

Breathe, Focus, Perform: Examining AR-Haptic Breathing Guidance in Fine Motor Skill Development

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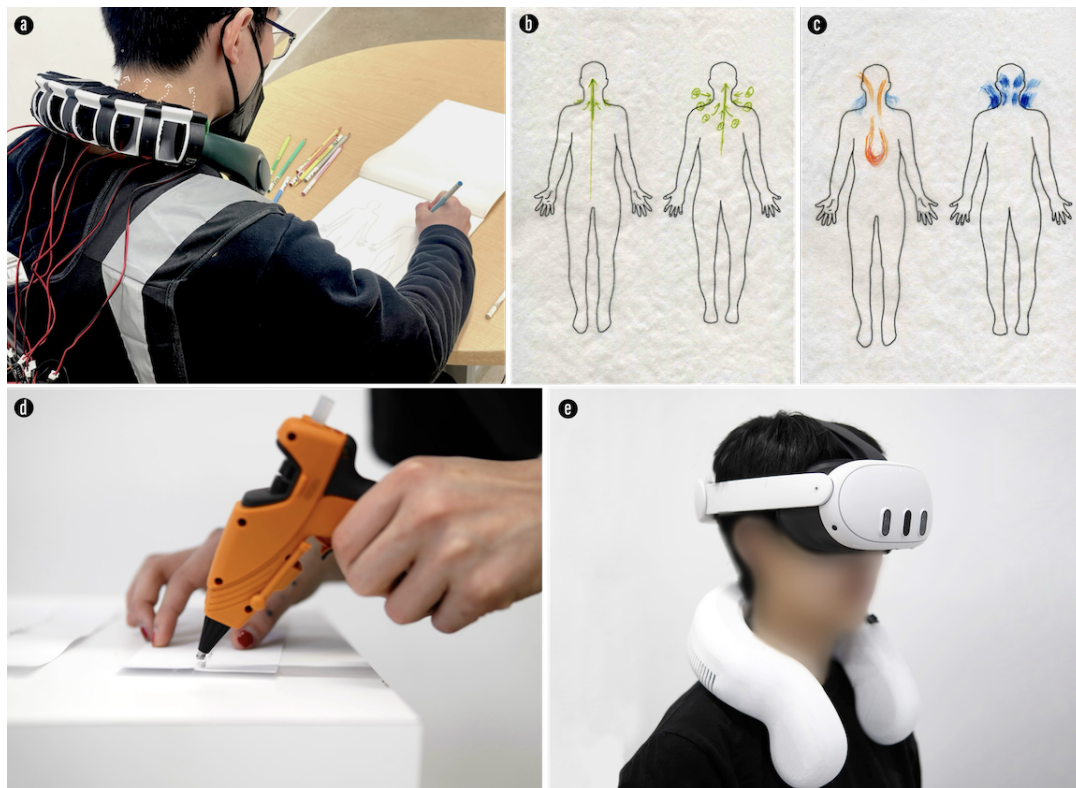


Figure 1: Images from early exploration and user study. (a) Participants wearing the early version of air-based haptic device and drawing a body map (b, c) Selected body maps from the early exploration (d) The hot gluing task during the main user study (e) A person meditating with the AR and haptic device

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Abstract

Developing fine motor skills requires complex coordination between physical and mental processes, which can be challenging for novices as they manage multiple sensory inputs while executing precise movements. To address this, we developed a proof-of-concept hybrid wearable system that guides mindful breathing through different combinations of AR feedback and air-induced haptic cues.

Fifteen participants took part in a mixed-method exploratory study involving paper-based precision tasks inspired by welding. The outcomes indicate that the breathing guide with haptic cues can positively influence task performance and highlight a connection among improved performance, enhanced body awareness, and attention regulation with mindfulness exercises. While initial findings are promising, larger validation studies are needed. This study examines the potential for integrating mindfulness into fine motor skill development through multimodal interaction, suggesting applicability in welding and other skills as a complement to traditional training.

CCS Concepts

• **Human-centered computing** → **Haptic devices**; **Empirical studies in interaction design**.

Keywords

Breathing Guidance, Mind-body Integration, Embodied Interaction, Haptic, AR, Wearable, Fine Motor Skill, Skills Training, Research through Design, Qualitative Methods, Quantitative Methods

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1 Introduction

Fine motor skills are essential in precision tasks such as welding, woodworking, surgical suturing, or even artistic tasks like pottery and calligraphy. They demand the integration of cognitive focus, bodily awareness, and refined motor control. Although these fine motor skills are central to both industrial labor and creative work, we observed that novices often struggle with anxiety, cognitive overload, or lack of embodied confidence when handling unfamiliar tools or performing delicate movements.

To help address these challenges, mindfulness techniques have gained attention as a potential tool to reduce stress and improve motor performance. One of the accessible mindfulness strategies is breath awareness, which can improve attention and prepare the body for action [8, 9, 43, 45]. Recent work has explored the integration of technology-mediated mindfulness tools, such as immersive breathing environments, biofeedback systems, or XR-based guided focus cues [17, 20, 25, 47]. However, few studies have systematically evaluated how different modalities, such as visual, biofeedback, and haptic, affect breathing engagement and, more importantly, performance in fine motor skill tasks supported by mindfulness.

Building on prior work in welding training [13], this study investigates the direct effects of guided breathing on body awareness and fine-motor task performance. We present a proof-of-concept multimodal breathing guidance system combining AR visual cues, real-time biofeedback, and air-based haptics. In this study, we aim to understand how different combinations of these modalities influence breathing engagement and task performance in fine-motor activities. This study does not intend to evaluate AR as a modality,

and we use an AR headset to present consistent visual cues in all experimental conditions. AR functions as a delivery platform for comparing the effects of visual guidance, biofeedback, and air-based haptic feedback on the neck.

To develop the system, we employed the Research through Design (RtD) approach [24, 67, 68] for designing the artifact and used formal mixed methods for the empirical evaluation. As live welding requires four to five hours of safety training, we designed a proxy task that involves gluing two pieces of paper together on the edge with a hot glue gun. This task shares the similarity in applying heat and manual material extrusion, while avoiding safety risk and minimizing confounding factors such as prior skill levels. This experimental design helped us assess the preliminary validity of the core concept and the technology design.

Our contributions are that we:

- (1) Develop an on-body wearable system that provides guided breathing exercises through visual cues, real-time physiological feedback, and air-based haptics.
- (2) Evaluate how combinations of these modalities affect users' ability to be aware of their breath and maintain attention.
- (3) Examine how such regulation techniques might facilitate readiness for fine motor skills.
- (4) Provide insights into the design of multimodal systems that support fine motor training through breathing awareness.

2 Related Work

Our work lies at the intersection of fine motor skill performance, mindfulness-based attention regulation, and multimodal feedback systems. We review related work across three core areas: (1) breathing and motor skill, (2) multimodal and sensory guidance in fine motor skill performance, and (3) multimodal breathing interfaces in HCI.

2.1 Breathing and Motor Skills

Performing fine motor skills, particularly in domains such as metalworking and woodworking, requires coordination between perceptual attention and precise manual control [44]. The complexity of this sensorimotor integration poses significant challenges for practitioners, including novices. Especially in high-risk multisensory environments such as welding, where heat, noise, and sparks can induce cognitive overload [35, 40]. Mindfulness-based interventions, particularly those involving breathing awareness, have been widely shown to regulate physiological arousal, improve focus, and reduce anxiety [11, 29, 51]. Among these, paced breathing, involving controlled inhale, hold, and exhale durations, has emerged as an accessible entry point into mindfulness practice to be aware of their breath [18]. Studies have shown that breathing aids sensorimotor learning because it is both automatic and consciously controllable, helping focus attention [30, 38]. It also improves body awareness and emotional regulation [29, 46, 49]. Though the studies we reviewed mostly engage gross motor skills, we believe that breathing can be essential for developing fine motor skills as well.

2.2 Multimodal and Sensory Guidance in Fine Motor Skill Performance

The acquisition of fine motor skills involves the coordination of perception, attention, and precise movement. It is essential in domains such as welding, woodworking, surgical training, and other skilled manual tasks. To increase performance, recent work in HCI and learning sciences has explored the use of interactive and extended reality (XR) technologies to support motor skill development. Augmented reality mirrors and overlays have been used to guide users' body positioning and motion [5], with applications extending into domains such as dance instruction [61], traditional papermaking [26], and welding [31]. These systems allow users to receive visual feedback on alignment, timing, and hand positioning, facilitating imitation and repetition without requiring constant expert supervision.

