Lewis Index (TFI)	0.849	>0.80	[11, 13]
Comparative Fit Index (CFI)	0.867	>0.80	[11, 13]
Goodness of Fit Index (GFI)	0.868	>0.80	[11, 13]
Adjusted Goodness of Fit Index (AGFI)	0.839	>0.80	[11, 13]
Root Mean Square Error Approximation (RMSEA)	0.067	<0.07	[12, 13]

3.2 Construct Reliability

For further internal analysis of the validity and reliability, composite reliability (CR), average variance extracted (AVE), and Cronbach's alpha were measured and presented in Table 2. The Cronbach's alpha values are all within the acceptable cut-off range, which indicates that all variables are consistent and reliable [14]. Furthermore, the AVE values are more significant than the minimum acceptable level of 0.40. Similarly, the values under CR are greater than 0.70, showing that the constructs have internal consistency reliability [15].

Table 2. Composite reliability.

Variable	Cronbach's Alpha	Average	Composite Reliability
Perceived Benefits (PB)	0.774	0.468	0.775
Culture (C)	0.720	0.430	0.717
Career Knowledge (CK)	0.711	0.416	0.730
Perceived Behavioral Control (PBC)	0.715	0.528	0.757
Social Norms (SN)	0.800	0.675	0.805
Attitude Toward the Behavior (ATB)	0.793	0.443	0.759
Behavioral Intention (BI)	0.826	0.469	0.779
Perceived Correct Decision (PCD)	0.828	0.549	0.829

4 Theoretical Contribution and Practical Implications

This research aids individuals in broadening their knowledge and identifying their potential skills and abilities, leading them to better jobs and future success. The findings of this study show that perceived benefits, culture, career knowledge, social norms, attitude toward behavior, and behavioral intention significantly impact Filipinos' career choices. Overall, this study offers a holistic model to assess one's perceptions when making a career decision, which can assist individuals in preventing job-skill mismatches, as this can directly affect one's productivity, development, and satisfaction.

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Introducing New Technological Tools into the Work of Dual-Training Teachers Through a Co-design Project

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Abstract. In the context of digital transition and workforce shortages in education, teachers seek innovative and easy-to-use tools to optimize their work. This paper focuses on an action-research study aiming at co-designing digital tools with teachers from a dual training program. These tools should help teachers better manage the supervision of apprentices during traineeships. The study highlights the importance of collaboration with school staff to design useful and safe work tools. The article describes the co-design process and the obstacles encountered in the implementation, primarily categorized into digital competencies, workload, and organizational support. These challenges hinder the willingness to innovate despite participants recognizing the benefits of the new tools. The discussion offers insights into the organizational conditions necessary for successful and healthy digital innovation in education. The findings underscore the need for dedicated time for tool familiarization, tailored training and adequate IT resources to enhance the effective use of digital tools in educational settings.

Keywords: Dual training · digital transition · collaborative research · co-design

1 Introduction

1.1 Digital Transition in Education

In the current landscape of digital transition and workforce shortages in education, it is crucial for teachers to leverage their existing experience while developing new skills. This challenge is especially acute in contexts where technological transitions are considered inevitable, such as in Quebec and North American schools, where digital competencies are integrated into the curriculum [1]. Digital competencies are the set of knowledge and skills necessary to use digital technologies effectively and responsibly.

While the advantages of digital tools in teaching are widely recognized [2], these transitions often proceed without sufficient involvement of the workforce or organizational support, causing stress and detrimental conditions to workers' health [3]. Teachers need to know how to use digital tools and support students in developing their digital

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competencies. For those who lack these competencies initially, additional support and resources are essential. They are required to develop these competencies quickly, as the digital transition has been exacerbated by workforce shortages and the pandemic [3].

This paper addresses the challenges faced by teachers to utilize their accumulated expertise while adapting to new technological tools. The objective is to better understand how to create safe and healthy conditions for such a transition.

