Attention Regulation Framework: Designing Self-Regulated Mindfulness Technologies

KAVOUS SALEHZADEH NIKSIRAT, Kochi University of Technology
CHAKLAM SILPASUWANCHAI, Kochi University of Technology, Asian Institute of Technology
PENG CHENG, PauseAble ApS
XIANGSHI REN, Kochi University of Technology

Mindfulness practices are well-known for their benefits to mental and physical well-being. Given the prevalence of smartphones, mindfulness applications have attracted growing global interest. However, the majority of existing applications use guided meditation that is not adaptable to each user's unique needs or pace. This article proposes a novel framework called *Attention Regulation Framework (ARF)*, which studies how more flexible and adaptable mindfulness applications could be designed, beyond guided meditation and toward self-regulated meditation. *ARF* proposes mindfulness interaction design guidelines and interfaces whereby practitioners naturally and constantly bring their attention back to the present moment and develop non-judgmental awareness. This is achieved by the performance of subtle movements, which are supported by non-intrusive detection-feedback mechanisms. We used two design cases to demonstrate *ARF* in static and kinetic meditation conditions. We conducted four user evaluation studies in unique situations where *ARF* is particularly effective, *vis-à-vis* mindfulness practice in busy environments and mindfulness interfaces that adapt to the pace of the user. The studies show that the design cases, compared with guided meditation applications, are more effective in improving attention, mindfulness, mood, well-being, and physical balance. Our work contributes to the development of self-regulated mindfulness technologies.

CCS Concepts: • **Human-centered computing → Interaction design theory, concepts and paradigms**; *Ubiquitous and mobile computing*;

Additional Key Words and Phrases: Mindfulness, self-regulation, framework, meditation, attention, attention-regulation, mobile applications, MBMA

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Authors' addresses: K. S. Niksirat, Center for Human-Engaged Computing, Kochi University of Technology, Japan, Room C301, 185 Miyanokuchi, Tosayamada, Kami City, Kochi 782-8502; email: kavous.salehzadeh@gmail.com; C. Silpasuwanchai, Center for Human-Engaged Computing, Kochi University of Technology, Japan, Room C301, 185 Miyanokuchi, Tosayamada, Kami City, Kochi 782-8502 and Computer Science and Information Management, Asian Institute of Technology, Thailand, 58 Moo 9, Km. 42, Paholyothin Highway, Klong Luang, Pathum Thani 12120; email: chaklam@ait.asia; P. Cheng, PauseAble ApS, Denmark, World Trade Center, Borupvang 3, 2750 Ballerup, Copenhagen area; email: pengcheng@pauseable.com; X. Ren (corresponding author), School of Information, Kochi University of Technology, Japan, Office A409, 185 Miyanokuchi, Tosayamada, Kami City, Kochi 782-8502; email: ren.xiangshi@kochi-tech.ac.jp.

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1 INTRODUCTION

Mindfulness practices have attracted growing interest. Scientific research demonstrates the benefits of mindfulness practices on stress [9], emotional states [128], attention [117], and positive attitudes such as compassion [53]. Given the prevalence of smartphones, it is not surprising that mindfulness applications are receiving increasing attention. Many mainstream mindfulness technologies use guided meditation [88]. However, guided meditation significantly suffers from the lack of contextual understanding of users' current state, where the interactions are unidirectional assuming a consistent level of comprehension and pace of learning regardless of individual user idiosyncrasies [67]. In other words, technology does not detect users' states and cannot provide real-time feedback. Hence, many users may not be able to self-regulate their attention.

This article presents a novel, theoretically grounded framework called *Attention Regulation Framework (ARF)* (see Figure 1 for the high-level description). It discusses how we can design more efficient and effective user sensitive mindfulness applications beyond guided meditation. Specifically, the framework focuses on the concept of "self-regulated meditation" [55], which is about performing certain regulation techniques in order to train the mind to spontaneously return the attention back to the present moment with non-judgmental awareness. This concept is not new, and it is inspired by age-old regulation techniques such as Walking meditation, Buddhist prayer beads and Tai Chi, where traditional mindfulness masters have leveraged many kinds of mediums for this purpose. For example, in Walking meditation, practitioners are asked to walk slowly with awareness focused on the fact that "I am walking." When the practitioners' mind wanders off and the steps become irregular, they redirect their attention back to the present moment by attending to the pace of their steps to walk slowly. In a similar manner, practitioners using prayer beads are asked to count the beads slowly but consistently. Practitioners learn to spontaneously bring their minds back to moment-by-moment attention when they lose count and/or become irregular in their rhythm because their minds have wandered off or they are "snoozing."

To develop a self-regulated mindfulness application, three key challenges remain to be addressed. *(1) Detection:* Technologies should be able to progressively monitor the user's state in real time. One promising solution is to use psychophysiological sensors (e.g., EEG, respiration [13, 48, 101]), where user's state can be detected in real time. But such devices have intrusive and disruptive effects on users' meditative states [30]. In addition, these devices are not readily accessible, and this factor defeats the purpose of wide distribution and accessibility to users in daily life. *(2) Feedback:* Feedback informs users regarding their current state, but it is crucial that the feedback should not induce any "judgmental" thoughts during meditation (e.g., including the rightness or wrongness of the users performance) [2, 42]. *(3) Regulation technique:* Many traditional approaches exist from which we can learn to design better "interaction" techniques with self-regulation. For example, Walking meditation, Tai Chi, and Qigong use gross-motor movements; Tibetan singing bowls and Buddhist prayer beads use fine motor movements; Breathing and Mantra meditations use meditative anchors. The key here is to choose suitable techniques that could fit well with the challenge-1 (i.e., the progress of the technique can be detected) and challenge-2 (i.e., audio/visual/haptic feedback is technologically appropriate and non-intrusive for a given regulation technique).

Thus, the article aims to address the following research questions: (1) How can technology detect the user's attentional states without using any add-on dedicated accessories? (2) What feedback mode can be incorporated into the interaction loop that would not induce judgmental thoughts, or reduce it? (3) What are the suitable interaction techniques for regulation?

To demonstrate and evaluate *ARF*, we developed two design cases based on common mindfulness practice scenarios [67], i.e., static (e.g., Zazen) and kinetic (e.g., Tai Chi). On the other hand, given the pervasiveness of smartphones, we focus on mobile applications as a platform for our design cases, a.k.a, Mindfulness-Based Mobile Applications (MBMAs).

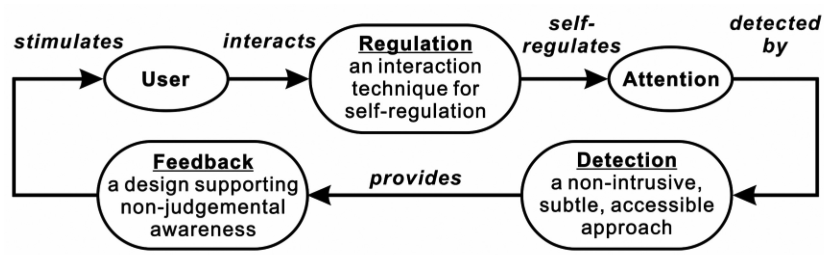

Fig. 1. Schematic diagram of Attention Regulation Framework (*ARF*) (a high-level description).

We organize the rest of the article as follows: In Section 2, we give an overview of related work. In Sections 3 and 4, we present *ARF* and our design goals. In Section 5, we describe the design of a static MBMA. In addition, we explain Studies 1 and 2, which evaluate "state" effects (i.e., meditative experience) and "trait" effects (i.e., long-term effects) [8, 67] arising from *ARF* in the static meditation condition. In both studies, we compared our *ARF* design cases with a state-of-the-art guided meditation MBMA. Similarly, in Section 6, we describe the design of the kinetic MBMA. We explain Studies 3 and 4 where Study 3 qualitatively assesses the user experience in the kinetic design case condition, while Study 4 compared the effect on user traits of our kinetic MBMA with a state-of-the-art MBMA and a control group. Last, in Sections 7 and 8, we discuss the framework, limitations, and future directions.

Overall, we found that *ARF*—as demonstrated through the design cases—is a beneficial approach to develop self-regulated mindfulness technologies. Our work informs future development of interactive meditation and has broad implications for designing mindfulness, well-being, and digital health interventions. Our work contributes to the field by (i) providing a framework for self-regulated mindfulness technologies and (ii) proposing smartphones as a subtle approach to encourage and promote self-regulation in everyday life.

2 RELATED WORK

This section provides an overview of traditional mindfulness practices and various approaches to the technology-mediated mindfulness systems and practices.

2.1 Traditional Mindfulness Practices

Mindfulness practice could be broadly categorized into static meditation (i.e., stationary but not necessarily immobile) and kinetic meditation (i.e., usually the movement of the extremities) according to the level of physical exertion required [67]. Some examples of static meditation are Samatha, Vipassana, and Zazen practices where practitioners pay attention to their breath, repeat a mantra, or visualize an object. There is abundant evidence confirming the benefits of static meditation in increasing attention span [40], regulating mood [117], and enhancing well-being [71]. On the other hand, for people who are restless and vigorous [111], kinetic meditation may well serve as a more suitable alternative. Kinetic meditation integrates the principles of static meditation such as focus, mindfulness, breath, and relaxation through bodily movements. In kinetic meditation, practitioners pay deliberate, non-judgmental attention to bodily movements [49]. Tai Chi, Yoga, Qigong, the Feldenkrais method, and Walking Meditation are various forms of kinetic meditation. A growing body of literature demonstrates that kinetic meditation not only has similar effects to static meditation (e.g., mood [41, 51, 81], mindfulness [18, 98], body awareness [21, 59], well-being [83, 93], quality of life [28]), but it can also yield additional physical improvements such as proprioception [126], stability [35], balance [39], and postural adjustment [27]. Based on this information, our design cases were developed according to these two common categories of mindfulness practice, static, and kinetic.

2.2 Technology-Mediated Static Meditation Approaches

The use of technology for mindfulness practice has attracted much recent attention. A large part of the literature is based on static meditation. The most common approaches use dedicated accessories such as biofeedback, tangible artifacts, and virtual reality (VR). For "detection," previous *biofeedback* studies used brain measurement methods to directly assess attention or physiological sensors to measure arousal, i.e., the activation of the autonomic nervous system. The most commonly used metrics to detect user states are electroencephalography (EEG) [48] or physiological sensors such as skin conductance [31, 101, 106], heart rate (HR) [87], respiration [34, 77, 87, 108, 118], and pulse rate [101].

For "feedback," earlier studies proposed integrating *biofeedback* into *dedicated rooms* (e.g., MoodLight [106], Breathing Light [108], Sonic Cradle [118]), *immersive VR* (e.g., RelaWorld [48], Virtual Meditative Walk [31], Meditation Chamber [101]), and *spatial augmented reality* (e.g., Inner Garden [87]). While most of the methods incorporated soothing audio-visual feedback [31, 48, 87, 101], few studies focused only on visual feedback (e.g., lighting [106, 108]), and some studies used audio feedback (e.g., user's own breathing sound [77], generalized relaxing sounds [118]).

For "regulation," most of the studies proposed focusing on objects as mediums to support self-regulation such as breath [31, 77, 87, 108, 118], a 3D virtual object [48, 101], or a bubble light [106]. Few studies used *tangible artifacts* in their interaction techniques. For example, Inner Garden [87] was developed using a sandbox to allow users to create their own world (i.e., terrain) before immersing in it through VR. In addition, Soma mat [108] used heat stimuli to guide user attention to different parts of the body.

To conclude, the aforementioned studies have several drawbacks. First, regarding the "detection" mechanisms, most of the biofeedback and wearable devices have disruptive effects [30], which increase the user's burden and might thus interrupt the meditative state (i.e., an altered state of consciousness [123]). In addition, the user requires special access to these devices, which is not commonly available. Second, regarding "feedback" design, none of the earlier studies provide an overarching explanation or theory upon which their designs are grounded. Third, regarding "regulation" techniques, these approaches may not support self-regulation in different scenarios and environments. For example, it may be difficult to implement biofeedback methods such as EEG in kinetic meditation due to motion artifact in the bio-signal. Moreover, biofeedback methods may not support the required mobility in movement practices. Our study aims to mitigate this limitation by proposing an alternative method, without the use of any additional dedicated biofeedback devices.

2.3 Technology-Mediated Kinetic Meditation Approaches

A number of platforms have been proposed for kinetic meditation. Some of these platforms [33, 38, 78] were designed to imitate practices based on gross-motor movements that mimic an instructor. For example, an earlier study [78] used gesture recognition as a detection technique and provided multimodal feedback (audio, visual, tactile) to reduce the movement error in a virtual Tai Chi training system. Another study [33] developed an augmented reality Tai Chi trainer using a head-mounted display (HMD) and a drone to provide appropriate visual guidance using redundant augmented instructors from different angles. A recent study also [20] proposed drones as effective artifacts that can facilitate attention to bodily movements.

On the other hand, there is a paucity of studies [13, 127] that have focused only on walking meditation. Breathwalk-Aware [127] is a closed loop system that provides audio-visual feedback according to footsteps and breath patterns. The system helps users to reduce their gait speed and decrease irregular steps, which are essential for walking meditation.

