

# TILO: Designing Soft Kinetic Cues for Embodied Biofeedback

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Figure 1: TILO: Take it in, let it out

## Abstract

Physical motion that induces breathing synchronization offers a subtle means of supporting users as they transition from commuting to cognitive work. To investigate how such cues are experienced in real task-onset contexts, we introduce TILO, an embodied physical interface that generates a 0.1 Hz expansion-contraction rhythm mapped to the user's heart rate. Through two user studies, we examined how this motion is perceived during early task engagement. Qualitative findings showed that TILO's movement was experienced as emotionally calming or activating, and as producing brief attentional shifts, while some users reported neutral or distracting effects. These results suggest the potential of breathing-based physical motion as a supportive secondary cue for easing task transitions.

## CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI); User centered design.**

## Keywords

HCI, Embodied Interaction, Design, Physical UX, TUI

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## 1 Introduction

People often begin desk work before their body and mind have fully settled from the residual activation caused by commuting. Prior research shows that commuting can produce both physical and emotional strain—lower subjective well-being with longer travel [16], transient increases in blood pressure and performance drops immediately after arrival [14], and elevated EEG- and heart-rate-based stress markers [15]. Together, these findings highlight the need for interventions that attenuate physiological arousal during the short



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transition to task-oriented work. In this context, slow breathing has emerged as a promising strategy, as it can reduce heart rate and increase HRV [5], alleviate stress [7], and support executive function and working memory [10][13].

## 2 Proposal: Physical Interface for Breathing Regulation

Among approaches to supporting breathing regulation, leveraging external physical rhythms has shown promise, with studies indicating that rhythmic cues can facilitate induction of respiratory synchronization and contribute to emotional regulation [4, 6, 12]. Building on this background, we propose TILO (Take It in, Let It Out), a physical interface that synchronizes its movement to the user’s heart rate to support the brief transition into task work. Unlike prior work focused mainly on physiological outcomes, this study qualitatively examines how such embodied cues are perceived and interpreted within real task contexts.

## 3 Design of TILO

### 3.1 Form and Material Design Rationale

TILO is a biofeedback device that stabilizes heart rate by visualizing the user’s breathing rhythm through physical expansion–contraction volume changes.: (1) Form-related: a curvature-based morphology that is perceived as gentle; (2) Material-related: elastic material that supports sufficient expansion and contraction.



Figure 2: Expansion–contraction shape of TILO

First, the impression conveyed by a device’s appearance has a direct influence on emotional regulation[2]. Consequently, TILO adopts a soft, curve-centered silhouette as its primary form language. Aronoff et al. note that rounded contours communicate emotional warmth, providing psychological grounding for this design choice[1]. Second, for the CMF design, we employed an elastic fabric with adequate multi-directional stretch and a calming tactile quality. Together, these elements enabled an interface that conveys the breathing rhythm through gentle volumetric changes 2.

### 3.2 Mechanism Design and Prototyping

TILO was designed to express a smooth motion of expansion and contraction along the x, y, and z axes, corresponding to the user’s heart rate signals. Each component is mechanically interconnected, and the structure was engineered so that its form appears to dynamically change in volume through interlinked rotational movements. The prototype was fabricated using 3D printer, consisting of five primary components: the base structure, lower rotation module, upper body, upper rotation module, and an internally positioned fabric tension module.



Figure 3: Internal components of TILO

When the motor is activated, the upper and lower rotational modules rotate simultaneously, thus driving ten linkage elements that connect the rotational modules to the flaps. The movement of these links causes the flaps to extend outward, expanding the fabric surface. The upward motion of the upper body induces vertical expansion, resulting in omnidirectional inflation of the lighting structure. In contrast, when the motor rotates in the reverse direction, the extended flaps return to their original positions and the upper body descends, contracting the form back to its original state.

### 3.3 Motion Design Based on Respiratory

The purpose of TILO’s movement is to act as a perceptual signal that encourages users to naturally align their breathing with their biological rhythm. To achieve this, the motion design draws on the temporal and morphological structure of human respiration so that it can function as a physiological synchronizing signal for the user.