1.2 Study Context

The action-research described in this article investigates the co-design of digital tools aiming to support the work of teachers in a dual training program. The study began in 2019 with schools offering the Work-Oriented Training Path (WOTP). The WOTP requires students to complete traineeships and the tools aimed to support teachers in supervising these placements. Given their training in special education or secondary teaching, teachers are often unprepared for work-based learning environments [4].

One key tool co-designed early in the study is a Class Notebook template in Microsoft OneNote, allowing for shared content with students via Microsoft Teams. This tool centralizes information, supports various data types, and is technically supported by participating school, ensuring continued IT support post-study. This tool was tested in simulated settings and implemented over a few months in the actual work of teachers.

1.3 Objective

The action-research aims to support teachers in supervising traineeships. This article identifies the factors influencing the effective use of these tools. In doing so, it might highlight conditions for a successful, safe and healthy digital transition in education.

2 Methods

2.1 Theoretical Framework, Research Design and Positioning

The framework used in this study is grounded in work activity ergonomics [5], particularly the concept of an "enabling environment," which encompasses the individual, technical, organizational, and social conditions required to support human development at work [6]. Indeed, digital tools must support teachers' health and inclusion and enhance their capacity to adapt and innovate, thereby expanding their operational leeway. This is combined with Sen's capabilities theory, which states that individuals can only exercise freedom of choice when conversion factors allow them to transform resources into effective actions [7, 8]. This theory will help understand the effective use of digital tools in teachers' work, given the same initial resource: the Notebook template. The study adopts methods from work activity ergonomics, constructive ergonomics, and design ergonomics, emphasizing co-design with diverse stakeholders [8, 9].

2.2 Participants

The study involved 10 teachers, selected for maximum variety in gender, age and experience (Table 1). One participant withdrew due to insufficient school support.

Table 1. Characteristics of Study Participants

Code	Gender Identity	Initial Digital Proficiency Level*	Experience in WOTP**
Tch.1	Woman	Medium	13 years
Tch.2	Woman	Low	15 years
Tch.3*	Man	High	2 years
Tch.4	Woman	High	5 years
Tch.5	Woman	Low	<1 year
Tch.6*	Man	High	3 years
Tch.7	Woman	Medium	4 years
Tch.8	Man	Medium	6 years
Tch.9	Woman	Medium	3 years
Tch.10 (withdrawn)	Man	Low	10 years

*Participants with an official mandate in educational technology within their institution
Digital Proficiency Level: According to work activity analysis (observations, verbalizations) and over a year of collaboration. Three criteria were used: initial use of digital tools, self-assessment, and needs for assistance.
Experience in WOTP: Number of years.

2.3 Data Collection and Analyses

Data sources included detailed minutes from co-design meetings, recorded and transcribed feedback sessions (from actual work testing and from simulated settings testing), and reflective journals maintained by team members. Thematic analysis was used.

3 Results

3.1 Digital Competencies

The Class Notebook was chosen to centralize educational materials, communications, and information. During initial co-design meetings, teachers emphasized the need for an all-in-one accessible tool. However, the extensive sections and pages presented navigation challenges for some users. Even after two months of weekly use, many teachers struggled, causing shame and a sense of failure in some participants.

Seven out of nine participants managed these complexities by focusing on pertinent features and tailoring the tool to their needs. When navigating familiar sections, they needed little to no assistance. More complex elements, like integrating documents or software, were often avoided due to insufficient digital skills, lack of time, or fear. Two participants chose not to share Notebook pages with students to prevent accidental access to confidential notes, preventing the tool from fully meeting their initial needs.

Additionally, students' digital competencies were seen as a challenge: "*I notice more and more their lack of ability to navigate the internet and software. We think students are good with tech, but they are only good on TikTok or finding music.*" (Tch.3)

Participants suggested various types of assistance to address these gaps. Those with higher initial competencies preferred self-learning tools (3/9), while less experienced participants (4/9) required personalized human assistance. They valued the technical support provided by the research team, doubting similar support would be realistic within their organization after the study ended. Digital competencies can be developed, but it requires time and help, which was another challenge, as explained below.