Another approach borrows the physical forms of traditional meditation artifacts, such as Chinese meditation balls (e.g., Philips Mind Spheres concept) and Tibetan prayer wheels (e.g., Channel of Mindfulness [120]). Both use technology to sense the particular pattern of movement (i.e., fine-motor movement) required by the associated meditation artifact and they further augment them with meaningful digital experiences such as rewards when a user achieves the right movement pattern.

As is implied in Sections 2.2 and 2.3, although many promising approaches have been developed, additional "dedicated" monitoring and feedback accessories, which are difficult to access make the adoption of these methods, devices and benefits difficult to acquire. We therefore propose a framework that would enable the development of "widely" accessible mindfulness technologies that do not require the support of cumbersome difficult-to-access augmentations.

2.4 Mindfulness-Based Mobile Applications (MBMAs)

The increasing prevalence of smartphones has created a unique opportunity for MBMAs. Many MBMAs that were developed for static meditation (Headspace,[1] Buddhify,[2] Calm,[3] and Smiling Mind[4]) and kinetic meditation (e.g., Meditation Moves,[5] 7-Minute CHI,[6] Tai Chi Fundamentals,[7] Pocket Yoga[8]) are available in application stores. Most of these MBMAs used the guided meditation method that requires users to listen and/or watch instructions. Using static MBMAs, users usually close their eyes and listen to instructions that are narrated by an instructor (e.g., "*pause for a moment, just noticing the feeling of the body, the way the body pressing down against the seat beneath you*" [37]). A significant drawback for such static meditation MBMAs is that they require users to find a quiet spot so that the instructions can be heard comfortably [99, 121]. Any lack of expertise and personalized guidance is likely to prevent practitioners, especially novices, from following all instructions in a precise manner. That is, the fixed pace of audio instructions could prove to be too slow or too fast for certain users.

Similarly, in kinetic MBMA applications, users watch and imitate the movements of an instructor while listening to the instructions (e.g., "*raise your hands gently in front of your chest as if you were about to start playing the accordion*") [80]. However, guided meditation that is unidirectional in its approach to communication (i.e., no feedback) does not take into account the users' unique levels of expertise or mobility and it does not offer flexibility in preferences. For example, it may not work well for practitioners who generally function at a slower pace (e.g., novices) or for practitioners who cannot learn and explore complex techniques efficiently or perhaps at all.

Aside from the MBMAs currently on the market, few studies in academia have explored the design space of MBMAs. Mole and his colleagues developed MindfulBreather [63], an MBMA allowing users to self-regulate through breathing while users have to lie down, place the phone on their abdomen and breath slowly (i.e., detected by mobile gyroscope). Users must tap the screen at the right time during inhalation to receive relaxing audio feedback. Although this work proposed the detection, feedback, and regulation elements, the technique is difficult to perform for users as

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it requires users to practice only in the lying position, and it defies the mindfulness preference for single pointed attention.

2.5 Our Experience

We posited the notion that more efficient and productive mindfulness applications could be designed beyond guided meditation methods, i.e., toward a self-regulated meditation. We developed an initial version of a framework [91] along with an app called *PAUSE* supporting static meditation. The iterative design of *PAUSE* has been reported in our previous work [14]. We continued to explore whether our framework could be applied in a similar fashion to support kinetic meditation. We have explored different detection approaches, feedback mechanisms, and regulation techniques, which led us to develop another app called *SWAY*. In this article, we build upon our previous research and development, exemplifying possible feedback, detection, and regulation techniques that support both static and kinetic meditation and describe our understanding in the form of a framework. Both *PAUSE* and *SWAY* apps are commercially available.[9] Our framework presents a personalized approach where users can self-regulate and adapt according to their own capabilities and preferences. Importantly, our view is that users know what best suits them, as people differ vastly in their abilities and expertise.

3 ATTENTION REGULATION FRAMEWORK

We developed an overarching framework to support self-regulation in mindfulness practices. This framework is called *ARF* (see Figure 2(a)). *ARF* is a closed-loop attention regulation process, which incorporates detection-feedback-regulation mechanisms. By discussing the theoretical principles, we describe features of mindfulness and explain how to incorporate such features into interaction design.

3.1 Detection

ARF aims to address the challenge of detection without using dedicated accessories. This was a difficult problem to address, because without the use of bio-tools, it was difficult to imagine how we could detect user current states. In response, we found *Embodied Cognition* [109, 122] to be a useful theory in addressing this challenge. Theories of embodied cognition remind us that our mind and body are intertwined, i.e., the way we perceive the world is influenced by our body and our body is influence by the way we perceive the world. This implies that any change in our body posture or condition might alter the state of our mind. In particular, *bodily movements* are closely related to our attention and emotion. Regardless of the size (e.g., fine or gross) and complexity (e.g., simple or complex) [54] of the movement, bodily movement affects the interoceptive (i.e., organ-based), kinesthetic (i.e., movement-based), and proprioceptive (i.e., spatially-based) senses. The stimulation of these senses can act as immediate, continuous, integrated, and distinguishable feedback modes [16] that stimulate awareness [92] and support spontaneous self-regulation. Research has shown that *embodied* cognition, by heightening attention, facilitates self-regulation [4]. In eastern forms of meditation, there are many use-cases where embodied cognition is exploited: Buddhist prayer beads, Tibetan prayer wheels, Chinese meditation balls, and Tibetan singing bowls, all of which use simple tangible artifacts to direct and regulate attention via bodily movements.

Embodied cognition informs us that it is possible to detect user states through their bodily responses such as assessing user's fine-motor movements (e.g., finger, hand movements) or their gross-motor movements (e.g., arm, leg, torso movements). This approach is different from the physiological approach because, instead of detecting and reporting back user states via objective

[9] www.pauseable.com.

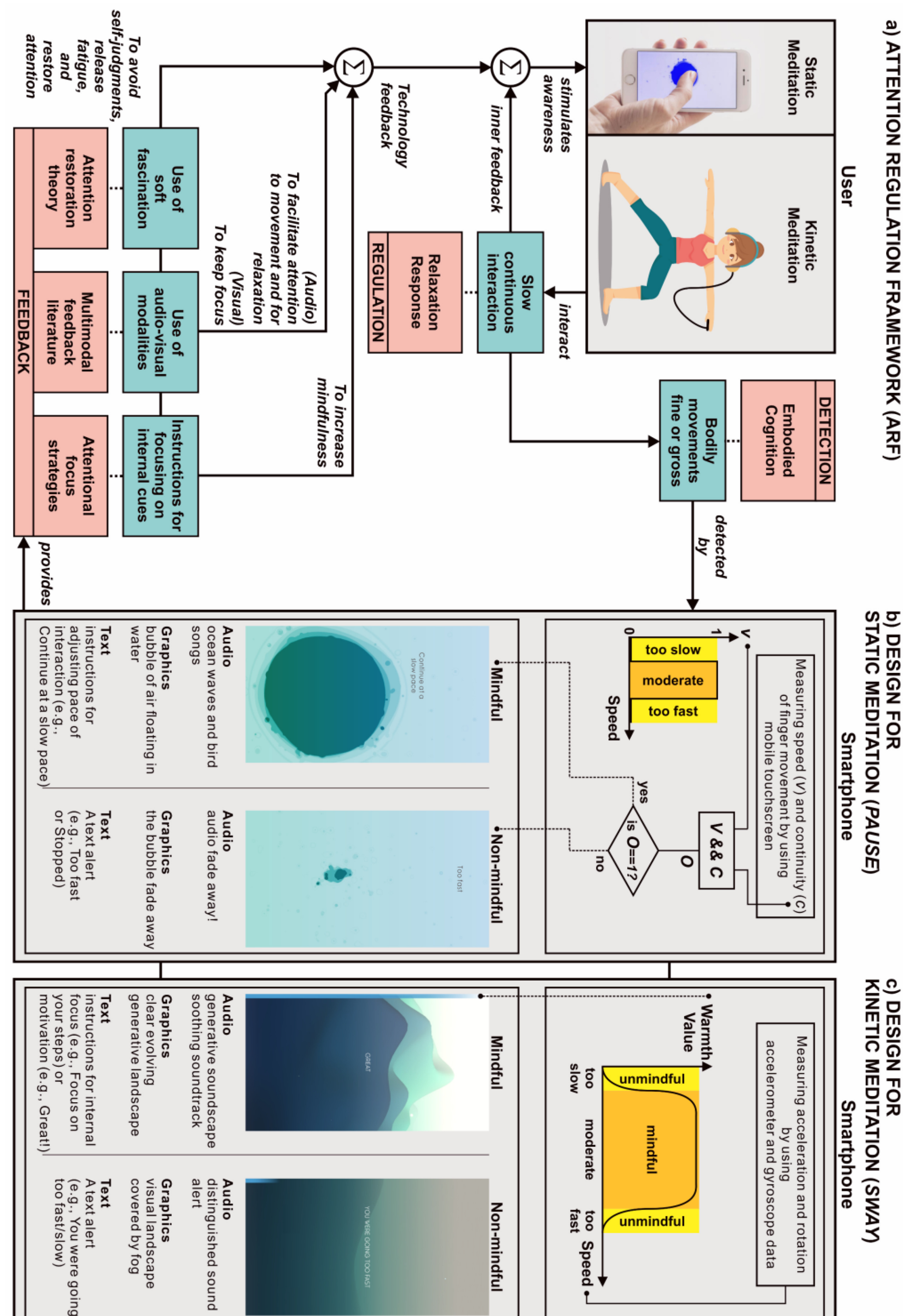

Fig. 2. (a) The *Attention Regulation Framework (ARF)*. (b) Design elements of *PAUSE* (static meditation). (c) Design elements of *SWAY* (kinetic meditation).

(external) physiological tools, embodied cognition means users can unobtrusively assess their own state via their own awareness of movements in their innate autonomic responses.

3.2 Feedback

Feedback is another important component of self-regulated mindfulness practice, where the goal of feedback is to prompt users to bring their attention back to the task in the present moment. The challenge lies in the constraints where the feedback design should not induce any judgmental thoughts (i.e., evaluating the experience as a right or wrong), cause any heightened emotional changes (e.g., becoming frustrated or sad) [2, 42], or further divert the attention (i.e., to the characteristics of the prompt). In this part, we address the challenge of feedback design. In addition, we review the literature in multimodal feedback and attentional feedback strategies to enrich our framework.

3.2.1 Soft Fascinations. Attention Restoration Theory [44] is an environmental psychology theory, which suggests that spending time with soft fascinations helps release mental fatigue and restore attention. A good example of soft fascination is gazing at nature or a beautiful landscape [6, 43] or listening to birdsong or the sound of a waterfall [1, 84]. Engaging with a soft fascination is an effortless activity so that it can lead to recovery from mental fatigue. However, the challenging part is to design effective soft stimuli in feedback design that avoid judgments during the practice. Use of tired cognitive patterns in design (e.g., a familiar sound, a known picture, or a light bar in the feedback) might entice the user into making judgments.

ARF suggests using soft-cognitive stimuli (i.e., pacifier) that are free of tired-cognitive patterns. Using appropriate soft stimuli in design will help the user to self-regulate attention without inviting positive or negative judgments.

3.2.2 Feedback Modality. A recent exploratory evaluation of the human senses suggested that in the static meditation, the hearing sense is effective in inducing relaxation, the visual and touch senses invoke better focus [62]. The study recommended the integration of those senses for different user states in order to achieve better user experiences. Findings of the Breathwalk-Aware study [127] demonstrated that using audio-visual feedback is more effective to improve walking regularity (footsteps, gait) than using only visual or only audio. On the other hand, few designs applied haptic feedback in mindfulness applications. In one exception, researchers developed atmoSphere [112], a haptic sphere ball that combined audio and haptic feedback based on the user's breathing rhythm. Another work [7] used vibration in mobile phones to guide user attention to a predefined breathing rhythm (i.e., inhalation and exhalation). However, there is not enough evidence regarding the efficacy of haptic feedback for self-regulation and mindfulness practice. Furthermore, earlier studies [7, 112] used haptics as a regulation technique and not as a feedback mechanism.

There is also a wealth of studies on rehabilitation [36, 89, 119] and sports training [47, 96, 107] demonstrating the use of multimodal feedback to facilitate attention to movement. Notably, most of the literature recommended the use of audio feedback. For example, in physiotherapy [119], audio feedback of motion including music and speech, could increase body movement awareness. In the sport of rowing [96], sonification (i.e., perceptualizing each motion and transferring it to users in the form of sound) improved the motor performance of the rowers and increased the boat's speed. More recent studies [103, 104, 113] have utilized the latest wearable technology and demonstrated the effectiveness of audio feedback on the participant's sense of control in daily movements [103] also changing the user's emotional valence, perceived sense of body weight and gait patterns when walking [113]. Besides, there is evidence showing the beneficial effects of haptic feedback and tangible interactions on leveraging motor performance including higher precision and learning, receptivity [52, 65]. Although the methodologies mentioned did not focus on mindfulness per se, they can guide our framework for better feedback design.