Beyond visual guidance, researchers have explored how interactive tools can scaffold the early stages of skill acquisition. For example, systems for sewing and weaving have introduced custom digital interfaces to assist with design and execution [36, 39, 58], lowering barriers for novice users. In more hazardous environments, VR simulations have been employed to reduce occupational risk, such as in woodworking and spray painting scenarios [37, 59]. These approaches largely focus on reducing external difficulty or providing technical instruction. While these approaches primarily address external challenges or deliver technical support, they often overlook the role of practitioners' internal state that can directly affect performance.

Our work addresses this gap by leveraging multimodal breathing guidance, including visual cues, biofeedback, and air-based haptics, to support somatic regulation during fine motor tasks. Rather than replacing traditional education, our approach complements it by addressing the learner's internal state, potentially enhancing attention, proprioception, and skill performance.

2.3 Multimodal Breathing Interfaces in HCI

Breathing has been widely adopted as a modality for mindfulness-based interaction in HCI. Mobile applications such as Headspace [2] and Aura [1] guide users through visual and audio cues, while commercial devices like Muse [3] and the Apple Watch [7] offer biofeedback and tactile prompts. Research systems have explored richer, more immersive approaches to breath guidance, including VR-based wellness studios [21], oceanic landscapes [56], and responsive environments like Inner Garden [50]. Real-time breath biofeedback, often presented visually as waveforms or expanding objects, has shown potential for increasing awareness and improving breath control [34, 48]. Visual AR-based feedback is frequently used for its immersive and attention-guiding qualities, as demonstrated in XR pass-through systems and guided meditation environments [47].

While visual and auditory cues are commonly used in breathing interfaces, there is increasing interest in engaging the body more fully through tactile or kinetic feedback, such as using shape-changing objects [20, 32] or breath-controlled virtual agents [55, 64], to deepen somatic engagement. Haptic feedback, particularly through air or temperature cues, has recently attracted attention

as a non-contact, affective modality [12, 33]. Although such modalities have been explored for conveying emotion or enhancing presence, they are rarely studied in relation to guiding physiological rhythms such as breathing. One notable exception is BreathePulse [25], which used a mounted fan and pulsed airflow to deliver breathing cues. However, few works rigorously compare multimodal combinations or explore underutilized modalities such as air-based haptic feedback. Our work addresses this direction by evaluating air-based haptic feedback as a subtle and embodied method for guiding breath, and differs from BreathePulse [25] in that we focus particularly in the preparatory phases of fine motor skill performances.

3 Designing the system

Using a Research through Design (RtD) method [24, 67, 68], which emphasizes design as a valid mode of knowledge production in HCI, we iteratively developed breathing-guidance (Figure 2), incorporating the feedback from participants. The RtD phase continued until the system reached a stable level of development suitable for evaluation. The final stage consists of an empirical study designed to validate the system's effectiveness and examine how different modes of breathing guide enhance fine motor skill performance with first-hand knowledge. The following sections explain in detail how we design the breathing exercises and iterations of the haptic device and AR system.

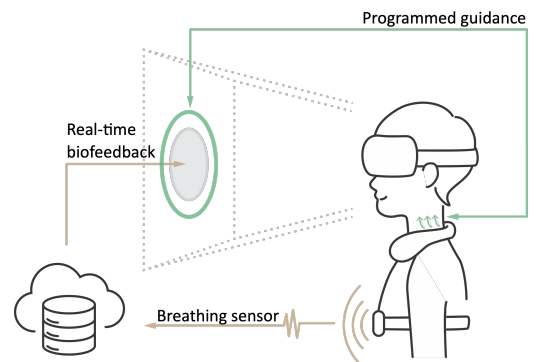


Figure 2: System diagram for the real-time biofeedback through a breathing sensor and programmed guidance

3.1 Breathing Exercises

To evaluate the role of breathing in enhancing attention during the subsequent tasks, we designed the exercises focused on maintaining awareness of breathing without specifically targeting slower breathing rates. These exercises align with attentional control training informed by [19], which aims to sustain focus on a non-threatening internal cue while heightening awareness of bodily rhythms and patterns. Maintaining a consistent breathing pace of 15 breaths per minute, close to the natural baseline, could be particularly effective for tasks requiring rapid or sustained attentional focus, functioning like a metronome to modulate cognition and behavior [66].

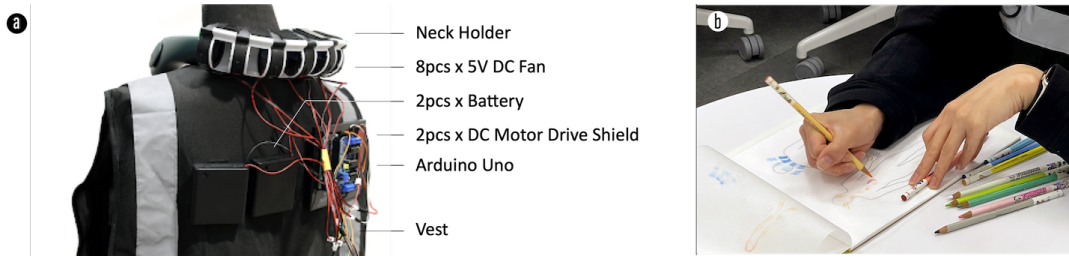


Figure 3: Image of the first version of the haptic device. (a) Image of the first version of the haptic device that can be worn around the neck, with a connection to an Arduino Uno and power sources and eight fans on the vest holding electronic parts. (b) Image of one of the participants wearing the device and drawing a body map on paper.

3.2 Haptic Device

We materialized the association of external airflow and internal breath, exploring how they move around us and how people experience this interaction as a mindful exercise. Building on previous research in breathing practices [8–10, 14, 27, 43, 45] that promote the awareness of breathing, the device was aimed to enhance similar experiences through haptic guidance rather than solely relying on audio and visual cues. We developed a haptic device that creates a gentle breeze around the neck area to guide users in their mindfulness breathing practice, helping them achieve a calming state (Figure 3).

3.2.1 Device Design and Wind Patterns. The device is a wearable apparatus that hosts an array of eight fans (Figure 3). The device is designed to be worn around the neck and takes advantage of the neck’s sensitivity to haptic sensations [16]. Additionally, this approach leaves the wearer’s hands free to engage in other activities and interactions.

Each of the eight fans can be independently controlled to be on or off, and various patterns of airflow were explored. The eight fans were programmed to produce different airflow configurations aligned with the natural breathing rate of 15 breaths per minute. There were three types of configuration, each with two different speeds which were labeled as a pattern in Figure 4. The first-speed setting has a rate of 7.5 cycles per minute, which is slower than the natural breath rhythm (patterns 1, 3, 5 in Figure 4). The second set of cycles operates at 15 cycles per minute, which is similar to natural breathing (pattern 2, 4, 6 in Figure 4), allowing us to explore whether there are preferences and hidden considerations.

The airflow configurations include the center-outward sweep (configuration 1, Figure 4. (a)), lateral sweep (configuration 2, Figure 4. (b)), and simultaneous on-off (configuration 3, Figure 4.(c)). The center-outward configuration turns on the two fans at the center first, and the lateral fans turn on one after the other, moving from the center to the edge. This imitates the accordion’s movement, simulating the inhale and exhale motion of bellows. It represents the lungs’ function as bellows, allowing individuals to synchronize their breathing with the configuration and visualize the filling and releasing of air in their bodies. The second configuration, lateral sweep, emulates tides, and the fans turn on in a sequence from one side to the other and reverse afterward. This is simpler compared to the inward-outward pattern, potentially making it easier for participants to follow and breathe together. The third configuration

is even simpler, with all fans turning on and off simultaneously. Despite its simplicity, its magnitude is much stronger as all eight fans blow at the same time. Each fan was implemented with an overlapping time between its action and the next one’s to turn on and off so that transitions between fans in all three patterns were smooth.