3.2 Workload and Priorities

Six participants identified lack of time and heavy workload as major barriers to effectively using the tools: "*I haven't had time to properly master it. Collaboration and sharing will be relevant once I integrate it.*" (Tch.8) The Notebook can be complex, requiring hours to organize. Due to constant workload, this time was unavailable. Two participants prepared their virtual space during summer vacation, even though the study included funds for substitutes. They declined this measure due to staff shortages.

The heavy workload caused teachers to prioritize tasks, often relegating digital tool training for students. This limited the use of the tool's sharing function, which teachers valued and asked for. This competition of priorities led three participants to feel a sense of failure, given their desire to participate actively in the study.

After familiarizing themselves with the software, participants appreciated the tool, which saved time and enabled new activities. Ultimately, the tool seemed to increase teachers' operational leeway, but the price they paid was weeks of overwork or unpaid work, both of which are deleterious to health.

3.3 Organizational Support

Beyond time constraints, participants reported significant difficulties related to work organization and administrative decisions. The schools did not systematically provide phones with internet data to WOTP teachers, even those frequently traveling between traineeship sites, representing an obstacle to tool use. Lengthy administrative processes also caused delays and discouragement. For example, purchasing tablets for the study took months, and reimbursement processes for participation time were cumbersome. IT support was hard to obtain for participants, contributing to Tch. 10's withdrawal.

Regarding equipment for students, two participants reported outdated or hard-to-access school equipment as obstacles. Significant disparities in digital policies within schools added challenges. While some reported extensive digital use, others faced policies limiting students' phone use, impacting tool implementation.

3.4 Collective Regulation

The action-research setting facilitated numerous meetings between participants with a variety of digital proficiency level, fostering shared tips and strategies. For novices, this was beneficial for familiarization, while experienced participants found assisting others encouraged them to explore new methods, aiding their development. Even novice-only exchanges were seen as facilitators. Formal collective regulation mechanisms within schools proved beneficial not only for digital competencies, but also for the development of new collective strategies for traineeship supervision. Study meetings have thus reinforced a known protective factor for health in the workplace. However, collective regulation requires time, which is scarce. One participant suggested dedicating pedagogical days to implementing innovative tools, enhancing team effectiveness.

3.5 Enthusiasm for Digital Tools

Despite numerous obstacles, there was a strong enthusiasm for improving practices and implementing digital innovations. Participants frequently emphasized the relevance of the proposed tools, noting their added value in accessibility, centralization, and data sharing, which simplified supervision and collaboration. The digital support also helped visualize abstract concepts for students: "*Showing unique work environments to the entire class using inserted photos is invaluable.*" (Tch.1) Two participants noted that arriving in traineeships with a tablet containing all necessary tools and information was simpler and showed professionalism compared to juggling a phone and a large binder. This professional image and the usefulness of the tools motivated participants, underscoring the importance of tools that align with teachers' work activities.

4 Discussion and Conclusion

This study identifies several conversion factors influencing the safe and healthy integration of digital tools in educational settings, such as digital competencies, workload, organizational support, collective regulation and enthusiasm [10].

The enthusiasm among teachers for improving their practices and using innovative tools highlights a willingness to embrace change. However, the challenges they face—such as heavy workloads that limit the development of digital competencies—often hinder this willingness [10, 11]. These obstacles underscore the need for targeted support and training to accompany teachers and students during this transition [12]. Otherwise, there are risks to teachers' health, such as stress, overwork, or unpaid work.

Moreover, organizational support plays a critical role in facilitating digital innovation [13]. The study reveals that inadequate IT infrastructure can create significant barriers and stress. Schools must ensure that teachers have access to necessary digital resources, including reliable internet connections and up-to-date equipment.