To conclude, *ARF* informs designers to select multimodal feedback. Audio feedback may be implemented in the form of soothing music, verbal instructions, or alerts. In addition, visual feedback such as graphics and text instructions can help users to be aware of their movement or simply keep them motivated for sustained practice. Last, haptic feedback can provide complementary support to guide user movements [97]. Nevertheless, designers have to be cautious about using haptic feedback as it may interrupt the user's mindfulness experience. Furthermore, the design of promising haptic feedback usually requires dedicated accessories, which is contrary to the ideals of our two design cases. Consequently, our two design cases use a combination of audio and visual feedback as soft-cognitive stimuli.

3.2.3 Instructions. To support the self-regulation of bodily movements, it is necessary to provide clear instructions. To better understand the effect of instructions in motor activities we refer to *Attentional Focus Strategies.* Attentional focus strategies are concerned with the relationship between movement and attention. Regarding the direction of attention when involved in movement, the focus of attention has been categorized into internal focus and external focus [64, 70]. Internal focus means *paying attention to inner, vestibular, and proprioceptive cues*, while the external focus means *paying attention to environmental cues.* Meditation experts usually have a higher levels of internal focus compared to external focus [26]. It is also known that in motor performance, focusing attention on the quality of movement (e.g., techniques) and the body (e.g., the position of the body) enhances the mindfulness experience [75].

ARF informs that focusing on body movement and other internally oriented cues (e.g., breath) can help users foster mindfulness. Designing appropriate instruction in the form of verbal or textual feedback could guide users to focus internally in order to achieve a mindful state. This principle is reflected in our two design cases where instructions are internally oriented, asking users to pay attention to the quality of their movements, rather than external objects/mediums.

3.3 Regulation Techniques

Here, we ask what kinds of interaction techniques could be applied to mindfulness practice. To answer this, we refer to the *Relaxation Response* principle [5]. "*Relaxation Response is a physical state of deep rest ... and the opposite of the fight or flight response*" [5]. According to the relaxation response principle, repeating an action at a slow pace helps practitioners release chemicals and brain signals to make the body relax and the emotions to settle. The slow pace of the relaxation response requires practitioners to pay attention to the present moment by disregarding daily thoughts. The relaxation response can be elicited through the slow repetition of a word, a sound, breathing, or a *movement.*

As mentioned in Section 3.1, bodily movements generate interoceptive, kinesthetic, and proprioceptive senses. Remarkably, moving the body at a *slow* pace heightens those senses and requires the user to pay attention to body movement in the present moment [92]. This reflects the common properties of Tai Chi, Yoga, Qigong, and Walking Meditation that are based on slow, continuous and gentle movements.

In light of the above, *ARF* informs designers regarding the beneficial exploitation of awareness of qualities of movement including pace and endurance in traditional practices. Slowness (pace) and endurance can easily be measured. For example, mobile applications can detect speed and the position of finger movements on a mobile touchscreen; they can also measure both the linear and angular speed and acceleration of mobile phone movements. In particular, for kinetic meditation, by detecting generic, slow, continuous body movement, instead of measuring complex movement patterns, technology can facilitate the accessible mindfulness practice for users.

To conclude, slow, continuous bodily movement can be a suitable interaction technique by serving as a mindfulness regulation medium. Slow movements are also well suited to the design of detection (i.e., is quite feasible for technology to detect the pace of movement) and feedback elements (i.e., soft-cognitive stimuli matches well with slow, gentle movement in terms of aesthetic design).

4 DESIGN GOALS

Our design goals are driven by the *ARF* to support self-regulation in mindfulness practices. We define our design goals regarding *detection, feedback*, and *regulation* in the following points: (1) To develop subtle movement detection mechanisms without using extra sensors and accessories and through exploiting fine-motor movement in static meditation and gross motor-movement in kinetic meditation conditions. (2) To use soft stimulus elements in feedback design to support attention-regulation without interrupting the user's non-judgmental awareness. To use audio-visual modalities to facilitate attention to movement while maintaining the user's focus. To use internally oriented instructions to foster mindfulness and body awareness. (3) To design slow, continuous, gentle movements as the regulation medium.

The following two sections describe how our two design cases can achieve these design goals in static meditation (Figure 2(b)) and kinetic meditation (Figure 2(c)) conditions.

5 DESIGN CASE 1: STATIC MEDITATION

5.1 *PAUSE*—Static Mobile Application

Here, we explain our design mechanisms for static meditation. We applied what we learned from *ARF* to our design approach including the interaction mechanism, the pace of interaction, audio feedback, and visual feedback (Figure 2(b)). *PAUSE* exploits embodied cognition and relaxation response theories to enable portable and easy to access spontaneous self-regulated mindfulness practice. It adopts repetitive, slow touch movements as the mode of interaction. According to the literature on multimodal feedback, audio and visual modalities have been chosen as feedback elements. Following the attention restoration theory that states that people can restore their attention by spending time with soft cognitive stimuli, *PAUSE* deploys ambient audio-visual elements that act as a feedback mechanism to stimulate the user's meta-awareness.

We chose touch interaction where the speed and continuity of finger movement can be precisely detected by the mobile touchscreen itself. *PAUSE* asks the user to slowly move one finger on the screen (Figure 3(a)). To move the finger slowly, continuously, and repeatedly, sustained attention is required. We also designed soft audio-visual cognitive stimuli. We used the amorphous image of a bubble of air floating in water combined with randomly displayed gradients and variations of motion that provide a feeling of something organic, random, minimalistic, and airy and promote effortless reflection. We used the sound of ocean waves and bird songs with a sweeping sound around one chord. This provides an un-intrusive repeating and soothing loop that allows the practitioner to focus within the required parameters of the slow repetitive finger movement. To adjust the pace of the interaction, we used text guidance to train users in the use of the slow mindful movement interaction. A visual circular guide was used at the beginning to train the user in the repetitive movement pattern.

The whole interaction cycle can be described as follows: the phone generates sound and audio feedback only when it detects slow, continuous, and repetitive finger movements (Figure 3(b)). The sound is the mechanism in the feedback loop that effectively calms the mind. Interaction with the visual element acts as an anchor to engage the mind. If the finger moves too fast, or

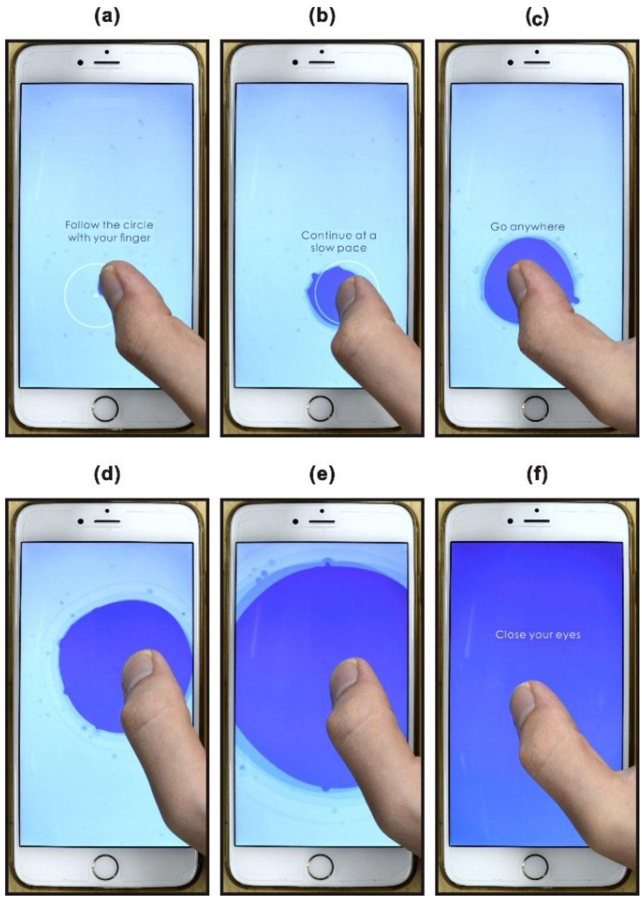

Fig. 3. Interaction steps in the static design case (*PAUSE*): (a) The user starts to follow the white circle with the finger on the screen. The audio is playing. (b) An amorphous floating air-bubble appears. *PAUSE* prompts the user to move the finger slowly. (c) The user freely moves the finger over the whole screen repetitively, continuously, and slowly. (d) *PAUSE* continually generates feedback while there is slow, continuous, and repetitive finger movement. The bubble gets bigger over time. The audio continues. (e) The bubbles size increases and requires the user to continue moving the finger and at a slow but steady pace. If movement is not sustained within these parameters, the bubble will fade away to remind the user to return to and maintain the necessary attention. If the attention is lost, the user needs to repeat the process from step b to return to a properly attended interaction. (f) Eventually, the bubble covers the whole screen, and *PAUSE* asks the user to close the eyes and to continue with the slow finger movement. Users should keep moving mindfully in a slow and repetitive manner. Otherwise, the feedback will fade out to thus prompting the user to bring the attention back.

stops, or is lifted from the screen, the amorphous audio-visual feedback fades away immediately to inform the user that they have not maintained steady, deliberate movement. The moment the user returns to attention within the required movement parameters, the interaction elements fade back in. Visual feedback gradually transitions to a sound-only experience (Figure 3(f)), when people close their eyes. By confining the interaction to strict parameters, sustained mindful attendance is encouraged.

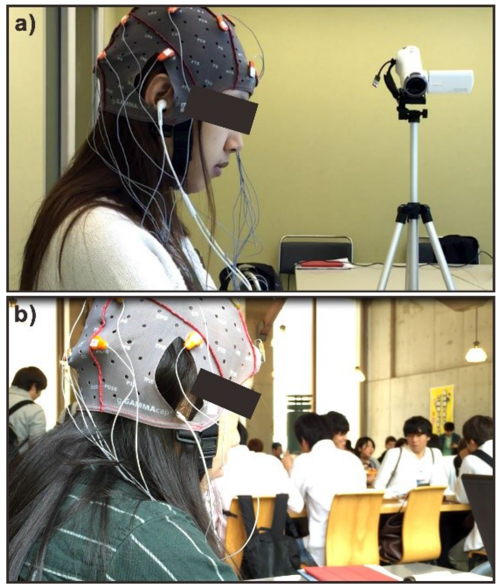

Fig. 4. Experiment setup for Study1: (a) A participant meditating in a room (calm environment), (b) university cafeteria (busy environment).

5.2 Study 1: Environmental Study

Study 1 evaluates state effects to investigate how well our static design case can perform compared with an existing mobile application in different environmental settings. For comparison, we selected *Headspace* that uses the traditional guided meditation method.[10] Since *ARF* emphasizes attention regulation, we wanted to determine whether *PAUSE* can outperform *Headspace* in busy environments (i.e., noisy). We also compared the performance of *PAUSE* with *Headspace* in calm environments (i.e., no noise).

5.2.1 Methodology. Experimental design. The experiment was conducted in a within-subjects design with two independent variables. The *App* variable was a within-subjects comparison of *PAUSE* and *Headspace*. The *Environment* variable was within-subjects, asking the participants to use the mobile application in both Calm and Busy environments (hereafter referred to as "Calm" and "Busy").

Participants. Eleven individuals (3 females) participated (age: M = 28.2, SD = 3.1, range = 22–35). One participant was left-handed. Only one participant reported doing weekly meditation. None suffered from any cardiovascular or brain diseases. The nationality of participants was as follows: Chinese (n = 5), Bangladeshi (n = 1), Estonian (n = 1), Indonesian (n = 1), Polish (n = 1), Russian (n = 1), Thai (n = 1). Participants were compensated with $10.

Task and procedure. Participants were asked to sign a letter of consent. Background information including daily stress levels and meditation experience was gathered. Participants were introduced to both apps where they were allowed to try each app 5 minutes. Participants were then trained in a total of four conditions including *PAUSE*-Calm, *PAUSE*-Busy, *Headspace*-Calm, *Headspace*-Busy (Figure 4). Conditions were counterbalanced using a Latin square. The whole experiment was

[10] *Headspace* is one of the most downloaded Apps with around 11 million downloads and 400,000 paying subscribers in the last 5 years [12].

done in 4 days; each condition was tested in one day and the trials included four 10-minute blocks with 5 minutes breaks between them. The Calm condition was trialed in a quiet room with 28.7–36.5 decibel (dB) range (see Figure 4(a)). The Busy condition was trialed in the university cafeteria during lunchtime with background noise ranging from 52.5 to 75.1dB (see Figure 4(b)).

A HR sensor was mounted on the participant's chest using a strap band. Before training, the electrode area of the strap band was moistened, and signal quality was checked using the Polar Beat app. Participants sat on a normal chair and wore an EEG cap. The participant's body was grounded through an anti-static wristband. For training with *PAUSE*, participants were provided with soft towels under their arms to prevent pressure points and fatigue while holding the phones in their hands. To eliminate EEG artifacts, participants were instructed to hold the phone with the non-dominant hand and perform the touch interaction with the thumb of the dominant hand. They were also asked to close their eyes after 1 minute and avoid any movement in the arms, legs, and neck. When training with *Headspace*, participants put the phone on the table after starting the training in guided meditation. They were also instructed to close their eyes and avoid body movements while training. Participants used a set of headphones, the volume of which was set at 80%. After the fourth day of trials, a semi-structured interview was conducted. The whole experiment was video recorded. See Supplementary material 1 for further information.