3.2.2 Pilot Study Setup. Breathing, as a focal point of body awareness, plays a key role in this process [52]. As a pilot study, we adopt a somaesthetic design perspective [28], especially the body mapping approach to evaluate participants’ felt experiences of airflow on the body [6, 15, 23, 57].

A total of five participants in their late twenties to early thirties were recruited (Table 1). Two participants had previous experience with breathing practice or meditation. Each participant experienced the six different wind patterns in random order. Each pattern was on repeated while they experienced it until they had completed the body mapping task. During this activity, individuals were asked to illustrate their experience and perception of each air movement pattern on a body map template with colored pencils (Figure 5). Following the activity, an interview was conducted using the body map to understand their overall experience with the six patterns and breathing practice.

3.2.3 Findings.

Body Mapping for Communication. Most of the participants’ body map drawings reflected the inhalation and exhalation cycles in Figure 5. Their body maps reflected the depth (Figure 5.iv and iiv) and frequency of their breathing (Figure 5.v and viii) in relation to the external air patterns and how they perceived the different air patterns (Figure 5.i, ii, iii, iv, and ix). Initially, participants faced challenges in visualizing air and its movement, as it was an unusual experience. Some participants resorted to numbering to overcome this hurdle, while others incorporated arrow signs to represent external winds. However, they still found their own way to record their experience in the body maps. For example, PP3 described how they tried to achieve “*that with the intensity of color. And I used blue because it felt cold. The darker color means more force.*” (PP3). PP2 took a different approach by using a “*curved edge [to] indicates where the wind becomes stronger, while the areas without the curve represent where it weakens.*” (PP2). Finally, PP5 used the length of the line to connote intensity, recalling: “*I think it’s the weakest air, so I kind of draw it very short.*” (PP5).

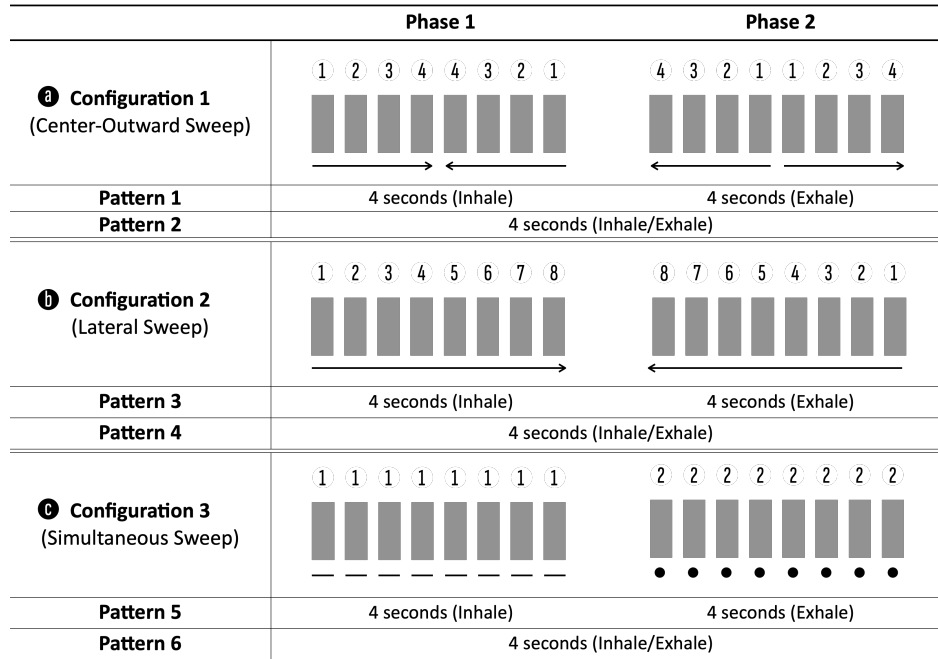


Figure 4: Different configurations of wind from the haptic device. Three labeled sections (a, b, c) that depict different configurations of wind from the haptic device. (a) configuration 1 is center-outward sweep movement of air on the fan. (b) configuration 2 refers to the lateral sweep in which the wind blows from one side to the other. (c) configuration 3 shows the simultaneous on-off wind patterns.

Code	Age	Gender	Background	Breathing Experience	Platform
PP1	20–30	F	Physics, Computational design	Never	–
PP2	20–30	F	Psychology, Interaction design	A little	Headspace
PP3	20–30	F	Architecture, Interaction design	Never	–
PP4	20–30	F	Biology, Interaction design	Often	YouTube, Self practice
PP5	20–30	M	Architecture, Computational design	Never	–

Table 1: Participant demographics and breathing experience in the pilot study.

During the interview, the participants explained that they used body maps to visualize their feelings, remember the experience, and communicate with the interviewers to describe their experience later.

Guiding Wind Patterns for Meditation. During the experience, we observed that participants frequently closed their eyes and concentrated on their breath, fully immersing themselves in the experience even though they had not been instructed to do so beforehand. In the interviews, they explained that this behavior was natural for them when focusing on their breathing. They noted that the haptic device allowed them to maintain this focused state without needing to open their eyes or make any adjustments. For example, PP5 described how they were “doing it unconsciously. I am easily distracted. This has helped me to focus on things I haven’t done and reflect on what I have done instead of being distracted and playing around.” (PP5).

The participants were influenced not only by the pattern of the wind but also by its intensity, which is directly related to the number of fans activated simultaneously. This was highlighted by PP2 who described how configuration 1 “repeats from the center, moving outward and then back. I don’t think this method will be effective for me, as it seems to jump between different points rather than maintaining focus. I feel it would distract me from paying attention to the sensation of the air, which is crucial for focusing on my breathing.” (PP2)

In general, participants preferred the configuration 2 over the other configurations. Two participants (PP3, PP4) specified that they liked weaker winds over stronger ones. For PP3 this was because they “would have expected the more forceful, like pattern [configuration 1] to be the most helpful. However, the patterns that worked were more like the last ones [configuration 2], and they were less forceful.” Also, participants (PP1, PP4) specified that configuration 3 is more suited to alerts rather than meditation, with PP1 describing how it

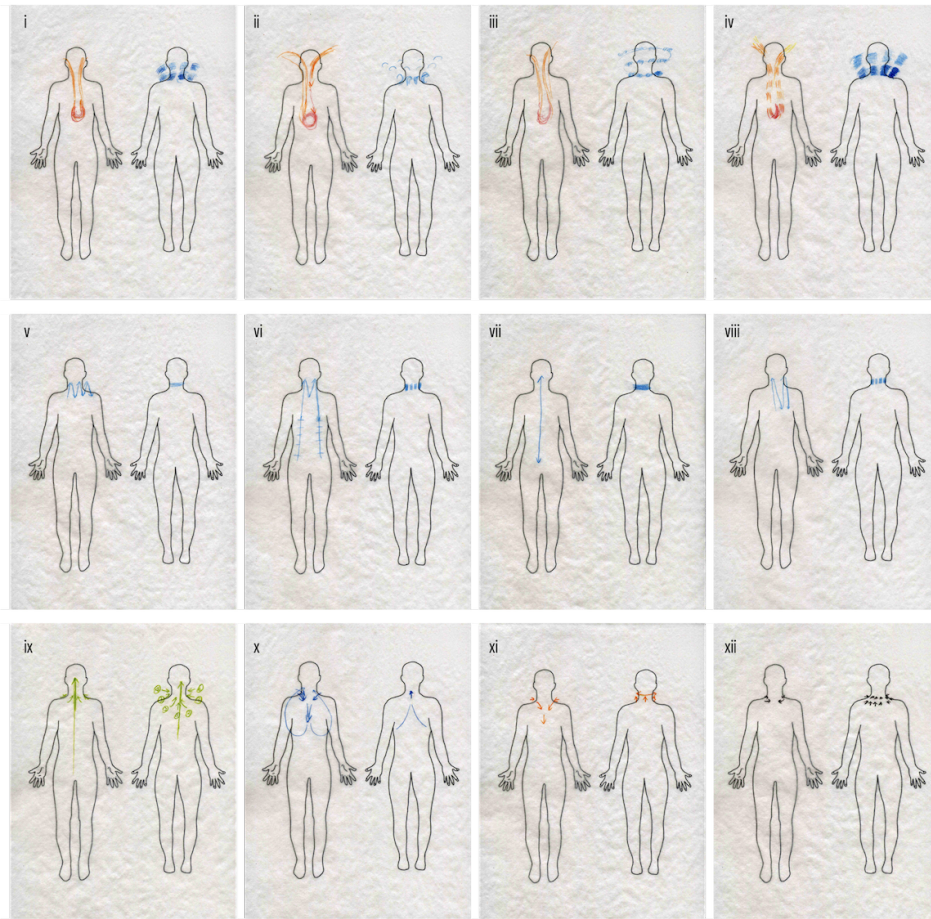


Figure 5: Selected images of body maps.

was “like a notification” even though it is the simplest and easiest to follow.