Collective regulation and collaboration among teachers emerged as powerful facilitators of digital innovation, as in other studies [13]. Regular meetings and shared strategies are known health protection factors, fostering mutual learning and problem-solving. Dedicating pedagogical days to digital tool implementation can enhance team effectiveness and ensure that innovations are safely integrated into teaching practices.

Fostering an environment that addresses these conversion factors is crucial for the safe integration of digital tools in education. By empowering teachers with digital competencies, providing robust organizational support, and encouraging collaborative practices, schools can create conditions that allow teachers to leverage their expertise while adapting to new technological demands.

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Ergonomics and Human Factors in Engineering Undergraduate Education: The Canadian Case

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Abstract. Professional engineers must ensure public welfare and environmental protection. Their undergraduate training, however, may not include the necessary Ergonomics and Human Factors (EHF) knowledge to succeed. This study describes the sufficiency of EHF presentation based on an international survey of professors with knowledge of EHF offerings in engineering undergraduate programs and the EHF presence based on relevant keywords in undergraduate university engineering course descriptions in Canada. Twenty-nine of the 37 survey respondents were affiliated with "systems" or "industrial" engineering programs and 36 believe EHF is at least "somewhat important" to engineering professionals. Perceived EHF presence by institution ranged widely from "insufficient" to "excellent" with the mid-point "good" appearing most frequently. A subset of 167 Canadian accredited undergraduate engineering programs showed wide variation of EHF keywords in course description with 144 (86%) programs having none, and "Industrial" and "Systems" programs having most relevant elective and required courses. Greater understanding of actual EHF presence across engineering undergraduate programs is required to ensure engineers have knowledge required to meet their professional obligations.

Keywords: Education · Engineering · Ergonomics and Human Factors · Keywords · Course description

1 Background

The practice of professional engineering "requires the application of engineering principles and concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment, or the managing of any such act" [1]. Furthermore, the Canadian Engineering Accreditation Board's 2022 definition of the "Graduate Attribute -Design" criteria includes "human factors" amongst the design constraints to be considered, along with: "health and safety, sustainability, environmental, ethical, security, economic, aesthetics …, feasibility and compliance with regulatory aspects, [and] universal design issues such as societal, cultural and diversification facets" [2]. This clearly links engineering design to impact on humans, directly and indirectly, consistent with

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studies in the literature showing that engineering creates risks for people in production systems and ignoring human factors negatively impacts quality and productivity [3–6]. Indeed, professional engineers' code of ethics in Canada includes "[holding] paramount the safety, health and welfare of the public and the protection of the environment and promote health and safety within the workplace" (section 1.1), and "[being] aware of and [ensuring] that clients and employers are made aware of societal and environmental consequences of actions or projects and endeavour to interpret engineering/geoscience issues to the public in an objective and truthful manner" (section 1.8) [7]. Without awareness and knowledge of Ergonomics and Human Factors (EHF), it is difficult, if not impossible for engineering practitioners to meet these ethical standards.

The objective of this study is to quantify the exposure of engineering undergraduate students to EHF concepts and content in their required studies. This knowledge can form a platform for reforming engineering undergraduate education, as required to enable graduating engineering students to meet their professional obligations in practice.

2 Study Methodology

This study includes two sections.

Firstly, in 2021, we surveyed professors affiliated with engineering undergraduate programs as listed in the International Ergonomics Association (IEA) educational directory and through personal contacts of the authors. Respondents were invited to participate in a follow-up individual interview. This section of the study received ethical approval from the Université de Moncton Ethics Review Board (CER 2021-048). Respondents during this initial study came from 10 countries (Table 1). Eleven of the 37 respondents agreed to a follow-up individual interview. Notably, these people all had direct relations to the EHF community. Descriptive statistics of the survey were compiled using Jamovi software [8].

Table 1. Origin of questionnaire respondents by descending frequency[9].