Measures. Mindfulness practice can impact users' autonomic nervous system [116] that unconsciously regulates bodily functions. We monitored the performance of *PAUSE* and *Headspace* by measuring physiological and electrophysiological metrics. The previous work reported the effect of relaxation on HR, breathing rate, skin conductance, and EEG [116]. We also used qualitative metrics for a better understanding of user experience during mindfulness practice. We used the following evaluation methods for our study.

Heart rate: An earlier study [128] showed that a brief mindfulness meditation session can reduce the HR, which is counted in beats per minute (bpm). To measure the HR of participants, a HR sensor was used. The signal was recorded at 1Hz sampling frequency. Mean HR and HR range were extracted for analysis. HR range is calculated to be the difference between the minimum and maximum HRs during practice. A decrease in mean HR and an increase in HR range correspond to better relaxation [128].

EEG: Spectral analysis of the EEG signal using Fast Fourier Transform (FFT) is correlated with the mindfulness state [8]. The power of the signal (μVolt^2) is usually studied in five main frequency bands: delta (0.5–4Hz), theta (4–7Hz), alpha (8–13Hz), beta (13–30Hz), and gamma (30–45Hz). Among the frequency bands, theta and alpha are correlated with the mindfulness state [94]. An increase in theta band activity is associated with meditative concentration, while an increase in alpha band activity indicates relaxation. The previous work [114] also studied low alpha (8–10Hz) and high alpha (11–13Hz) band activities, showing an increase in the theta and low alpha bands during Zen meditation. A review of over 60 papers [8] discussing EEG profiles in the state of meditation with Yoga, Zen, Qigong, and Yogic meditation demonstrated that regardless of the various aims of these practices, they produced similar patterns such as an increase in theta and/or alpha powers. However, Tibetan Buddhist meditation that focuses on compassion shows an increase in high-frequency gamma power.

We used a 16-channel dry electrode EEG cap to measure the electrical activity of the brain. Each electrode has 8 pins made of a special gold alloy. The pins are long enough to easily make contact with cranial skin. The use of g.SAHARA dry EEG electrodes for research had already been validated by an earlier work [32]. Recorded channels were selected among the international 10–20 set of electrode positions with a linked-ears montage. However, we only chose five channels (Fp1, Fp2, F3, Fz, F4) that are close to the anterior cingulate cortex (ACC) and prefrontal cortex (PFC) areas, the most active areas of the brain during mindfulness meditation [115]. EEG signals were

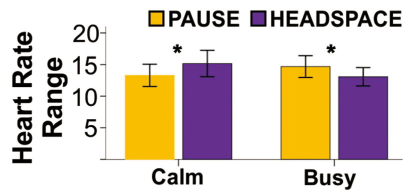

Fig. 5. Heart rate range in beats per minute (bpm). The error bars indicate ±SE (standard error).

amplified and digitized through the amplifier. Signals were recorded at 256Hz sampling frequency and filtered using a 0.1 to 100Hz bandpass filter. EEG signals were preprocessed before analysis. Signals were passed through a 60Hz notch filter and a 1–30Hz Butterworth (12dB/Octave) bandpass filter. Later EEG artifacts were removed manually, and detailed artifacts were eliminated using independent component analysis (ICA). After preprocessing, FFT was applied to the EEG signal in order to extract the power of the signal in the frequency domain. Averaged theta and low alpha band activities for the five mentioned channels were then analyzed.

Interview: Semi-structured interviews were used asking questions about the users' mindfulness experiences when using *PAUSE* and *Headspace* in the Calm and Busy. We used a simple open coding process where we created labels based on meaning to analyze the interviews.

5.2.2 Results and Discussion. For parametric evaluation, data were checked using the Kolmogorov–Smirnov test and homogeneity of variance was tested using Levene's test. We analyzed the relaxation effect by comparing *App* and *Environment* using repeated measures analysis of variance (ANOVA). Significance was set at $\alpha = 0.05$. SPSS was used to perform the analysis. However, EEG data did not pass the parametric evaluation test. Thus, Wilcoxon Signed-Rank tests were used for nonparametric analysis.

Heart rate. There is an interaction effect in *App* × *Environment* ($F_{1,43} = 5.87$, $p < 0.05$, $\eta^2 = 0.12$) on HR range (Figure 5). In the Calm, simple main effect analysis revealed that HR range for *Headspace* (M = 15.15, SD = 6.94) is significantly ($p < 0.05$) higher than for *PAUSE* (M = 13.29, SD = 5.83). Moreover, HR range for *Headspace* in the Calm is significantly ($p < 0.05$) higher than in the Busy (M = 13.06, SD = 4.83). We did not find any effect on mean HR. The results revealed that participants successfully reduced their HR in the Busy using *PAUSE* rather than *Headspace*. On the other hand, *Headspace* shows better performance than *PAUSE* in the Calm condition. The results may be grounded in our framework design. Our results suggest that *PAUSE* is particularly effective in the Busy as the framework emphasizes attention regulation and thus trains users to remain focused in the midst of everyday distractions.

EEG. Figure 6(a) summarizes theta band activity results. Statistical analysis of theta band activity showed a higher power ($Z = -2.84$, $p < 0.01$) for *PAUSE* in the Busy (M = 20.45, SD = 2.51) than *Headspace* in the Busy (M = 14.92, SD = 3.69). Surprisingly, the power for *PAUSE* in Busy is higher than ($Z = -2.93$, $p < 0.01$) for *PAUSE* in Calm (M = 15.68, SD = 3.02). These results show that in the Busy, deeper mindfulness might be achieved using *PAUSE* compared with *Headspace*. Additionally, the results show that *PAUSE* might work effectively (delivering deeper mindfulness) in the Busy compared with the Calm. Figure 6(b) summarizes low alpha band activity results. The analysis showed higher low alpha-band activity in the Busy ($Z = -2.67$, $p < 0.01$) for *PAUSE* (M = 28.57, SD = 13.16) than for *Headspace* (M = 18.75, SD = 6.42). Low alpha band activity analysis revealed that participants experienced more relaxation using *PAUSE* in the Busy.

We found consistent results between EEG and HR indicating that *PAUSE* helps users achieve deeper mindfulness and better relaxation than *Headspace* in the Busy condition. On the other hand, in the Calm condition, *Headspace* was as effective as *PAUSE*. As discussed for HR, *ARF* leads

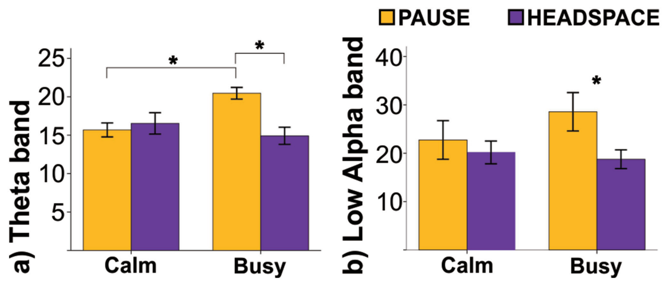

Fig. 6. (a) EEG Theta band (4–7 Hz), (b) EEG Low alpha band (8–10 Hz) for *PAUSE*, and *Headspace* in the Calm and Busy environments. The error bars indicate ±SE.

users to ignore distractions in the Busy condition, and also to experience deeper mindfulness and better relaxation in the Busy. On the other hand, earlier studies [72, 125] showed that spectral analysis of EEG signals during finger movement affects the delta, alpha, and beta band activities. However, the consistency of our results between EEG, HR, and interviews confirms the validity of our findings.

Interview. For a better understanding of user experience after training with *PAUSE* and *Headspace* in the Calm and Busy, we conducted semi-structured interviews.

Notably, most of the participants (9/11) agreed that mindfulness practice using *Headspace* in the Busy is difficult. [P9]: "*I do not prefer to meditate in the public place. I could not concentrate at all on the instructions.*" We learned that most of the participants (8/11) preferred to use *PAUSE* while meditating in the Busy. [P1]: "*The instructions of Headspace need high concentration, which I did not have due to many distractions in the cafeteria. Moving my finger slowly and repeatedly helps me to be conscious of my mind and body and ignore distractions.*" [P10]: "*Gentle touching of the screen makes me feel that I release some pressure. When noise is too much I try to focus more on the bubble, music, and my finger to keep my mental state.*"

Four participants talked about the effect of continuous feedback. [P7]: "*Continuous audio-visual feedback from PAUSE helped me ignore distractions in the public place. This is in contrast to Headspace which sometimes suddenly stopped after talking for a long period of time.*" Six participants talked about the difficulty of following Headspace (due to the pace of the interaction). [P1]: "*When I started training with Headspace, I could not catch the process very well. After several uses, now I can follow it. But still when the environment is noisy and once the monk stopped talking, my mind wandered off.*"

On the other hand, by observing participants in the experiment, we found a unique difference in *PAUSE* over guided meditation, i.e., given its interactivity, *PAUSE* is preferred by users (8/11) who are more easily distracted, or less motivated to meditate. By contrast, participants with higher motivation (3/11) prefer to use *Headspace* regardless of the environment because they have adequate motivation and knowledge to follow instructions. For example, a participant [P3] said: "*Headspace helps me meditate similar to what I did before without a phone. I think Headspace is good enough. Cafeteria noise cannot disturb my meditation.*"

5.2.3 Summary. In summary, the findings of Study 1 show that (i) *ARF* and the static design case can be particularly useful in the busy environments. This is an interesting result as it suggests that our framework is robust against noises and distractions, which are barriers to meditation. (ii) Our approach may be particularly beneficial for a specific group of users, i.e., people with less focus or confidence.

5.3 Study 2: Intervention Study (I)

To understand how *PAUSE* performs against an existing mobile application in the long-term (trait effects), we conducted Study 2. We selected *Headspace* that had already been investigated in a qualitative way [50] for long-term use, showing that *Headspace* can lead participants into improved emotional and mood states.

5.3.1 Methodology. Experimental design. The experiment was conducted in a mixed design with two independent variables. The *App* was between-subjects, comparing two apps: *PAUSE* and *Headspace*. The *Training* was within-subjects, comparing pre-test with post-test states. We selected 5 days of training because earlier studies [56, 117, 127, 128] showed that as little as three to 5 days of training can significantly enhance attention and mood regulation.

Participants. Eighteen university students and staff members (8 females) were recruited (age: M = 27, SD = 4.3, range = 20−34). All were right handed. Only one of the participants had received routine mindfulness training before. None of them had used mobile applications for meditation before. The nationality of participants was as follows: Chinese (n = 8), Egyptian (n = 2), Indonesian (n = 2), Iranian (n = 2), Bangladeshi (n = 1), Burmese (n = 1), Indian (n = 1), Thai (n = 1). Each participant was paid $10.

Task and procedure. Similar preparatory steps were conducted as in the previous study. Participants were randomly assigned to either *PAUSE* (5 males and 4 females) or *Headspace* (5 males and 4 females) groups. Participants were instructed in the use of mobile applications. One day before training, both groups were given an Attentional Network Test (ANT). The ANT took 20 minutes, and the display was located 65cm away from participants. Afterward, participants were asked to complete three questionnaires to rate their general well-being, mood, and happiness. The three questionnaires took about 45 minutes to complete. On the following day, participants trained using the mobile application in two sessions. Each session consisted of 10 minutes of training with a five-minute break between sessions. The mindfulness practice was repeated over 5 days. All participants used headphones for training. At the end of the fifth day of training, participants were given another ANT, which was followed by the same three questionnaires. The whole experiment was video-recorded for later analysis. Check Supplementary material 1 for details.

Measures. As mentioned, traditional mindfulness practices improve attention [117], mood [100], and well-being [71]. Therefore, we measured the trait effects of mindfulness practice using the following methods.

Attention: An earlier work [117] showed that directed attention significantly improved after long-term meditation. Given that the directed attention is a common source for self-regulation and executive functioning [45], we used ANT [25]. ANT measures three attentional networks [79]: executive (i.e., resolving conflicts among response), alerting (i.e., maintaining an alert state), and orienting (i.e., information selection from sensory inputs). ANT included 4 blocks and 312 trials. Mean accuracy, mean response time, alerting, orienting, and conflict effects were measured. For details about ANT see [25].

Mood: A 65-item *Profile of Mood State* (POMS) [22] was used to evaluate changes in mood. Participants rated mood on a 5-point Likert-scale from 0 (not at all) to 4 (extremely). POMS factor analysis provides six different factors: *anger-hostility, confusion-bewilderment, depression-dejection, fatigue-inertia, tension-anxiety*, and *vigor-activity*. The first five factors are scored negatively (i.e., a lower score indicates higher emotion) while the *vigor-activity* factor is scored positively (i.e., a higher score indicates greater vigor). *Total mood disturbance* has been calculated by adding the five negatively scored factors minus the positively scored factor. POMS is a well-established metric to assess mood. Several studies used POMS. For example, studying the effect of an 8-week

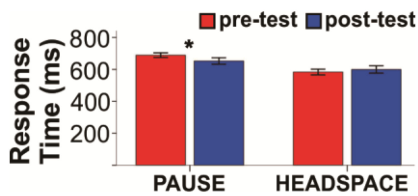

Fig. 7. Response time in millisecond (ms). The figure shows a significant reduction in response time after 5 days of training with *PAUSE*. The error bars indicate ±SE.