We also noted that participants described their perception of the haptic sensation with the airflow as a whole-body experience, even though the airflow targeted the neck. PP2, for example, shared that “I feel like the air is going into the upper part of my head, like, maybe into the brain.” (PP2). This feedback demonstrates that even within a restricted area, the elaborate shapes and patterns of airflow can significantly impact the other parts of the body and one’s perception. This embodied experience could potentially be connected to participants’ comments about how the patterns evoked descriptions of scenery and memories. PP2 for example remarked how the air flows in configuration 3 “were kind of bursting in, like a firework.” Configuration 2, the pattern that sweeps from one side to the other, reminded multiple participants of the shore with the tides, for example PP3 shared how it “it felt like when waves are at the beach when they crest onto the shore. ... I anticipate those to feel more like waves...” (PP3)

Interestingly, participants stated that using a haptic device in breathing was slightly different from the previous mindfulness practices. For example, PP3 “didn’t consciously follow the pattern....

I think I would be more conscious of my breathing pattern after this wind.” (PP3). Participants didn’t feel it was strictly necessary to follow in certain ways, but they found their own rhythm to be aware of and regulate their breathing, for example PP4 “tried to match it with the air I felt. But I think I found workarounds like following the rhythm.”

3.2.4 System Improvement. For the main user study, we decided to use configuration 2 at a speed of 15 breaths per minute based on our findings, since some participants found it difficult to follow the slow breathing pace, and the mismatch with their natural breathing led to discouragement. This also caused them to focus more on the activity itself rather than on their breath. Also, we found that configuration 2 allowed participants to easily connect with their real-life experiences, which could improve user engagement.

In terms of physical prototype, the haptic device in the pilot study was connected to a battery on a wearable vest, which caused the vest to shift backward, leading to discomfort and weight on the back. To address this, we developed the second version, which is standalone with a custom-designed PCB to minimize the size of the circuit and designed to be worn around the neck (see Figure 6).

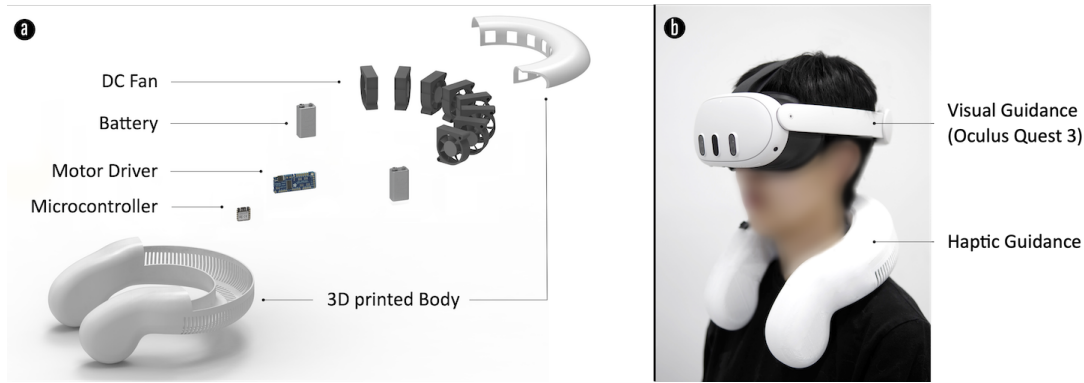


Figure 6: The improved system. (a) Exploded image of the second version of the haptic device that can be worn around the neck, revealing the electronic components such as fans, batteries, the motor driver, and the microcontroller (seeeduino). (b) Image of a person wearing both the haptic device and the AR headset to demonstrate the meditation session.

3.3 AR System Design

Although AR was not the central focus of this study, it served as the baseline delivery platform to ensure consistent and flexible presentation of visual guidance across all conditions.

AR pass-through feedback lets users engage comfortably, aligning with our design criteria. For instance, it enables users to re-examine the task they were working on while breathing, focus solely on the user interface, or close their eyes to block out visual stimuli, helping them regulate their breathing as they feel comfortable. Additionally, AR functions as a comparative tool in studies drawing from UI-based guided mindfulness principles, reducing the need for extensive explanation and making it well-suited for self-guided practices.

We developed the AR visuals in two configurations: guided breathing based on a standardized breathing rate of 15 breaths per minute and one version incorporating live biofeedback. The guidance circle turned green when expanding (Figure 7.a.i) and purple when contracted (Figure 7.a.ii). The animation has a smooth transition, with expansion and contraction rates decreasing at extrema, mimicking human breathing. The visual guide with biofeedback was programmed to layer on top of the guidance circle. It was a solid white circle that expands and contracts in proportion to an individual's breath depth measured using a Mindfield eSense breathing sensor (Figure 7.b). Biofeedback was tailored to each participant's respiratory depth, which is measured prior to using the interface. This initial measurement was used to normalize the white circle to fit the display space, ensuring that the biofeedback accurately reflected each participant's unique maximum and minimum respiratory depths (Figure 7.c).

4 The User Study

This project builds upon a prior study [13] aimed at supporting novice welders through an AR feedback system. Accordingly, AR serves as the default modality for the studies, providing a baseline for evaluation. In this work, we propose to extend the system by incorporating an air-based haptic interaction modality to further enhance user feedback. To examine, compare, and contrast the air-based haptic and AR feedback approaches in supporting fine motor

skills, we used mixed methods. We outline the study design, data collection, and analysis methods through which we explore the effectiveness and experience of the integrated AR-haptic system.

4.1 Task Design

To investigate the impact of interactive techniques for breathing guide and perceived stress during the task performance, we instructed the participants to complete a hot gluing task. We chose this task because it shares similarities with more advanced practices and in particular metal welding. The quality of both the hot gluing task and the welding coupons depends on the following aspects (See Figure 8 and Figure 9):

- hand stability
- travel speed
- tool angle
- hand-eye coordination
- similar muscle groups in the wrist and forearms

However, unlike metal welding, it can be completed safely with novices in a laboratory environment, without the need for extensive safety training prior to tasks.

In the hot gluing task, novices were required to create a straight and consistent line that glued two pieces of paper together at the edge, emulating the precision required in welding. The task was timed, for 7 minutes, and participants were asked to create as many lines as possible in the given time. The time constraint was used to emulate a stressful work condition that would require them to be consistent, precise, and efficient.

To assess their work quality, we took inspiration from welding practices and developed assessment criteria that are consistent with those used in metalworking. These measures are described in Section 4.5.1 and include adhesion rate, consistency, bead quality, and completion count. A visual reference is in Figure 9. This allowed us to measure and compare task performance resulting from the integration of mindful breathing, AR, and haptic feedback systems.

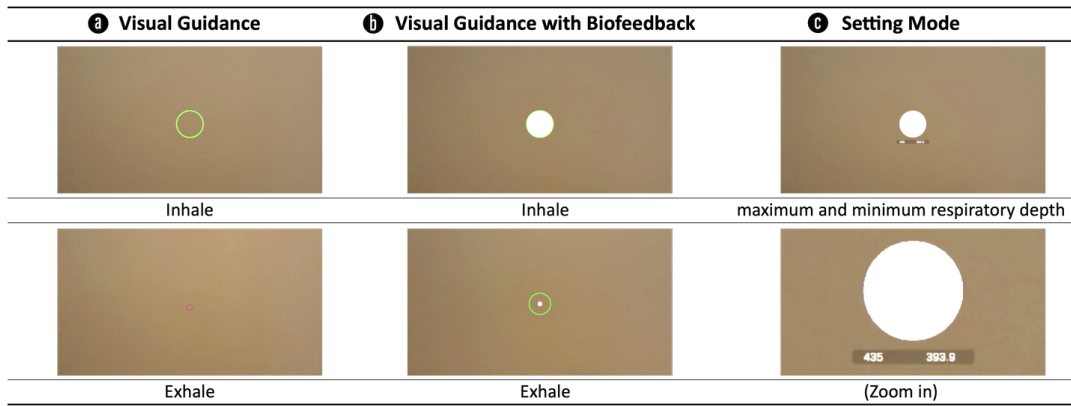


Figure 7: Screenshots from the AR system. (a) the animation of only the green circle when there is no biofeedback. (b) the white circle as biofeedback along with the guidance (c) Setting mode to show how the white circle is set to match the breathing depth.