Country	Number of respondents	Number of Institutions
USA	16	15
Philippines	8	5
Canada	3	3
Brazil	2	2
Israel	2	1
Netherlands	2	1
Greece	1	1
India	1	1
Mexico	1	1
Thailand	1	1

Secondly, to study the full variety of engineering programs, it was decided that course descriptions of required courses of all undergraduate engineering programs should be considered. Thus, in 2023, a manual search for EHF keywords (Table 2) in the course descriptions of all accredited engineering programs within 20 Canadian universities (English or French) was undertaken. Each of four EHF experts read the courses likely to include EHF content, searching for pre-determined EHF keywords [9]. Statistics were compiled using MS Excel software.

Table 2. Course description keywords indicating EHF presence (* denotes variable content).

English keywords	French keywords
Ergono*	Ergono*
Human* (Factor)*	Facteur(s) humain*(s)
Health and Safety*	Santé et sécurité*
Occupational Biomechanics	Biomécanique occupationnelle
User	Utilisateur
Task/Work analysis	Travail humain
Inter-personal skills, team dynamics*	Dynamique en équipe: collaboratif; communication interpersonnelle*
Human-centric	Centré sur l'humain, Focus sur l'humain
(User) interface	Interface utilisateur, opérateur
Organisational/Behaviour/Industrial psychology	Psychologie industrielle, organisationnelle
Job specific tasks	Travail spécifique/précis
Workstation	Poste de travail
Human-machine interactions/interface*	Interface utilisateur-machine, cerveau-machine
Usability	Utilisabilité
(User) interface	Interface utilisateur, opérateur

3 Results

3.1 2021 International Survey Results

The original questionnaire respondents revealed wide discrepancies in the access to EHF courses:14 respondents indicated a single engineering program includes EHF courses at their institution however at the other extreme, one respondent indicated 10 programs with EHF courses. Similarly, perceived sufficiency of the presence of EHF in engineering curricula varied widely (5 "excellent"; 14 "good"; 4 "Moderately sufficient"; 4 "Partially sufficient"; 4 "insufficient"). Twenty-six respondents believe EHF is "extremely important" to engineering professionals (70%) with ten more rating it as "somewhat important" (27%). Interestingly, 29 of the 37 respondents of the respondents (78%) were affiliated with a program name including "industrial", and 10 (27%) included "systems" in their department title, although the percentage of engineering programs including these titles is rare (6% in Canada) and "industrial or manufacturing" engineering accounted for less than 4% of the undergraduate student enrollment [10]. Across the institutions, the number of engineering courses devoting at least 50% to EHF ranged from 2 to 37 (median 5.0).

3.2 2023-4 Canadian EHF Course Keyword Study

The EHF keywords (listed in Table 2) were defined through discussion amongst four Canadian Certified Professional Ergonomists (CCPE designation), although some keywords were not always linked with EHF content (for example "Interface" can be used in a fluid dynamics or purely computer-programming context, without concern for EHF). Each identified course was verified for relevance by one of the CCPE experts. An effort was made to include a representative variety of programs, so programs in both official languages of Canada (English and French) and from each of the 10 Canadian provinces were included in this pilot search.

The EHF keyword search across Canadian accredited undergraduate program course descriptions in 20 universities showed Industrial and Systems engineering programs had the most elective courses (on average 4.3 and 3.2, across 4 and 3 programs, respectively with as few as one course per program, each). Only mechatronics, informatics and software programs also had at least 1 elective course on average containing EHF keywords across the programs considered. Of the 167 programs considered, 144 had no required courses mentioning EHF keywords. Typically, the number of optional courses relating to EHF was greater than the required courses (Fig. 1).

Following the 2023 manual pilot study of course descriptions, qualitative analysis software, MAXQDA [11] has been applied to study required courses within a subset of seven Industrial Engineering programs. The preliminary number of relevant courses was consistently higher than the verified number (at least 1 and as many as 27 more courses), indicating further analysis is required before applying the protocol generally.