Figure 4: Schematic of temporal characteristics of human breathing

Characteristics of human breathing were derived from the cardiopulmonary interaction model[11] and respiratory patterns[8]. Based on these references, we modeled TILO’s motion on key temporal features of human respiration. The inspiratory–expiratory ratio was set at 1:1.2, reflecting the typical pattern in which inhalation is shorter than exhalation. The asymmetric breathing profile—rapid

rise and slow plateau during inhalation and sharp drop followed by gradual decay during exhalation—was derived from physiological lung-volume dynamics. This nonlinear shape was implemented using Bezier-based animation in Blender, forming a 10-second loop (0.1 Hz) with a maximum expansion angle of  $65^\circ$ . The curve was then converted to time–angle data via the Blender2Motor pipeline and applied to the Dynamixel servos[9]. As a result, TILO reproduces a continuous expansion–contraction gesture that perceptually mirrors the asymmetric timing of natural breathing.

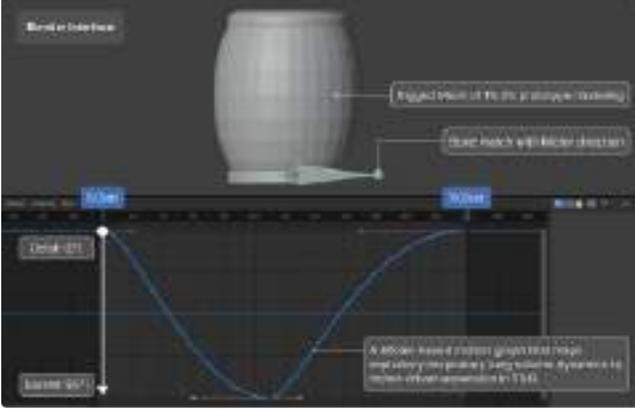


Figure 5: Graph editor of motion profile in Blender

### 3.4 System Implementation

**3.4.1 Motion Waveform Extraction and Mathematical Formulation.** To reproduce the breathing-induction motion on the physical prototype, the keyframe-based animation designed in Blender was first converted into time–angle pairs and exported as JSON data. Because this animation data cannot be directly used for real-time control, it was then transformed into a mathematical model. For this purpose, the time–angle sequence was approximated using a fifth-order Fourier series, yielding the following waveform function:

$$\begin{aligned} \theta(t) = & -30.874088 + 28.399587 \cdot \cos(\omega t) - 14.349339 \cdot \sin(\omega t) \\ & + 0.189372 \cdot \cos(2\omega t) + 2.217746 \cdot \sin(2\omega t) \\ & + 1.718131 \cdot \cos(3\omega t) + 0.141681 \cdot \sin(3\omega t) \\ & - 0.036796 \cdot \cos(4\omega t) + 0.534673 \cdot \sin(4\omega t) \\ & + 0.384801 \cdot \cos(5\omega t) + 0.052438 \cdot \sin(5\omega t) \end{aligned} \quad (1)$$

**3.4.2 Heart-Rate-Adaptive Parameter Mapping.** The breathing inducing motion was designed to adapt its amplitude and frequency to the user’s heart rate. As heart rate increases, the motion provides a longer cycle and a larger expansion–contraction amplitude, thereby guiding deeper and slower breathing. The mapping rules were constructed using the typical resting-state heart rate range for adults (60–100 bpm)[3].

- Amplitude Mapping

$$\theta_{\text{target}} = \theta_{\text{max}} \times \frac{HR_{\text{curr}} - HR_{\text{min}}}{HR_{\text{max}} - HR_{\text{min}}} \quad (2)$$

$$HR_{\text{min}} = 60\text{bpm}, HR_{\text{max}} = 100\text{bpm}, \theta_{\text{max}} = 65^\circ \quad (3)$$

- Frequency Mapping

$$f_{\text{target}} = f_{\text{max}} - (f_{\text{max}} - f_{\text{min}}) \times \frac{HR_{\text{curr}} - HR_{\text{min}}}{HR_{\text{max}} - HR_{\text{min}}} \quad (4)$$

$$f_{\text{max}} = 0.25\text{Hz}, f_{\text{min}} = 0.10\text{Hz} \quad (5)$$

- Breathing Cycle Timing

$$T_{\text{insp}} = \frac{1}{f \times 2.2}, T_{\text{exp}} = \frac{1.2}{f \times 2.2} \quad (6)$$

**3.4.3 Real-Time Breathing-Induction Control Pipeline.** The system operates in a reactive motion by mapping the amplitude and frequency of the respiration-induced motion in real time according to the user’s heart rate. The system operates sequentially in a four-step pipeline of (1)bio-signal measurement, (2)heart rate calculation, (3)parameter mapping, and (4)respiration-induced motion reproduction.