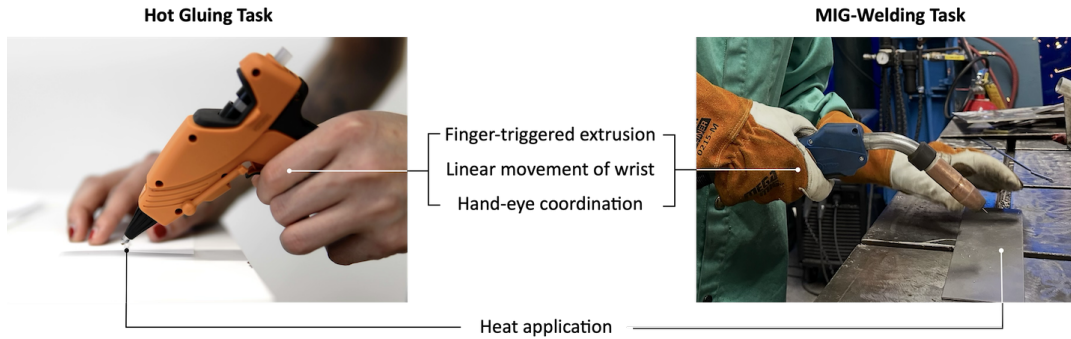


Figure 8: Comparison of hot gluing and MIG-welding tasks, highlighting similar hand movements, trigger-controlled material application, and heat-based bonding processes

Table 2: Composition of four mindfulness conditions that are combinations of AR and haptic feedback

Label	Description	AR Guidance	AR Biofeedback	Haptics
VO	Visual Only	Y	N	N
VF	Visual Feedback	Y	Y	N
VH	Visual + Haptics	Y	N	Y
VFH	Visual Feedback + Haptics	Y	Y	Y

4.2 Study Design

The study took about 90 minutes, and each participant was randomly assigned to three of the four conditions, presented in Table 2. If all participants were to try all four conditions, the extended study duration raised concerns about potential fatigue. Each condition assessed a version of the system and included some combination of the presentation of:

- **AR Guidance:** provides visual cues for breathing. These cues are presented at a fixed rate, 15 breaths per minute, and are represented by a guidance circle that continuously expands and contracts in accordance to the fixed rate.
- **AR Biofeedback:** provides real-time visual feedback based on the participant's breathing rate based on data collected

from the breath sensor. It was represented by a solid white circle in the view on top of the fixed-rate AR guidance.

- **Haptic Feedback:** blows air in the programmed lateral sweep configuration to provide tactile guidance on the wearer's neck. It was synchronized with the AR guidance.

Participants performed the breathing session and gluing task in a sequence such that each condition was tested with a similar number of trials and the order they appeared in the session sequence was balanced (Table 2).

- **Condition 1: Visual Only (VO):** The system includes only the AR Guidance, providing visual cues for breathing.

- Condition 2: Visual with Feedback (VF): The system features both the AR Guidance and AR Biofeedback, offering visual cues and real-time feedback on breathing rates.
- Condition 3: Visual and Haptics (VH): The system incorporates AR Guidance along with haptic feedback from the neck-mounted device, providing visual cues and tactile guidance.
- Condition 4: Visual Feedback and Haptics (VFH): The system combines AR Guidance with both AR biofeedback and haptic feedback, delivering visual cues, real-time breathing rate feedback, and tactile guidance.

4.3 Session Sequence

The study contained two key components:

- (1) the task of gluing two paper pieces together at the cut edge neatly and securely with hot glue;
- (2) guided breathing exercises with animated visuals in augmented reality, with or without feedback from breath sensors and/or haptic feedback from the neck-mounted device.

All participants wore the breath sensor, Mindfield eSense [42], on their chest to collect the breathing rate throughout the study for the real-time biofeedback. They also completed a short survey about their previous experience with mindfulness exercises and AR experiences. The participants watched a 5-minute video to learn about the paper-gluing task. At the same time, we took a baseline measurement of their breathing rate. The video covered several key aspects: an introduction to the hot glue gun, safety guidelines, a demonstration of the gluing task to connect two pieces of paper, and examples of both high-quality and low-quality work. After viewing the video, participants completed a practice task to allow them to familiarize themselves with the process and the study procedures.

Next, they conducted a paper gluing task to document their baseline performance. The main session is a paired breathing exercise and paper gluing task. Participants first experienced one of the guided breathing exercises, randomly selected from the four conditions we listed earlier, for 5 minutes, then reported their perceived stress levels and focus levels through a short survey. The following paper gluing tasks lasted 7 minutes each with no guided

breathing, and after each task, participants filled out a survey about their perceived concentration level on the task. This cycle repeated three times. After the last task, we conducted a 15-minute interview where participants were asked about the guided breathing exercises and possible improvements. Table 3 shows the sequence and timing of the main study. The survey questions are shared in the Appendix.

4.4 Participants

Participants were recruited through campus bulletin board posters and email. They completed a screening survey in which they were asked about their previous experience with using hot glue guns, and mindfulness practices, and AR. Following the screening, eleven female and four male participants ranging in age between late twenties and early thirties were enrolled. They were randomly assigned to three experimental conditions from the breathing exercises listed in Table 2. Four participants had prior experience with the paper gluing tasks, eleven participants had prior experience with mindfulness practices, and only one participant had some experience with using AR for mindfulness practices. About half of the participants mentioned the main reason why they tried mindfulness practices was to reduce stress and anxiety. Participants were compensated with a \$15 gift card on completion of the study.

4.5 Data Collection and Analysis

4.5.1 Task performance. To assess task performance, the authors gathered and analyzed breathing data, glued paper samples, and transcribed audio recordings for each participant. To evaluate the effect of each condition on fine motor skills performance, four measures are employed (see Figure 9).

Adhesion rate. Adhesion rate is the ratio of the length where adhesion occurred (effective bonding area) to the total length where adhesion was attempted (total length of the paper strip). An example is shown in Figure 9, left.

Consistency. Consistency is evaluating the ability to maintain a steady hand and consistent travel speed during gluing. It is the ratio of the area where the consistent thickness of glue was applied on each paper sample to the total length of the paper. An example is shown in Figure 9, middle.

Bead quality. Bead quality evaluates for smoothness, uniformity, and consistency in size and shape. It is the ratio of the minimum to maximum size of the glue beads. An example is shown in Figure 9, right.

Completion count. The completion count assesses the number of glued paper strips in each task.

Each glued paper strip was inspected by the two primary authors and the four measures were derived with rulers and agreed upon for each participant's outcomes. Finally, interviews and survey data were qualitatively coded (described below) and used to examine participants' perceptions and experiences of the systems introduced and their impacts on task performance.