Mindfulness-based Stress Reduction program on cancer patients [29] showed a correlation between an increase in mindfulness and decreased stress and negative moods.

Well-being: General Well-being was measured using a 22-item *Psychological General Well-being* (PGWB) index [23]. The PGWB index asked for ratings on a 6-point Likert-scale from 0 to 5. PGWBI is a well-known inventory, which was used in earlier work [15] to evaluate the effect of an 8-week Mindfulness-based Cognitive Therapy program on the well-being of patients with a major depression problem.

Happiness: The 4-item *Subjective Happiness Scale* (SHS) [68] was used to measure happiness. SHS questionnaire was rated on a 7-point Likert-scale from 1 to 7. Earlier studies measured happiness [68] as an indication of emotional well-being.

5.3.2 Results and Discussion. The same analysis method with Study 1 was used. We analyzed training effects by comparing *Training* and *App* using repeated measures ANOVA. To check the internal consistency of the questionnaires, Cronbach's-α was used. Cronbach's-α are 0.88, 0.93, and 0.81 for POMS, PGWBI, and SHS, respectively.

Attention. Results are shown in Figure 7. We found an interaction effect in *Training* × *App* ($F_{1,16}$ = 5.48, p < 0.05, η^2 = 0.26) on *response time*. Simple main effects analysis showed a significant difference (p < 0.05) in the *PAUSE* group between the pre-test (M = 689.1, SD = 44.3) and post-test (M = 652.6, SD = 60.7), but no significant difference for the *Headspace* group. The results indicate that 5 days of training improved response times with *PAUSE*, but not with *Headspace*. It is worth mentioning that before training, participants in the *Headspace* group had a lower response time compared with the *PAUSE* group. Given that random assignment is the fairest approach for the comparison studies, we did not manipulate the random assignment at the beginning of the experiment.

There are also main effects for *Training* on *conflict effect* for all responses ($F_{1,16}$ = 5.22, p < 0.05, η^2 = 0.25) and on *conflict effect* for only correct responses ($F_{1,16}$ = 10.80, p < 0.005, η^2 = 0.40). There is a significant difference between the pre-test (M = 104.1, SD = 23.6), and the post-test (M = 89.2, SD = 20.3) in both groups for the *conflict effect* of all responses. Similarly, for the *conflict effect* of correct responses, post-test (M = 89.0, SD = 20.2) significantly improved compared to the pre-test (M = 108.3, SD = 21.2) in both groups. However, there was no difference in improvement between *PAUSE* and *Headspace* groups. In other words, both apps helped participants to improve their directed attention. There are no significant effects on accuracy, alerting effect or orienting effect. In general, our results show that after 5 days of training, directed attention improved in both *App* groups. Additionally, *PAUSE* reduced response times while *Headspace* did not. The results indicate that consistent training with *PAUSE* leads to greater improvement in attentional skills.

Mood. Results are summarized in Figure 8. There are main effects in *Training* on *total mood disturbance* ($F_{1,16}$ = 13.97, p < 0.01, η^2 = 0.47), *confusion-bewilderment* ($F_{1,16}$ = 5.44, p < 0.05, η^2 = 0.25), *depression-dejection* ($F_{1,16}$ = 7.45, p < 0.05, η^2 = 0.32), *fatigue-inertia* ($F_{1,16}$ = 14.68,

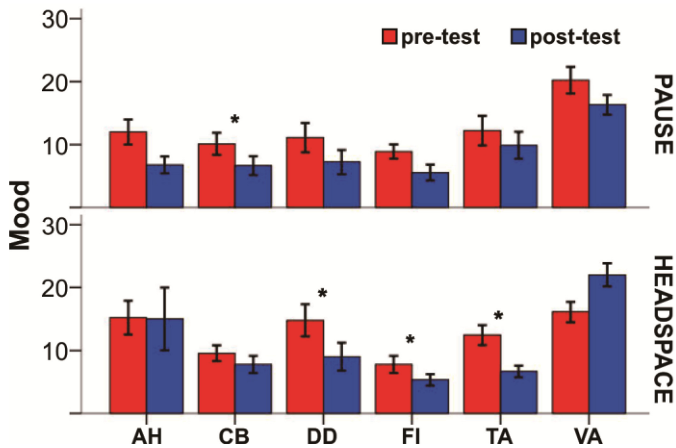

Fig. 8. Intervention effect on mood. Using *PAUSE* helped participants reduce the *confusion-bewilderment* scale while *Headspace* reduced *depression-dejection, fatigue-inertia*, and *tension-anxiety*. The error bars indicate ±SE. List of the acronyms: anger-hostility (AH), confusion-bewilderment (CB), depression-dejection (DD), fatigue-inertia (FI), tension-anxiety (TA), and vigor-activity (VA).

$p < 0.001$, $\eta^2 = 0.48$), and *tension-anxiety* ($F_{1,16} = 11.18$, $p < 0.01$, $\eta^2 = 0.41$). However, there is no effect on *anger-hostility*, or *vigor-activity*. Simple main effect analyses indicate that both apps improve the self-regulation of emotions ($p < 0.05$). In addition, main effect analysis on the *PAUSE* group shows non-significant reduction on *depression-dejection* ($p = 0.14$), *fatigue-inertia* ($p = 0.054$), and *tension-anxiety* ($p = 0.19$). Similarly, *confusion-bewilderment* reduction in the *Headspace* group is not significant ($p = 0.16$). There is no effect in *App* and *Training* × *App*.

Results showed that although *PAUSE* had a greater effect on attention, *Headspace* performed better in the regulation of emotion. *Headspace* was more effective in the treatment of depression, anxiety, and fatigue subscales. The results may have stemmed from the guided meditation technique. In the *Headspace* design, a monk directly gives instructions to practitioners, on attitudes that may convey humane aspects in an effective way, e.g., relaxation and kindness. This may help practitioners reduce negative emotions.

Well-being. There is a main effect in *Training* on *General Well-being* ($F_{1,16} = 29.45$, $p < 0.001$, $\eta^2 = 0.65$). Participants reported higher post-test well-being ($M = 3.72$, $SD = 0.71$) than pre-test well-being ($M = 3.32$, $SD = 0.68$). There is no effect in *App* and *Training* × *App*. The results indicate that *PAUSE* is as effective as *Headspace* for improving well-being. Our findings revealed that similar to traditional mindfulness practices [71, 76], mindfulness training using mobile applications can increase user well-being.

Happiness. There is a main effect in *Training* on *Happiness* ($F_{1,16} = 4.45$, $p < 0.05$, $\eta^2 = 0.22$). Post-test happiness ($M = 4.67$, $SD = 0.82$) is higher than pre-test happiness ($M = 4.31$, $SD = 0.75$). However, a simple main effect analysis of each *App* revealed that while happiness significantly increased after using *Headspace* ($p < 0.05$), *PAUSE* was not significantly effective. We did not find any effect in *App* and *Training* × *App*. The results are consistent with our findings for depression and anxiety subscales of mood. Our results showed that training with *Headspace* can improve happiness.

5.3.3 Summary. In sum, we found that *ARF* and the static design case can effectively improve attention, mood (confusion scale), and well-being even after a short-term intervention.

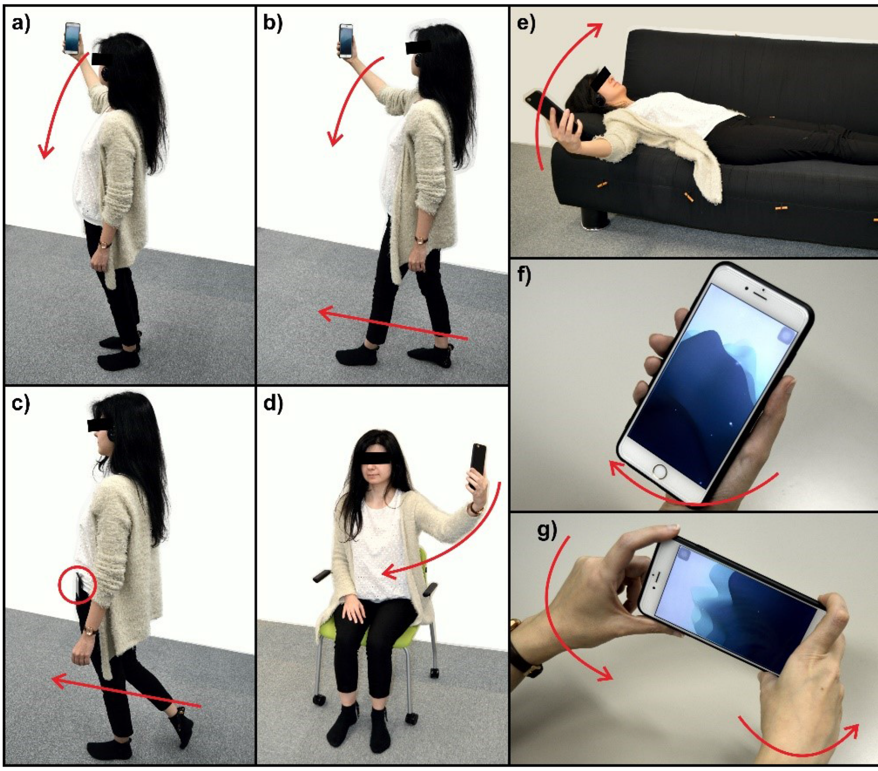

Fig. 9. Participant movement patterns in the kinetic design case. (a) Moving the arm in standing position, (b) moving the arm while walking, (c) walking with eyes closed while the phone is in the pocket, (d) sitting and moving the arm, (e) lying down and moving the arm, (f) sitting and rotating the wrist with eyes open, (g) sitting and rotating both wrists with eyes open.

6 DESIGN CASE 2: KINETIC MEDITATION

6.1 *SWAY* – Kinetic Mobile Application

Practitioners of movement meditation pay mindful attention to slow regular movements over a period of time. *SWAY*'s detection mechanism is designed to monitor the pace and regularity of the practitioner's movements and to prompt them when movements become irregular or discontinuous (Figure 2(c)). This is achieved by determining the average accelerometer and gyroscopic input over a given period of practice time and checking to see if those values are within given bounds for maximum mindfulness effect. It is only when the movements (e.g., rotation and acceleration) are within the given bounds that the practice can be considered as mindful movement. The upper and lower bounds were set through an iterative process in pilot studies.

We propose the notion of *warmth value* (i.e., a visual sidebar that is constructed after mindful movement is detected, see Figure 2(c)). Mindful movement increases the warmth value while non-mindful movement decreases it. The *warmth value* in *SWAY* prompts the user to maintain or return to the mindful state by distinguishing intended mindful movements from other "accidental" slow movements that often last only a very short time. This approach allows *SWAY* to detect any mindful movements regardless of the movement pattern from tiny wrist movements (Figure 9(f) and (g)) to larger arm movements (Figure 9(a), (b), and (d)). *SWAY* can also be carried in the user's pocket

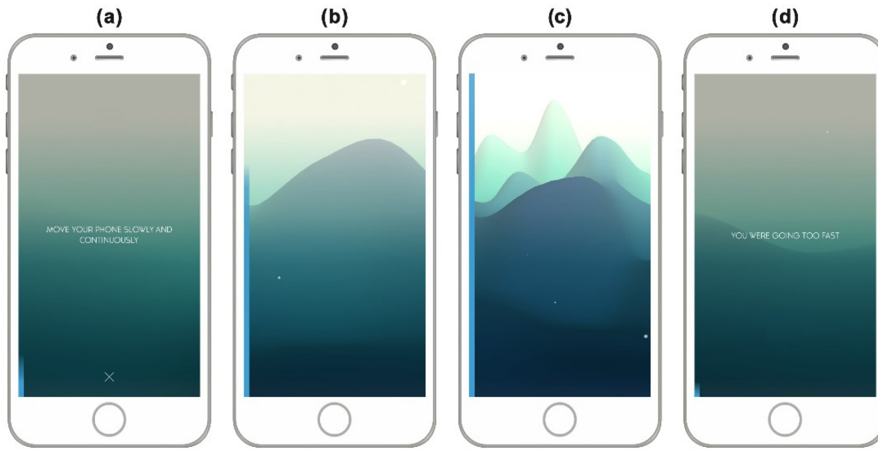

Fig. 10. Interaction steps for the kinetic design case (*SWAY*). (a) *SWAY* instructs the user to move the phone slowly and continuously. (b) The visual sidebar (warmth value) is filled after a couple of seconds of continuous slow movement. While the audio and visual feedback parameters are being generated, the visual feedback is still covered by fog. (c) The landscape becomes clear. While moving slowly and continuously the visual feedback induces the feeling of flying over an endless mountain range. The phone instructs the user to focus on the quality of the movement and the steps. Now the user can close the eyes, put the phone in the pocket and continue with mindful movement. (d) If the user becomes distracted, stops the movement or moves too fast, the audio-visual feedback fades away. A dedicated sound alert and text feedback prompt the user to bring the attention back to the present moment.

to enable mindful walking (Figure 9(c)). The *warmth value* works as a buffer, allowing the user to make small mistakes as they attempt to master the movements.