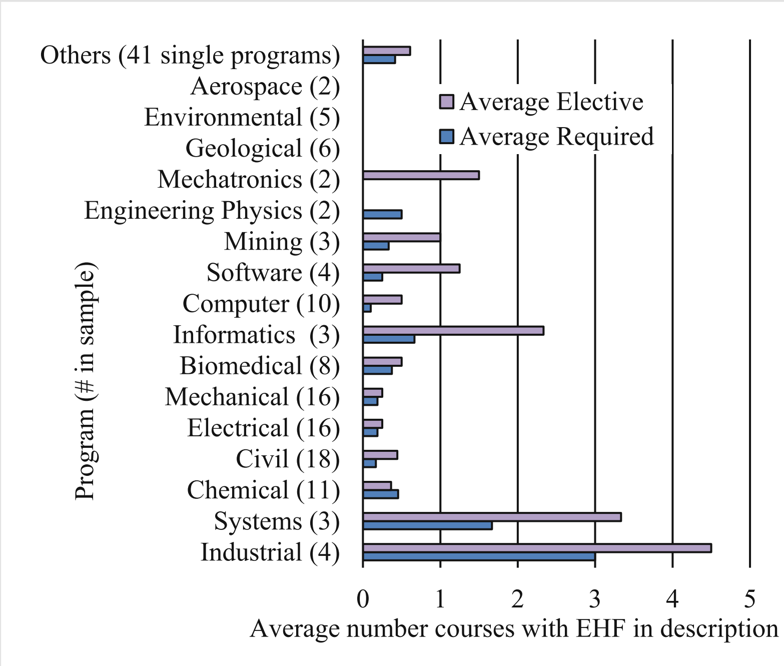

Fig. 1. Courses descriptions including EHF keywords amongst 167 Canadian programs.

4 Discussion

The survey respondent population among those aware of EHF in their engineering programs was limited in number and scope. The 37 survey responses indicate concern about the sufficiency of EHF content provided given its perceived importance.

The search of published course descriptions across a country's undergraduate engineering programs holds greater potential for an unbiased measurement of EHF presence in engineering curricula. Indeed, required courses including EHF are rare, and their number is highly variable. When including the breadth of engineering programs, EHF is often completely absent.

Funding for a subsequent study to quantify EHF presence across required courses in all Canadian undergraduate engineering programs was received from the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) based at the University of Waterloo, Canada in 2023. This financed the purchase of qualitative analysis software and hiring a research assistant. This work is ongoing.

Challenges have been revealed during this pilot study which must be resolved before expanding the study scope. Reliability and efficiency of course description searches is key. Which keywords are truly relevant to EHF? The terms "system" or even "safety" can be used to describe human or strictly machine elements. Although automated keyword searching shows potential for increased efficiency, multiple keywords may occur in a single course so cross-checking to avoid inflated course numbers becomes crucial. How must individual programs be analysed when large sections are common with other programs? How should keywords best be counted: binary (presence/absence) or number (importance) or repetition? Even with qualitative analysis software, the longest element is accessing all relevant course descriptions and importing these into the database (takes about 1 minute per course with 36 required courses in Mechanical Engineering at one institution, for example). Responding to these questions will be key for international expansion of the programs considered.

An institutional and subject categorisation coding system has been created. This was tested on a five Canadian universities' programs and with detailed verification of seven Industrial engineering programs.

5 Conclusions

Understanding the current exposure of graduating engineers to EHF is crucial since this profession carries primary responsibility for operations system, and hence job, design and employee risks. Past data collected shows highly variable exposure, with a tendance toward insufficiency: zero exposure to HF concepts in 86% of the programs surveyed in a subset of Canadian engineering universities [9]. Further research using systematic qualitative content analysis will clarify the required exposure to EHF of undergraduates in engineering. Future research will provide a systematic structure to evaluate EHF presence in course descriptions across all accredited programs in Canada. This structure can be applied subsequently in other countries. The knowledge on EHF training in engineering education will pose a platform from which engineering undergraduate education reform can be considered.

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