4.5.2 Interview. All interviews were recorded and labeled with assigned codes. Following transcription, an affinity mapping process

Table 3: Session Sequence

Session Sequence	Respiration Measure	Time
Introduction	–	5 mins
Pre-Survey	–	5 mins
Watching Guide Video	Baseline Rest	5 mins
Trial Task	–	5 mins
Gluing Task	Baseline Task	7 mins
Breathing	Conditioned Breathing	5 mins
Gluing Task	Conditioned Task	7 mins
Breathing	Conditioned Breathing	5 mins
Gluing Task	Conditioned Task	7 mins
Breathing	Conditioned Breathing	5 mins
Gluing Task	Conditioned Task	7 mins
Post-Survey	Interview	15 mins

Table 4: Information of main user study participants

Code	Hot Glue Experience	Breathing Experience	AR Experience	Breathing in AR
P1	A little	A little (Apple Watch)	A little	No
P2	A little	A little (Video, Audio)	A little	No
P3	A little	A little (Studio, Audio)	A little	No
P4	Often	Often (Video, Audio)	Often	A little
P5	A little	Often (Audio)	Often	No
P6	A little	A little (Studio, Video, Audio)	A little	No
P7	A little	Often (Self practice)	A little	No
P8	Often	No	All the time	No
P9	A little	A little (Video, Audio)	Often	No
P10	A little	A little (Audio)	Often	No
P11	Often	A little (Self practice)	No	No
P12	A little	No	A little	No
P13	Often	No	Often	No
P14	A little	No	Often	No
P15	A little	Often (Video, Audio)	A little	No

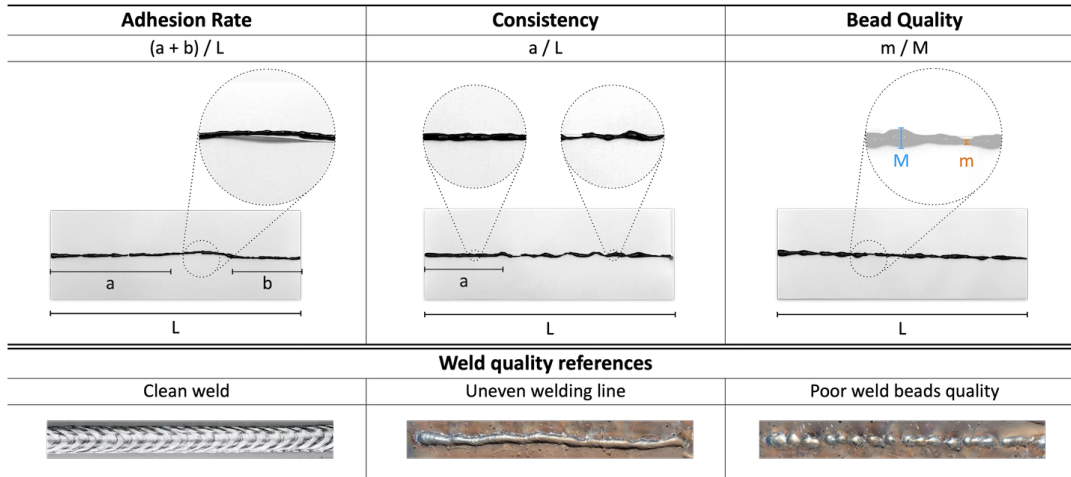


Figure 9: Three metrics used to measure task performance as related to welding quality: Adhesion rate is the ratio between attached segment and paper length, Consistency measures the percentage of even glue application, and Bead quality is the ratio of thinnest glue over thickest glue.

was used to organize the data into broad categories, which were then axial-coded to examine relationships between the categories to draw insights. Two primary authors first analyzed the data independently, followed by a reviewing and comparing phase, and finally, a collaborative analysis was conducted.

4.5.3 Data Analysis with Adjustments for Participants. Since each participant only participated in three out of four breathing experiences in addition to one baseline measurement, the performance difference across individuals needs to be accounted for when comparing the effect of each breathing exercise. For example, a person who naturally glues faster than everyone else but does not participate in condition X would cause condition X to have a lower average completion rate.

To account for such individual differences, we fit a random intercept model to our data. A random intercept model is a type of mixed linear model that builds on linear regression models but assigns an intercept for each participant, allowing their data to shift while maintaining the relative effects between conditions¹. This model could also handle the skipped condition. Furthermore, since the order of encountering the conditions was balanced to the maximum extent, we did not include time as a variable in the random intercept model, hence no learning effect was considered. Compared with a simple linear regression model, we found the log-likelihood of the random intercept model to be significantly higher ($p < 0.001$),

¹See an example of this model at <https://stats.oarc.ucla.edu/other/mult-pkg/introduction-to-linear-mixed-models/>

showing that there are significant variations across individual participants and a need for the intercepts.

The result section uses the adjusted coefficients from the random intercept model to represent the effect of each condition. Error bars show the standard error from model fitting (with Python “statsmodels” package).

For significant changes between conditions, we also run Wilcoxon signed-rank tests with data from only the participants who experienced both conditions, so that there is no missing data for pairing and hence no need for a random intercept model.

We also used Spearman’s correlation calculation on the unadjusted data to explore whether task performance and reported experience had significant monotonous correlations.

5 Results

5.1 Task Performance

Four measures outlined above were employed to assess task performance and establish the effect of each breathing exercise on fine motor task performance. Regardless of the completion rate, the results indicate that either visual biofeedback or a haptic device generally increased the performance of the gluing task as compared with the absence of interactive breathing feedback. Haptics significantly enhanced performance when participants did not receive visual biofeedback, making it the most effective approach. However, we observed that the presence of real-time visual biofeedback generally diminished the positive effects of haptic feedback on adhesion rate, consistency, and bead quality. We acknowledge that due to the sample size of 15 participants and moderate p-values in a few cases, these results are more indicative of the direction of influence than definitive proof of effect. We next describe these results in detail and results from all four measures are presented in Figure 10.

5.1.1 Adhesion Rate. The haptic device enhanced performance and was the most effective approach for improving adhesion (Figure 10.a). Compared with using only a guiding circle in the visual-only condition (VO), adding the haptic device to this configuration (VH) saw a significant increase of 12% in adhesion rate ($p = 0.008$). Using Wilcoxon signed-rank tests to compare VH and VO on 8 participants who experienced both in varied orders shows significant improvement as well, with Wilcoxon stat = 1.000, $p = 0.01$, and an estimated power of 0.91. Providing visual feedback in the absence of the haptic device (VF) showed weak improvement in adhesion rate ($d = 0.06$, $p = 0.187$). However, providing visual feedback when there was already a haptic device (VFH) weakly decreases the performance ($d = 0.07$, $p = 0.104$).

5.1.2 Consistency. Adding visual feedback alone, haptic feedback alone, or both, improves the consistency of work with correlations of varying strengths (VF: $d = 0.076$ $p = 0.141$, VH: $d = 0.107$ $p = 0.033$, VFH: $d = 0.080$ $p = 0.120$), as in Figure 10.b. Notably, the haptic device (VH) significantly enhances consistency when visual biofeedback is absent ($p = 0.033$), with an increase of 10%. Using Wilcoxon signed-rank tests to compare VH and VO showed weaker results, with Wilcoxon stat = 7.000, $p = 0.148$, and an estimated power of 0.30.

5.1.3 Bead Quality. In Figure 10.c, adding haptic feedback to the guide without visual feedback (VH) significantly improved this performance, with an increase of 7% compared with no visual feedback (VO: $p = 0.036$). Using Wilcoxon signed-rank tests to compare VH and VO showed weaker results, with Wilcoxon stat = 10.000, $p = 0.312$, and an estimated power of 0.07. The improvement remains as a weak inclination compared with having only visual feedback (VF: $d = 0.05$, $p = 0.164$). Adding visual feedback to this configuration (VFH) weakly reduced the performance ($d = 0.05$, $p = 0.120$).

5.1.4 Completion Count. All the interventions improved the completion count (Figure 10.d), compared with the trial task by the participants (baseline = 7.533 paper strips) (VO: $d = 0.83$ $p = 0.164$, VF: $d = 0.47$ $p = 0.430$, VH: $d = 0.54$ $p = 0.349$, VFH: $d = 0.75$ $p = 0.206$). However, no significance was found in the differences between interventions.

5.2 Perceived Mindfulness Reported in Survey

Participants answered questions about their perception of the breathing exercise after each condition (stress-lowering effect and system-distracting effect), and rated their concentration on the task after each task. The questions were answered on a five-point Likert scale, as in Appendix A. We present these survey results in Figure 11.

5.2.1 Stress-lowering Effect of Breathing Exercises. We asked the participants if the breathing exercise was effective in lowering their stress, and the response is in Figure 11.a. The median of the responses is the same across the four conditions, though the average varies (VO: average = 3.81, VF: average = 3.55, VH: average = 4.17, VFH: average = 3.72). More people reported lower scores for the guiding circle with visual biofeedback (VF), indicating that it is not as effective. Replacing the visual biofeedback with the neck device (VH) was reported as the least stressful among the four conditions (VH: average = 4.17). The ability to lower the stress during the session also improved task performance measured with bead quality based on Spearman’s correlation ($p = 0.023$).