SWAY's *audio feedback* is designed as a generative soundscape, which means the audio experience never repeats itself making each new session a new audio experience. To motivate continuous mindful movements when the user moves mindfully, a continuous soothing soundtrack is generated in real time. If the movement becomes too abrupt or stops, distinguishing sound alerts notify and remind the user to return to mindful movements. Audio feedback plays a vital role especially in the situation where the user is not looking at the screen, has the eyes closed, or has put the phone in a pocket (Figure 9(c) and (e)). In these circumstances, sound is the primary feedback mechanism in *SWAY*.

SWAY's *graphical feedback* is an ever-evolving generative landscape. At the start of the session, the landscape is covered by fog (Figure 10(a) and (b)). When the user starts mindful movements, the *warmth value* builds up, the fog clears revealing the landscape while the visual perspective rises giving the user the feeling of flying over an endlessly evolving landscape (Figure 10(c)). When non-mindful movements are detected, the perspective drops, and fog returns and progressively covers the landscape (Figure 10(d)).

SWAY's *text feedback* was purposefully designed to direct the user's attention and internal focus. Text feedback is a trigger point of the closed-loop framework. At the beginning of the practice, textual feedback guides the user in various aspects: "*move your phone slowly and continuously,*" "*direct your attention to the movement,*" and "*be aware of your body.*" Whenever the user successfully conducts mindful movement, *SWAY* instructs users to look away from the screen and allow the audio to guide them into the present moment. However, the moment that the user is distracted, moves too slowly or too quickly, a message is displayed such as: "*You were moving too slow/fast*" (Figure 10(d)).

6.2 Study 3: User Experience of Mindful Movement

A user study was conducted to investigate if our kinetic design case can contribute to kinetic meditation. We collected qualitative and quantitative data to explore the usability and state effects of *SWAY*.

6.2.1 Methodology. Participants. Thirteen university students and researchers including 5 females (age: M = 28.5, SD = 4.9, range = 23–36) were recruited. None of the participants were experts in kinetic meditation. The nationality of participants was as follows: Chinese (n = 9), Canadian (n = 1), French (n = 1), Indian (n = 1), US (n = 1). Participants were paid $10.

Task and procedure. After granting their informed consent, the participants were introduced to *SWAY*. They were asked to use the application in a creative way by exploring different approaches to interacting with *SWAY*. Participants practiced barefoot or wearing socks only. A 7-m × 7-m area in the laboratory was provided for training. Participants were asked to practice kinetic meditation in three 10 minutes sessions with 5 minutes rest after each session. After the third session, an interview was conducted. The interviews lasted 20–30 minutes and were audio recorded for later analysis. The whole experiment was conducted in a quiet space. Check Supplementary material 1 for details.

Measures. Semi-structured interviews including several open-ended questions were conducted assessing the mindfulness experience of the users and the ways they interacted with *SWAY*. In this study, we used only qualitative metrics and omitted using any psychophysiological sensor for the following reasons: (1) bio-signals such as EEG are highly susceptible to motion artifacts, (2) movement can be a potential confounding factor for psychophysiological metrics such as HR, where we could not easily distinguish changes in the signal level resulting from mindfulness practice on one hand and physical movements on the other.

Two questions were asked of the participants. The first question investigated the affective state of the participants using Russell's two-dimensional circumplex space model [90]. The model annotates and demonstrates different human emotions based on arousal and valence dimensions. Russell's model is widely used in HCI literature to measure user "affect" [57, 66]. Participants were asked to first carefully study the arousal-valence emotional chart [74] (see Supplementary material 2), and then "*select three affective states that they felt most closely, considering all sessions.*" The second question measured the feedback preferences of the users in terms of the usefulness and effectiveness of the feedback type (audio, graphics, and text) and considering all sessions. Participants were asked to *rank the most important* (=3)*, the second choice* (=2), *and the least important feedback type* (=1).

6.2.2 Results. This section describes the main findings of Study 3 about the user experience of *SWAY*. To analyze the interviews, an open coding process was used to extract labels from the meaning of the sentences and create the themes. To analyze quantitative data, affective states were shown in a tabular format and illustrated by heat mapping the emotions that have been selected by participants. Last, to investigate a possible effect of feedback type on preference, the Friedman nonparametric test was used. Wilcoxon Signed-Rank tests were also used for pairwise comparisons between the feedback types. P-values were Bonferroni corrected.

The Participants' backgrounds. The expertise of the users is an important factor that can influence their feedback. Nine participants never experienced kinetic meditation. Three participants [P1, P3, P6] reported practicing Tai Chi in their school a couple of years ago. Another participant [P12] had experience of Yoga training, but she was not a frequent practitioner. Although all the participants were frequent smartphone users, only one of them [P8] reported using an MBMA for a static meditation.

Overall engagement. Most participants (12/13) agreed that they had a successful mindful experience. [P2]: "*before the experiment, I had a lot of thoughts in my mind. But when I started to use the app, it slowly became engaging for me, and then I closed everything outside.*" [P3]: "*I liked it. The difference was that when I practiced Tai Chi before I required to follow some specific pattern of movements. But SWAY allows me to be more freestyle while performing mindful movements.*" [P7]: "*Sometimes, in the workplace, my mind wanders, and it is drifting thinking. But here I need to think about the slow movement. So basically, instead of going away, the phone always takes me back.*"

Detection. SWAY detects users' movements and warns them if they are not moving within the proper speed range. Many participants (12/13) reported that they received more interruptions in the first session, and in the latter sessions they did not receive any, or just a few interruptions. [P8]: "*At the beginning of the first session, I got many interruptions because I was faster, but later it almost never happened.*" [P12]: "*In the first try, it frequently told me that I was going too fast. I thought probably I am not very good at mindfulness but later I learned how to properly use it.*" Most of the participants (11/13) reported that speed thresholds of *SWAY* are well designed and helped them to practice kinetic meditation. [P4]: "*I tried a movement like the rotation of the earth on the orbit around the sun (i.e., ellipse shape, 'faster slower faster slower'), and still I could train. The range is quite nice, and it allows me to try different moves.*" Two of the participants [P3, P6] reported that they even would like to try more strict speed range. [P6]: "*I like moving very slow. So even if the app can force me to be slower, it will be helpful.*" However, one participant suggested expanding the speed range for more difficult movements. [P7]: "*Sometimes in the large arm movements, if I am in an extending position, it is difficult to keep the movement slow and I don't want to receive the negative feedback.*"

Feedback. Audio, graphics, and text are the main elements of *SWAY* feedback. Twelve participants reported that audio feedback effectively helped them to successfully experience mindful and relaxing practices. [P2]: "*The music helps me to create my own world in my mind and disconnect from my thoughts.*" [P5]: "*Sound makes me feel relaxed. There are many elements inside ... birdsong, fire, wind ... it is very interesting to observe them.*" However, one participant [P13] reported that notification sounds for high speed had a negative effect on him. [P13]: "*The 'too fast' sound was loud and shocking, and it disrupted my experience. I recommend using a smoother sound for the notifications.*"

Notably, many participants (10/13) indicated that they found the visual feedback (graphics and text) useful at the beginning of the training, but they stopped using it during the training. Nine participants mentioned that graphics were helpful to start using the application. [P2]: "*In the very beginning, maybe the first 30 sec it is useful. But I don't want to imitate the visual content inside my mind. So, I like to close my eyes and create my own world.*" [P12]: "*The graphics were definitely relaxing. I did not look that much but it was really nice.*" [P8]: "*I am very sensitive to aesthetics like font design or color. So, the graphics gave me the first impression of the app and motivated me to use it. But this is a kind of motion app, and I don't want to look on the screen while moving.*" Eight participants shared similar thoughts about the usefulness of the text feedback in the beginning. [P1]: "*I like the text too. I like the motivations on the text. When I realized that the sound was associated with telling me that I was going too fast, I did not have to look at the text anymore ... but the text taught me how to use it.*" [P11]: "*The text is informative than the graphics. I can understand I am in which state. But after I knew how to use the app, I didn't use it anymore.*" One participant reported that reading the text while moving the body was difficult for her. [P6]: "*I was stretching my arms and it was not possible at all to read the text. I think audio alone is helpful enough to understand what I am doing.*"

Regulation. Remarkably, many participants (10/13) mentioned the role of the slow movement on cultivating focus and attention. Eight participants reported that they focused only on slow body movements during the practice. [P6]: "*I closed my eyes and focused on slow and continuous movements. I can say I could better perceive my muscles. I felt something strange! Something like a magnetic field between my hand and my body! The same feeling happened to me when I trained Tai Chi long time ago.*" [P11]: "*I basically focused on my steps. How do my feet touch the ground? But sometimes I forgot about my steps and start mind wandering. In that time, usually, I went fast and then the phone dragged me again to the focused state.*" [P13]: "*I focused on the movement. I tried to figure out what kind of movement can be a good move to do not be fast. I just imagined the phone as a cup of water and played with that to do not let the water pour over the floor.*" Two participants [P5, P12] used the app by focusing on the slow movement and audio. Where the other three participants [P1, P2, P8] mentioned that they only focused on the audio.

Pattern of use. There was a lot of variability in the pattern of use regarding body movements and eyes mode. Most of the participants preferred to do not move two body parts in parallel (11/13). Eight participants reported using the app while walking. Only two of those [P3, P12] moved their arm at the same time while walking, and the other six held the phone in their hand or pocket. [P11]: "*When I walk and move my arms at the same time, I cannot manage the slow speed. So, I prefer only walking.*" While the other participant mentioned [P3]: "*I think that only walking is too habitual. I need something more for focus, I think hand movement can help with that.*" The other four participants used the app while standing and moving the arms [P6], sitting on a chair and moving the arm [P4] or wrist [P13], and lying down on a couch while moving the arm [P7]. However, one participant [P10] reported that he experienced both movements separately, i.e., without combining the leg and arm movements at the same time. [P10]: "*I walked without moving my hands, and then I stopped walking and moved my hands.*" Except for one participant [P13], all others performed gross movements. [P13]: "*I thought it is difficult for me to do large movements. So, I tried to find a more relaxing way to do it. I just try to make it easier and I rotated slowly my wrist, and sometimes I did with my both wrists.*" One participant reported doing random arm movements, where four participants reported moving their arms in predefined trajectories including circle [P6, P10], infinity (∞) [P4], and back and forth [P12]. Six participants performed the training with open eyes, where four of them [P1, P3, P8, P9] mentioned safety reasons such as fear of a collision or falling down. Four other participants [P2, P10, P11, P12] performed both eyes open and closed in sequence. [P2]: "*Closing eyes is much relaxing. When my eyes are open, my mindful state gets disrupted. So, I just half opened my eyes to perceive where I am and then closed again to focus*".

Use in daily life. Some participants developed different scenarios as potential use cases of *SWAY* in their everyday life. For example, two participants [P2, P5] indicated the potential impact of *SWAY* on stress relief compared to listening to music. [P5]: "*When I feel stress, I usually listen to music. But depending on what I am listening, music can lead me to a sad or happy mood. While SWAY makes me more focused and also more aware of myself.*" Another participant [P6] contrasted *SWAY* with painting. [P6]: "*I usually do the painting. It helps me to practice mindfulness and be happy. But painting is a long and difficult process. The great point about SWAY is that it can help me in a few minutes to focus.*" Finally, a participant [P1] shared that *SWAY* is a way to make better use of his time. [P1]: "*Usually, waiting for my partner makes me feel anxious or even angry! I think it should be a good time for practicing SWAY.*"

Context of use. Most of the participants reported their desire to use the app in a different environment than the laboratory. Four of them [P4, P6, P9, P12] wished to use the app in big and natural environments such as a park. [P6]: "*I like to try it in a park. I can feel better if I can try on a natural surface like grass.*" While three participants [P2, P5, P11] shared safety concerns, three other participants [P3, P10, P13] mentioned privacy concerns wishing to do it in their own bedroom where no one can see them.

Table 1 The Most Selected States Are Peaceful, Relaxed, Calm, Amused with 7, 5, 4, and 3 Repetitions, Respectively

chosen states	selections
"peaceful"	7 times
"relaxed"	5 times
"calm"	4 times
"amused"	3 times
"delighted," "feel well," "interested"	2 times
"at ease," "attentive," "confident," "contemplative," "convinced," "expectant," "glad," "light-hearted," "melancholic," "pensive," "serious," "sleepy," "startled," "taken aback"	1 time

Most of the participants reported experiencing high-valence and low-arousal. Refer to the heat map in Supplementary material 2 to see emotion ratings on arousal (y-axis) and valence (x-axis).

Further suggestions. Finally, the participants talked about their suggestion for further development of the application. Five participants [P6, P7, P8, P12, P13] expressed that our phone is heavy for training and they would like to use the app on a smartwatch or a smart ring. Others asked us to create thematic scenarios (e.g., Japanese garden, campfire) [P1], make a tutorial for app use [P4], or provide safety information for users who want to use it outside [P9]. A participant [P12] also reported that sometimes she did not know what to do with her non-dominant hand.

Conclusion of the interview. Most of the participants were able to practice kinetic meditation successfully. Our findings reveal that *SWAY* can promote slow continuous movement and can facilitate focus on body movements. Our findings also demonstrated that *SWAY* allows participants with different interaction and movement preferences (i.e., users with mobility differences) to train in kinetic meditation using different postures according to their preferences.