Figure 6: TILO System Pipeline

## 4 User Evaluation

In this study, we conducted two rounds of user testing to evaluate the TILO prototype and its user experience. The first test aimed to identify areas for improvement by assessing the technical completeness and usability of the initial prototype. The second test used an improved prototype to examine TILO’s influence on users during cognitive task performance. Both tests included qualitative interviews to capture participants’ subjective experiences and perceptions.

### 4.1 First Test: Usability and Design Validation

User testing showed that participants generally responded positively to TILO’s expansion–contraction motion, and some reported that their breathing began to synchronize with the device’s rhythm. However, several participants noted that the mechanical noise during actuation was more noticeable than the movement itself and disrupted relaxation. Based on this feedback, we refined the prototype’s structure and design.

### 4.2 Second Test: TILO’s Effect on Cognitive Tasks

In the second test, we investigated whether TILO’s biofeedback influences users’ task engagement during cognitive performance. Ten participants completed a user study in which they performed three minutes of light walking to simulate commuting strain, followed by a five-minute arithmetic task. Each participant completed

both Case A (without TILO) and Case B (with TILO active) in a within-subjects design. Post-experiment, we conducted in-depth interviews to capture subjective experiences.

**4.2.1 Perception of the Breathing-Inducing Motion.** Qualitative analysis of participants' subjective experiences revealed that most found TILO's heart-rate-responsive physical motion visually engaging and reported actual effects on breath regulation and calming. P2 stated, "It felt fascinating, as if it were moving in sync with my heartbeat." P4 described it as "a feeling that it was regulating my breathing." P3 reported an experience of respiratory entrainment: "Because the light was breathing slowly, I naturally began to breathe more slowly as well." P5 mentioned, "Seeing the robot move according to my heart rate made me realize how fast my heart was beating, which calmed me down." Most participants interpreted the device's movement as "breathing," though the degree of actual respiratory synchronization varied among individuals.

**4.2.2 Impact on Task Performance.** Some participants experienced emotional relief and attentional refreshment from the lighting during the arithmetic task, which they reported positively supported organizing their thoughts and recovering focus. P1 stated, "The device felt like it was cheering me on, giving me energy that helped me solve problems better." P4 mentioned, "It calmed me down when I became anxious while solving problems," and P7 noted, "Looking at TILO briefly made me feel refreshed and better able to concentrate." In contrast, P2 and P8 acknowledged the lighting's presence but reported it did not help with task performance. P9 and P10 mentioned that the movement was rather distracting and interfered with their concentration.

## 5 Discussion

We compared participants' performance in the condition without TILO (A) and with TILO (B) to examine how their subjective perceptions related to actual task outcomes. Task performance was calculated as the product of accuracy (%) and the number of problems solved. These findings indicate a consistent pattern between participants' subjective reports and measurable performance outcomes. This suggests that TILO's breathing-based biofeedback may support emotional regulation and cognitive control in ways that tangibly enhance task performance.

**Table 1: Participants' subjective impressions and performance changes between conditions A and B.**

Participant	Subjective Experience	A	B
P1	Encouragement	11.97	16.94
P3	Entrainment	8.01	12.96
P4	Calming	4.00	5.04
P7	Refresh	4.02	6.00

## 6 Conclusion

This study presented the design of TILO and examined how its heart-rate-synchronized breathing motion is experienced during the transition into cognitive task work. Participants reported diverse responses, such as emotional calming, activation, and brief

attentional shifts, indicating that a physicalized breathing rhythm can serve as a supportive cue during early task engagement. These findings suggest that an embodied physical interface that expresses respiratory-like motion may function as a secondary cue that supports emotional settling and attentional redirection during task engagement. The current prototype operates using a directly attached heart-rate sensor; however, future implementations could incorporate wearable bio-signal devices to enable more seamless operation. Further research—including quantitative assessments with larger and more diverse user groups—will be necessary to more rigorously evaluate effects of TILO and refine its role within breathing-based interaction strategies.

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