The stress-lowering ratings in Figure 11.a were highest for VF and VH conditions, which corresponds with the performance gains observed in VH and VFH (Figure 10 a–c). This suggests that participants’ perceptions of comfort and reduced stress aligned with measurable improvements in adhesion rate, consistency, and bead quality when feedback and haptics were involved.

5.2.2 Distracting Effect of the Breathing Exercises. Participants evaluated whether the guides were distracting. As shown in Figure 11.b, the four conditions varied more in this evaluation. When presented with only the guiding circle (VO), participants found it the least distracting, with a median of 2 and an average of 2.18. On the other hand, with all three elements present (VFH), participants reported a median distraction level of 4 and an average of 3.27. Compared with using the haptic device without feedback (VH: median = 2.5, average = 2.67), the presence of visual feedback alone (VF: median = 3, average = 2.90) is slightly more distracting. There is a strong negative correlation between the ability to lower stress and the feeling of distraction during the breathing exercises ($p < 0.001$).

The subjective ratings in Figure 11.b show that participants found the VFH condition (visual, feedback, and haptic) the most distracting. Although it is not statistically significant, it reflects

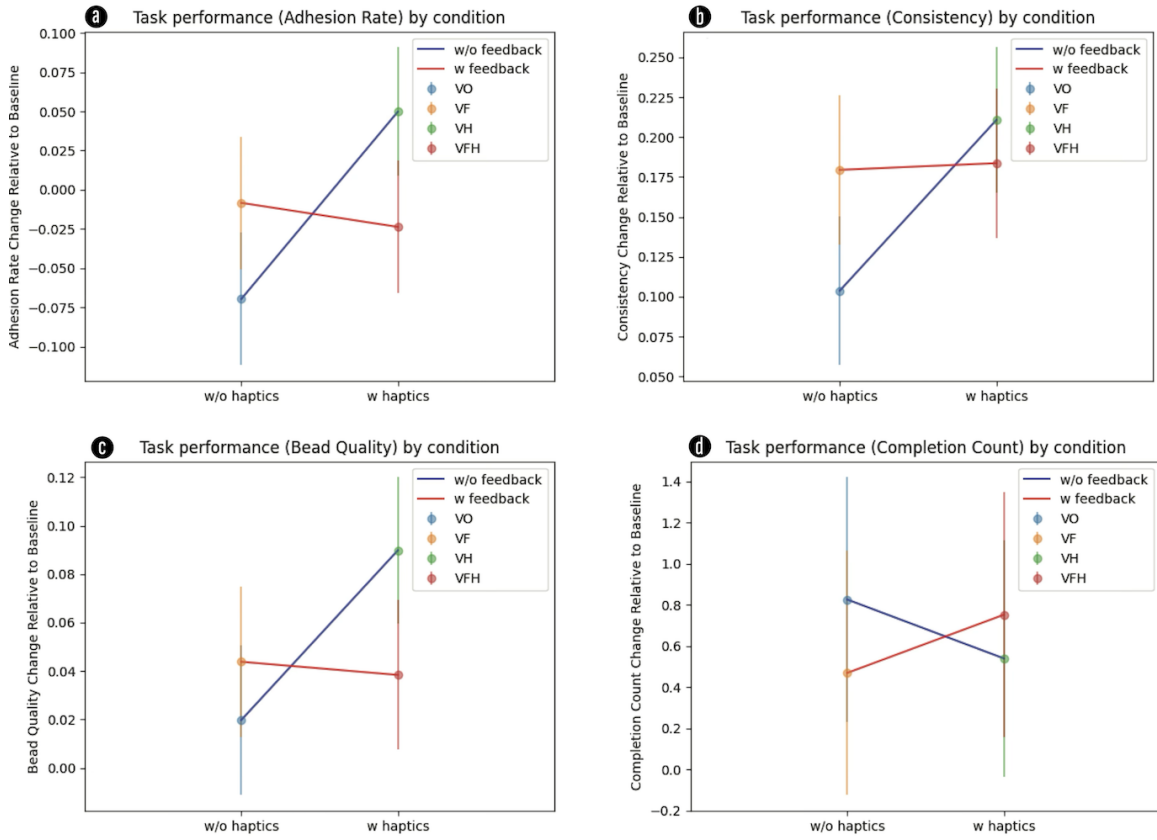


Figure 10: Plots of the four measures of task performance: (a) adhesion rate, (b) consistency, (c) bead quality, and (d) completion count.

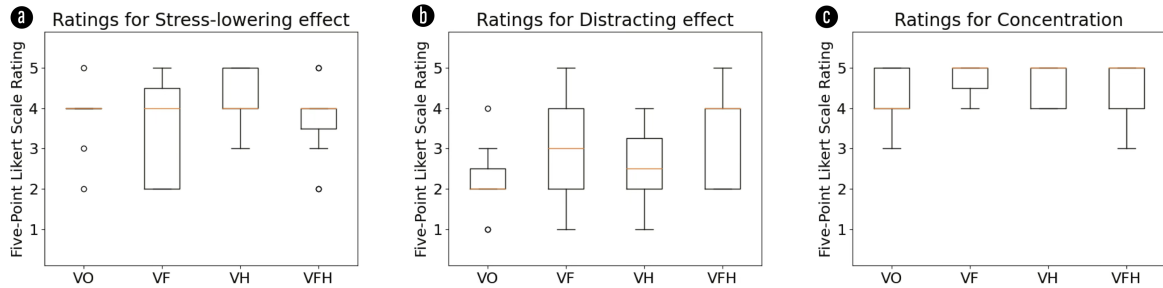


Figure 11: Plots of survey responses to questions on perceived mindfulness: a) stress-lowering effect, b) distracting effect, c) concentration.

the quantitative performance data in Figure 10.d showing slower task completion under this condition. This alignment suggests that the added modalities may have increased cognitive load, leading to reduced speed without compromising quality.

5.2.3 Concentration Level on the Task. Participants responded to, “On a scale of 5, how would you define perceived concentration on the task?” and the results are presented in Figure 11.c. The breathing

exercises that only presented the guiding circle (VO) was the least helpful in helping people to concentrate, with a median concentration of 4 and an average of 4.27, while the other interventions had at least half of the people reporting a concentration of 5 (VF: average = 4.73, VH: average = 4.67, VFH: average = 4.45). In addition, when analyzing the correlation between the level of concentration and task performance, we observe a strong positive correlation that

higher levels of reported concentration improve the adhesion rate of the glue line ($p=0.001$).

Concentration ratings (Figure 11.c) were high across all conditions, and this matches the generally strong performance trends (Figure 10), with haptic feedback providing the most noticeable benefits.

5.3 Interview

We also examined the qualitative data from the semi-structured interview to understand two aspects of the participants' experience that arose inductively from axial-coding: intuitiveness and agency.

Intuitiveness: We define intuitiveness as guidance that is easy to comprehend and follow without requiring additional explanation. The majority of participants appreciated the clarity and simplicity of the haptic guidance, describing it as intuitive and easy to act on. For example, P10 remarked that it was *"easier for me to follow because it is straightforward"* while P13 stated *"the great green circle really helps me like, I know, when should I inhale, like when it goes too big a screen circle..."*. Similarly, P1 found that *"It feels more authentic than just relying on visual instructions. It's easier to follow and allows me to fully concentrate on the guidance."* This intuitiveness was a support to mindfulness with P8 finding the wearable device to be *"more effective than doing it on my own because it helps me determine if I'm breathing at the right frequency and whether I'm actually taking a deep breath or not."* (P8)

We observed that some participants chose to close their eyes to better engage breath work. This was best supported by the haptic device with seven participants (P2, P3, P8, P9, P10, P12, P14) in this condition closing their eyes during the breathing session. They also reported the haptic guidance was more intuitive and aligned with familiar meditative practices: *"...it's something that allows you to close your eyes... For me, mindfulness truly happens when I feel most at ease, and that comfort comes when I shut my eyes and begin to tune into my senses. That's when I can fully immerse myself and start to feel calm."* (P8)

In contrast, nine participants (P2, P4, P5, P7, P8, P12, P13, P14, P15) mentioned that the visuals provided to guide breathing were distracting, especially when real-time biofeedback was present. The visual guides seemed to take away from the bodily experience of breath and was less conducive to relaxation. To compensate for this, some participants, like P14, also closed their eyes to focus attention on breathing: *"The visual symbol was... it was more, more like stressful, actually, so I just closed my eyes."* (P14)

P5 offered a comparison the biofeedback and haptic sensory experience: *"With the air coming out, I can feel it directly... besides focusing on breathing, there's also a practice of sensing different parts of the body to relieve stress and increase awareness. I find this approach more familiar and effective for me"* (P5). Additionally, two participants (P13, P15) mentioned that the AR visual guide without real-time biofeedback was helpful since it was intuitive to understand when to inhale and exhale. P15 compared this to their normal behavior during meditation: *"Usually, when I'm meditating, I close my eyes and try not to think of anything, ...but actually looking at the [green] circles was helpful."* (P15).