Affective state. We asked participants to select three affective states that they felt during the practice sessions. Table 1 shows that the majority of the answers are in the high-valence and low-arousal area (see Supplementary material 2). The most common felt emotions were: "Peaceful," "Relaxed," "Calm," "Amused" with 7, 5, 4, and 3 responses, respectively. "Delighted," "Feel well," and "Interested" were each selected twice. Our findings showed that most of the participants noted experiencing high relaxation and pleasure during the practice.

Feedback preference. We also asked participants to rank the most effective and useful feedback element. There is a main effect of feedback type for participant preference ($\chi^2(2) = 19.54$, $p < 0.001$). The results indicated that audio feedback is preferable to graphic feedback ($Z = -3.27$, corrected $p < 0.01$). Audio is also preferable to the text ($Z = -3.27$, corrected $p < 0.01$) when there is no significant difference between the graphics and the text (corrected $p = 1.00$). Figure 11 shows, notably, that all participants selected audio feedback as the most important feedback type. This result is congruent with the results of the interviews where we found that the audio feedback is the most effective and favored feedback type during *SWAY* practice. While the graphics and text are significantly important during the learning process, they can be disregarded for the rest of the practice.

6.2.3 Summary. To sum up, we found that: (i) *ARF* and the kinetic design case allowed participants to self-regulate using various postures (i.e., different interactions). The findings are notable because they support users with different interaction preferences, i.e., users with mobility differences. (ii) Most of the participants reported experiencing high pleasure and relaxation during the practice. (iii) Audio was the most effective feedback type.

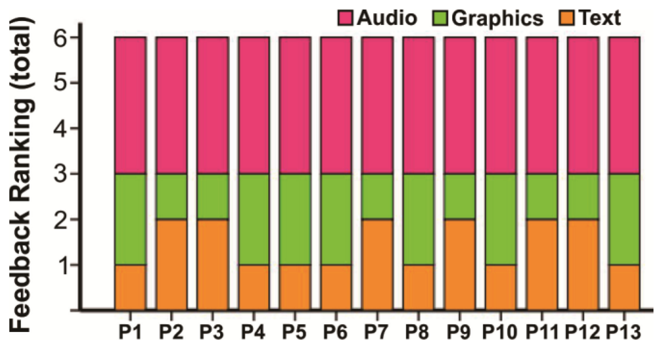

Fig. 11. Feedback preference. The figure shows the ranking of each feedback type per participants (3: most important, 2: second choice, 1: least important).

6.3 Study 4: Intervention Study (II)

To investigate the effectiveness of *SWAY* on mental and physical wellbeing in the long-term (trait effects), we conducted an interventional study. We compared three groups: (1) *SWAY*, (2) a kinetic meditation application called *Meditation Moves* (*MM*), and (3) a passive control group (i.e., no intervention). We selected *MM* as an active control group because it uses the guided meditation technique and represents the existing applications in the market. On the other hand, in line with Study 2 that showed the effectiveness of five-day training, we selected 5 days of practice for our experiment.

6.3.1 Methodology. Experimental design. A mixed design experiment was conducted. The *Training* was within-subject comparison of pre-test and post-test results. The *App* was between-subject comparing the *SWAY* with the *MM* and the control groups.

Participants. A total of 52 university students and members of staff were recruited. Individuals in Study 3 did not participate in Study 4. One of the participants was excluded due to a balance disorder. 17 participants (6 females) were allocated to the *SWAY* group (age: M = 26.2, SD = 4.7, range = 19–35), 17 participants (2 females) to the *MM* group (age: M = 22.2, SD = 1.2, range = 20–25) and 17 participants (6 females) to the control group (age: M = 23.7, SD = 6.2, range = 20–40). All the participants were novices and none of them had experienced kinetic meditation. The nationalities of participants were Chinese (n = 19), Japanese (n = 28), Iranian (n = 2), Indian (n = 1), and Russian (n = 1). Participants in the *SWAY* and *MM* groups were paid \$40, while control group participants were paid \$10.

Task and procedure. Consent forms were gathered from the participants. Demographic information including health background, meditation and exercise experience were collected. Participants were randomly assigned to one of the groups. Participants were blind to the group allocation, and research staff did not discuss the details of the experiment (e.g., hypothesis) with them. Participants were instructed to complete the questionnaires in a fixed order one day before starting the intervention. The balance test was conducted immediately before starting the intervention. All the participants were explicitly instructed "*not to practice the balance test during the experiment days*". In addition, participants in the *SWAY* group were asked "*not to include the balance practice in their SWAY movements.*" In the control group, participants did not receive any further instructions and only attended pre-tests and post-tests.

SWAY and MM training were performed in the same environment as the Study 3. A smartphone holder attached to a camera tripod was used for MM group training. The MM group used a smaller 2-m × 2-m area as they had to stand behind the smartphone and watch the screen. In the *SWAY* and *MM* groups, participants were taught how to use the applications. Participants in the *SWAY* group were instructed to conduct large whole-body movements including using their arms and legs and to be creative in experimenting with movements. *MM* offers mindful movements from Tai Chi and Qigong. Participants in the *MM* group were asked to stand 70cm away from the smartphone and follow the visual and audio guidance of the instructor. After the instruction, participants in the *SWAY* and *MM* groups trained with the applications for 5 days, 3 sessions every day (total 15 sessions). Each session took 15 minutes. Participants had 5 minutes rest after each session was completed. During the rest period, participants sat in a chair without using any applications or smartphones. After finishing the fifth day's training, participants were asked to conduct the same balance test as done on the first day. Next, participants were asked to complete the post-questionnaires in the same order as the pre-questionnaires. Participants had 15 minutes' rest between the balance test and answering the questionnaires. They took a 5-minute break after finishing each questionnaire. Post-tests were conducted for each participant at the same time of the day that the pre-tests were conducted. Check Supplementary material 1 for details.

Measures. We used the following metrics before and after the intervention period.

Mindfulness: A 39-item *Five Facet Mindfulness Questionnaire* (FFMQ) [3] was used to measure mindfulness. The FFMQ asked for ratings on a 5-point Likert-scale from 1 (never or very rarely true) to 5 (very often or always true). The following five facets of mindfulness were evaluated [11]: *observing* (i.e., attending to or noticing internal and external stimuli), *describing* (i.e., noting or mentally labeling these stimuli with words), *acting with awareness* (i.e., attending to one's current actions), *non-judging of inner experience* (i.e., refrain from evaluations), and *non-reactivity to inner experience* (i.e., allowing thoughts and feelings to come and go). The negative items were reversed before factor analysis. Recent studies used FFMQ to show the effectiveness of yoga and mindful movement in achieving mindfulness [9, 28].

Body awareness: To assess *body awareness*, we adopted a 6-item questionnaire from an earlier study [58]. The list of questions is provided in Supplementary material 3. Our body awareness questionnaire asked participants for ratings on a 5-point Likert-scale from 1 (never or very rarely true) to 5 (very often or always true). The first three questions addressed *body sensation* (i.e., the ability to sense the body or notice changes in the body) and the second three questions measured the *quality of attention* (i.e., the level of attention paid to the body). In the earlier studies, body awareness has been assessed in kinetic meditation [19] and it has been seen as the common principle of such practices [59].

Well-being: We measured General Well-being using the PGWB index as described in Study 2. The PGWB index has been used previously to ascertain the effectiveness of yoga practice in improving well-being [60, 83].

Mood: POMS was used to measure mood, as described in Study 2. It has been used in earlier studies [51, 61] to demonstrate the impact of kinetic meditation on mood enhancement.

Balance: Proper body balance is a necessary factor for a high quality of life and, in particular, it is vital and particularly relevant to elderly people [105] and patients [10] (e.g., multiple sclerosis) in order to decrease the risk of falls and to increase life expectancy. Many intervention studies have demonstrated that long-term kinetic meditation training can improve balance function [39], proprioception [126], and postural stability [35]. Thus, we used a *Single-Leg Stance* (SLS) task [46, 86] to assess *postural sway* and *balance time*. To conduct SLS, a VICON marker was firmly mounted to the top spot of the participants' torso (i.e., 7th cervical vertebra—C7). Participants were instructed to stay in a predefined area on a firm surface and stand on one barefooted leg only. They were asked to position the other leg on the posterior side of the knee of the standing leg and cross their arms over the chest.

The balance test was conducted in four blocks in a fixed order: (1) right leg—eyes closed, (2) left leg—eyes closed, (3) right leg—eyes open, and (4) left leg—eyes open. Participants were given one-minute to practice the single leg stance before the main experiment. Each block was run in three trials with a rest between them (i.e., 30 seconds for trials shorter than 1 minute and half of the trial time for trials longer than 1 minute). In the eyes closed condition, participants were asked to stand as long and stably as possible. In the eyes open condition, participants were instructed to stand as stably as possible for only 30 seconds while looking at a marker approximately 2 meters away.

Postural sway [102] was assessed in both the eyes closed and the eyes open conditions by measuring the distance of the line of gravity (i.e., vertical line from the center of mass) from the origin of the VICON coordinate system. To extract the amount of fluctuation in postural sway, the standard deviation of the distance signal was calculated. We observed individual differences between participants in this task. Some users even dropped their leg before 30 seconds. Given this reason and to eliminate fatigue, the motion signal was analyzed in three different portions: 0–10 seconds, 10–20 seconds, and 20–30 seconds. Since the human balance system is highly dependent on visual perception [17], we expected a higher effect on the closed eyes than the open eyes. On the other hand, *balance time* was measured only for the eyes closed condition. We observed considerable individual differences in balance time. While some users can stand for only several seconds, other users can maintain their balance for minutes. Thus, to provide a meaningful unit, we normalized the time results across participants.

6.3.2 Results and Discussion. Parametric evaluation of the data was examined using the Shapiro–Wilk normality test and by checking Skewness and Kurtosis. None of the metrics could pass the normality test. The training effect for each group was analyzed using Wilcoxon Signed-Rank tests by comparing pre-test and post-test results. Significance was set at $\alpha = 0.05$. Effect size (r) was calculated for non-parametric repeated measures *t*-tests [73]. Cronbach's-α were 0.77, 0.94, 0.88, and 0.52, for FFMQ, POMS, PGWBI, and body awareness, respectively.

Mindfulness. Figure 12 illustrates the results. There is a main effect in *Training* for *observing* in the *SWAY* group ($Z = -2.22$, $p < 0.05$, $r = 0.38$). The result shows that *observing* is higher in the post-test ($M = 28.18$, $SD = 6.37$) than the pre-test ($M = 24.47$, $SD = 6.34$), while for the other groups there are no significant differences between the pre-test and the post-test (*MM*: $p = 0.22$, control: $p = 0.14$). We also found a significant effect in *Training* on *acting with awareness* for the *SWAY* group ($Z = -1.97$, $p < 0.05$, $r = 0.34$). The analysis shows *acting with awareness* for the *SWAY* group is higher for the post-test ($M = 30.65$, $SD = 4.09$) compared to the pre-test ($M = 27.76$, $SD = 5.88$). There are no significant differences between the pre-test and post-test results in the *MM* and control groups (*MM*: $p = 0.89$, control: $p = 0.27$). We did not find significant improvement in the other facets. Our findings showed that *SWAY* training can enhance *observing* (the ability to attend to internal/external stimuli) and *acting with awareness* (the ability to pay attention to the present moment). Our finding is consistent with a previous study [11] showing that traditional kinetic meditation has a greater effect on observing and acting with awareness.

Body awareness. Figure 13(a) shows the results. There is a main effect in *Training* on *body sensation* for the *SWAY* group ($Z = -2.08$, $p < 0.05$, $r = 0.35$). Participants in the *SWAY* group had significantly higher *body sensation* in the post-test ($M = 3.39$, $SD = 0.94$) than the pre-test ($M = 2.92$, $SD = 0.67$). There is also a marginal effect in *Training* for the *MM* group ($Z = -1.95$, $p = 0.051$, $r = 0.33$), where participants in the *MM* group had higher *body sensation* in the post-test ($M = 3.59$, $SD = 0.71$) than in the pre-test ($M = 2.96$, $SD = 1.01$). No significant difference ($p = 0.72$) was observed in the control group. There is also a main effect in *Training* on *quality of attention* for the *SWAY* group ($Z = -2.96$, $p < 0.01$, $r = 0.51$). Pairwise comparisons showed that for the *SWAY*

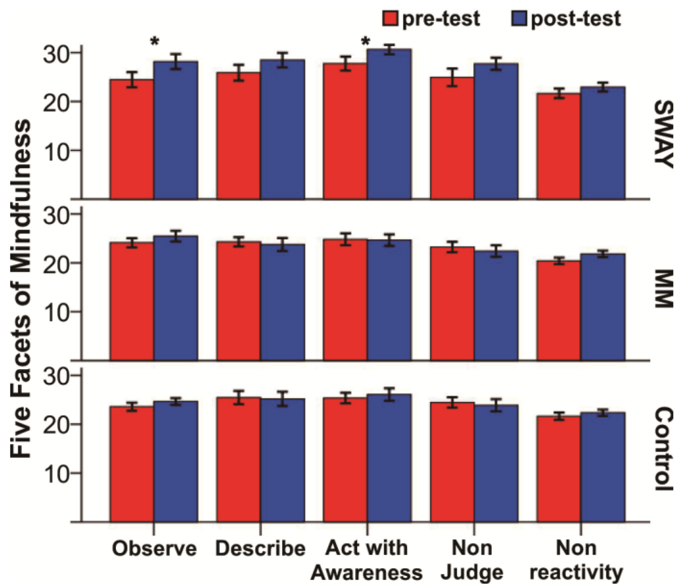

Fig. 12. Effect on *mindfulness*. The figure shows a significant improvement in *observing* and *acting with awareness* only for the *SWAY* group. The error bars indicate ±SE. Significant effects are indicated by an "*" symbol. MM stands for Meditation Moves app.