Agency: This aspect involves the supportive elements that enhance participants' sense of control and autonomy. This aspect

encompasses the participants' ability to interact with and manipulate the system in ways that align with their personal preferences to support individualized ways of focusing. For example, P9 remarked how the visual guidance *"felt like I had more control because there weren't fixed guidelines, like matching the white circle to the green. Instead, it was more about letting myself be open to the experience."* This was not uniformly experienced. Multiple other participants (P2, P3, P7, P12, P14) also mentioned that some of the visual references were demanding. They described the visual guides with biofeedback as a stressor, particularly when they could not match their breathing rate with the target rate. Participants noted this experience as discouraging with, for example P12 describing how *"the visual reference was making me more stressed. I was trying to sync with it, then I kept failing."*

In the response, and as noted above, a group of participants (P2, P3, P8, P9, P10, P12, P14) actively closed their eyes to eliminate the visual feedback. They instead relied on the sense of their own body or the haptic feedback. They noted how the haptic airflow had less defined start and end points, as compared to the AR visual cues. The ambiguity in the airflow allowed them to focus more deeply on their breathing rather than feeling constrained by external prompts. The combination of the haptic feedback with real-time biofeedback felt especially incompatible for participants who found they had to *"concentrate too much to match my breathing with the circle, and I ended up not concentrating on my breathing."* (P7). P8 similarly found the real-time biofeedback to be *"distracting because the goal of my breathing task has shifted from calming myself down to try to catch up with the reference dot."* (P8)

6 Discussion

Findings suggest that air-based haptics, combined with mindful breathing practice, can enhance body awareness and fine motor skill performance. The minimal haptic and visual interfaces of the stimulus proved to be unobtrusive and may effectively support mindfulness and attention in a fine motor task. We now discuss design insights and broader opportunities for integrating mindfulness into skill performance.

6.1 Attention as a Design Element of Guided Mindfulness

Breathing exercises have been a key focus in prior mindfulness research [17, 34, 48, 60], yet there is limited work on utilizing breathing as a method to create body awareness that could improve attention and proprioceptive abilities. Our findings suggest that many participants valued the breathing sessions in between tasks and perceived increased attention to the task.

In addition, we found that attention is a key element in designing mindfulness practice guidance. Participants preferred guidance that was straightforward, unobtrusive, and non-evaluative due to its intuitiveness and agency. This finding contrasts with current approaches using biofeedback, such as breathing rate [60] and EEG measures [4, 34], in mindfulness practices. These prior works aim to use biofeedback to enhance bodily awareness by providing users with a sense of control. However, in the context of skill acquisition and performance, which demands sustained attention to the task after mindfulness practice, participants reported that the guidance

that required too much attention, such as real-time biofeedback, ultimately distracted them from both mindful breathing and fully engaging in the task.

6.2 Bridging Multimodal Embodied Association and Skill Performance

Within our approach, the form of haptic feedback, namely using airflow as sensory stimuli, is not widely seen in mindfulness or biofeedback applications. We found that participants valued this form of guidance in both the early exploration and the main study, as it evoked associations with other embodied experiences. For example, participants associated the experience with being by the ocean and feeling the natural breezes. For others, the sweeping patterns from the center fan to the outside fans connected them with the experience of performing opening and closing stretches in yoga. For participants, these associations with other embodied experiences brought them deeper into the mindfulness experience and cultivated a sense of intimacy. While we did not intentionally design for these associations, the airflow haptics provided space for evocative associations and were supportive of cultivating effective mindfulness practice.

These embodied associations extend beyond emotional status and into task performance. Unlike more intrusive modalities, airflow does not interfere with visual attention or hand movements, making it particularly compatible with fine motor tasks. While air has primarily been used in playful or artistic contexts [12, 53, 54, 62, 65], our findings suggest it has untapped potential for practical applications where mental readiness and physical precision intersect. As a medium linked to breath and the environment, airflow connects internal awareness and external action. This opens up opportunities to explore designing with a broader range of human factors, such as embodied memory, associations with nature, and sensory regulation, to enhance learning and performance in skill-based practices.

6.3 Mindfulness for Novices in Fine Motor Skill Task

Recent research has developed technical tools to lower barriers to entry and accelerate skill acquisition across various fine motor activities, such as paper cutting [39], weaving [58], sewing [36], and welding [13]. Yet, as technical aids advance, there is an increasing recognition of the need for complementary support strategies that address the mental and emotional dimensions of learning. Taken with findings that show the frustration and early failures common in these practices can disempower novices, sometimes causing them to abandon skill development altogether [22], managing stress and improving body awareness could be as crucial to successful skill acquisition as technical assistance itself.

In this work, we explored mindfulness-based approaches, particularly breathing exercises aiming at cultivating bodily awareness as a means to improve task performance. Participants reported that the haptic airflow device, combined with static visual cues, increased their awareness of both breath and body position, which has been confirmed to be possible in movement practices such as the Feldenkrais Method [41]. Over time, such improvements in perceptual and performance states may translate into deeper,

more efficient skill acquisition. By integrating mindful activities, novices may not only achieve better immediate performance but also develop the mental resilience and focus needed for long-term mastery.

7 Limitations and Future Work

There are some opportunities for refinement and limitations to note. For example, we noted that there was a 0.1 second offset per cycle in synchronizing real-time visual guiding circle and haptic guidance although such discrepancies were minor. Also, this study relies on fifteen participants which is a relatively low sample for quantitative studies. Given this, we have balanced qualitative and quantitative evidence to provide indicative findings, however, repetition with a larger and more diverse participant pool would be valuable to support the generalizability of these findings and further investigate nuances. Our work also focuses on one of a variety of guided breathing techniques. Others included box breathing and alternate nostril breathing [46]. While Yadav and Mutha [63] showed the positive effect of having a breathing practice on motor skill retention, opportunities exist to compare different breathing practices and evaluate their effectiveness. Similarly, the various airflow pattern configurations introduced in early explorations have the potential for further investigation. Moreover, interview data suggests the potential of the haptic device alone to benefit guided breathing. This is a promising avenue to investigate the air-based haptic device alone in fine motor skill scenarios or formal mindfulness practices.

Finally, and importantly, the current study was conducted in a controlled lab environment. While paper crafting with hot glue was used as a stand-in for welding, it does not fully capture the physical demands and stress of actual working conditions. Our future research will apply these interactive methods to these tasks to evaluate how well they prepare novices to engage with more realistic and demanding scenarios. This will help assess the transferability and applicability of these breathing techniques to other hands-on skills.

8 Conclusions

This research demonstrates the potential of integrating mindfulness techniques into fine motor skill training through a hybrid wearable system combining AR feedback and air-based haptic cues. Findings from our Research through Design approach to designing the system and mixed-method study to evaluate the system suggest that guided breathing can enhance bodily awareness and support attention, and has the tendency to improve task performance, specifically in terms of adhesion rate, consistency, and bead quality of hot gluing two pieces of paper. These results highlight the opportunities for incorporating multimodal mindfulness guidance into vocational skill training as a complement to conventional methods. Future work will focus on validating these effects with larger participant groups and in a real-world training context.

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A Appendix

A.1 Survey question after the task

- (1) How would you define perceived concentration on the task?
(1 = Not at all, 5 = Very much)

A.2 survey question after the meditation

- (1) The breathing session was effective in lowering my stress.
(1 = Strongly Disagree, 5 = Strongly Agree)
- (2) The guides were distracting. (1 = Strongly Disagree, 5 = Strongly Agree)