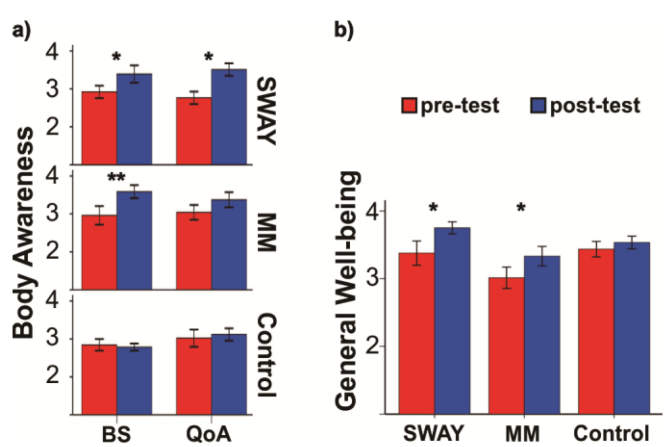

Fig. 13. Effect on (a) *body awareness* and (b) *well-being*. (a) Significant enhancement in *body sensation* (BS) and *quality of attention* (QoA) for the *SWAY* group. (b) Significant enhancement of *well-being* for the *SWAY* and *MM* groups. The error bars indicate ±SE. Significant effect and marginal effect are indicated by "*" and "**" symbols, respectively. MM stands for Meditation Moves app.

group, *quality of attention* is higher for the post-test (M = 3.51, SD = 0.69) than for the pre-test (M = 2.76, SD = 0.67). The analysis did not show any significant improvement in the *MM* and control groups (*MM*: p = 0.14, control: p = 0.58). The results show that *SWAY* improved body awareness by influencing sensitivity to the body and the quality of attention. These two factors are closely related to *observing* and *acting with awareness*—two facets of mindfulness that were significantly improved by *SWAY* training. However, the results should be interpreted with caution due to the low internal consistency of the body awareness questionnaire.

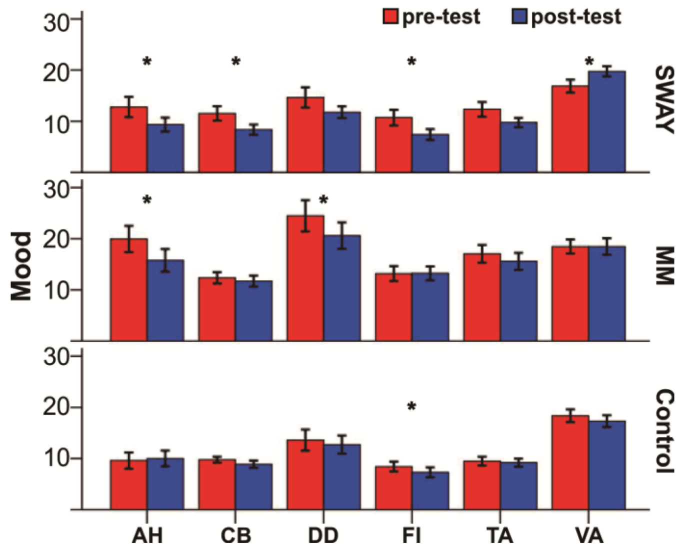

Fig. 14. Mood. The figure shows a significant reduction for *SWAY* training on *anger-hostility* (AH), *confusion-bewilderment* (CB), and f*atigue-inertia* (FI) and improvement in *vigor-activity* (VA). *MM* training demonstrated a significant effect on *anger-hostility* (AH) and *depression-dejection* (DD). *Tension-anxiety* (TA) did not show any effect any of the groups. The error bars indicate ±SE. Significant effects are indicated by an "*" symbol. MM stands for Meditation Moves app.

Well-being. Figure 13(b) summarizes the well-being results. There is a main effect in *Training* on well-being in the *SWAY* group ($Z = -2.77$, $p < 0.01$, $r = 0.47$). The well-being rate for the *SWAY* group is higher for the post-test ($M = 3.75$, $SD = 0.37$) than for the pre-test ($M = 3.38$, $SD = 0.74$). There is also a main effect in *intervention* for the *MM* group ($Z = -2.32$, $p < 0.05$, $r = 0.40$). There is no difference between the pre-test and the post-test ($p = 0.24$) in the control group. The findings reveal the effectiveness of both *SWAY* and *MM* on well-being improvement. The results are consistent with previous studies of traditional static meditation [71], traditional kinetic meditation [83], and technology-mediated static meditation (Section 5.3.2).

Mood. Figure 14 summarizes the mood results. There is a main effect in *Training* on *total mood disturbance* in the *SWAY* group ($Z = -2.58$, $p < 0.01$, $r = 0.44$). Participants in the *SWAY* group rated *total mood disturbance* significantly lower in the post-test ($M = 26.94$, $SD = 21.28$) than the pre-test ($M = 45.06$, $SD = 35.13$). There is also a marginal effect in *Training* on *total mood disturbance* in the *MM* group ($Z = -1.94$, $p = 0.052$, $r = 0.33$). We found lower *total mood disturbance* in the post-test ($M = 58.41$, $SD = 32.16$) than the pre-test ($M = 68.53$, $SD = 35.96$) for the *MM* group. There is no significant difference in the Control group ($p = 0.41$). There is a main effect in *Training* on *anger-hostility* in the *SWAY* group ($Z = -2.05$, $p < 0.05$, $r = 0.35$). The *SWAY* group demonstrated less *anger-hostility* in the post-test ($M = 9.35$, $SD = 5.67$) than the pre-test ($M = 12.76$, $SD = 8.24$). There is also a similar effect in the *MM* group ($Z = -2.65$, $p < 0.01$, $r = 0.45$). Participants in the *MM* group had lower *anger-hostility* in the post-test (*MM* = 15.76, SD = 9.11) than in the pre-test (*MM* = 19.94, SD = 10.62). No effect on *anger-hostility* was found in the control group ($p = 0.50$).

In the *SWAY* group, there is a main effect in *Training* on *confusion-bewilderment* ($Z = -2.59$, $p < 0.01$, $r = 0.44$). We found less *confusion-bewilderment* in the post-test (*MM* = 8.35, SD = 4.18) compared to the pre-test ($M = 11.53$, $SD = 5.80$) for the *SWAY* group, but not for the other groups (*MM*: $p = 0.31$, control: $p = 0.15$). In the *MM* group, there is a main effect in *Training* on

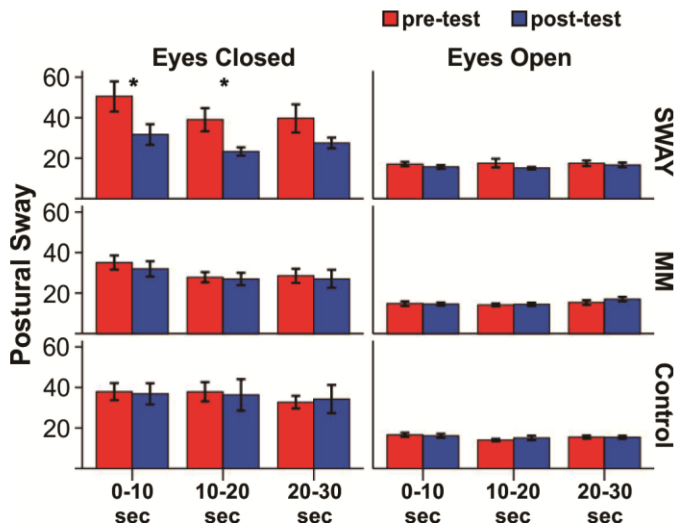

Fig. 15. Postural sway. The figure shows significant improvement (i.e., reduction) in *postural sway* in millimeters (mm) for the eyes closed condition in 0–10 seconds and 10–20 seconds time portions for the *SWAY* group. The error bars indicate ±SE. Significant effects are indicated by an "*" symbol. MM stands for Meditation Moves app.

depression-dejection (Z = −2.30, $p < 0.01$, r = 0.39). Participants in the *MM* group showed less *depression-dejection* in the post-test (M = 20.59, SD = 10.68) compared with the pre-test (M = 24.47, SD = 12.61). The *SWAY* and control groups did not show any significant effect on *depression-dejection* (*SWAY*: p = 0.17, control = 0.41). There is a main effect in *Training* on *fatigue-inertia* in the *SWAY* group (Z = −2.75, $p < 0.01$, r = 0.47). The rated *fatigue-inertia* for the *SWAY* groups is lower in the post-test (M = 7.41, SD = 4.36) compared to the pre-test (M = 10.71, SD = 6.39). Unexpectedly, there is also a similar effect in the control group (Z = −1.99, $p < 0.05$, r = 0.34). Participants in the control group reported lower *fatigue-inertia* in the post-test (M = 7.29, SD = 4.01) than the pre-test (M = 8.41, SD = 4.05). The *MM* group did not have any effect on this factor (p = 1.00). None of the groups demonstrated a significant effect on *tension-anxiety* (*SWAY*: p = 0.09, *MM*: p = 0.31, control: p = 0.61). There is a main effect in *Training* on *vigor-activity* in the *SWAY* group (Z = −3.24, $p < 0.001$, r = 0.56), but not in the other groups (*MM*: p = 0.81, control: p = 0.29). Participants in the *SWAY* group reported greater *vigor-activity* in the post-test (M = 19.76, SD = 4.12) than the pre-test (M = 16.88, SD = 5.19).

To sum up, the results demonstrate that *SWAY* training can reduce *anger-hostility, confusion-bewilderment,* and *fatigue-inertia*, and improve *vigor-activity*, and *total mood disturbance*. Our results also demonstrated the effectiveness of *MM* training on *anger-hostility* and *depression-dejection*. While *SWAY* can influence both physical and psychological aspects, *MM* only impacts psychological aspects. Last, *SWAY* could not significantly improve *depression-dejection* or *tension-anxiety* factors. Reviewing near-marginal statistical findings (*depression-dejection*: p-value = 0.17, *tension-anxiety*: p-value = 0.095) indicates that those factors may require a longer period of training for potential improvement.

Balance. Figure 15 summarizes *postural sway* results. Statistical analyses of the *eyes closed* condition for the *SWAY* group indicated lower fluctuation in 0–10 seconds (Z = −2.96, $p < 0.005$, r = 0.51) for the post-test (M = 31.70, SD = 20.98) than for the pre-test (M = 50.49, SD = 30.56). In addition, the movement fluctuation for the *SWAY* group in 10–20 seconds was lower (Z = −2.67,

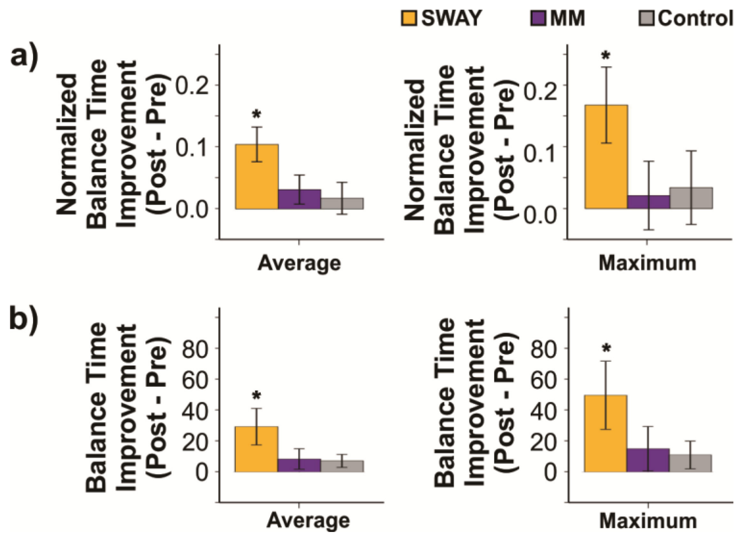

Fig. 16. *Balance time* improvement (post-pre). (a) The figure shows significant improvement for the *SWAY* group between the pre-test and post-test normalized mean and maximum balance times (second). (b) The figure shows results without normalizing balance times. The "*" symbol shows the significant differences from zero. The error bars indicate ±SE. MM stands for Meditation Moves app.

$p < 0.01$, r = 0.46) for the post-test (M = 23.32, SD = 7.86) than for the pre-test (M = 39.01, SD = 21.99). There was no significant difference in fluctuation in 20–30 seconds for the *SWAY* group (p = 0.069). Analyses for the *MM* and control groups showed no difference between the pre-tests and the post-tests in 0–10 seconds (*MM*: p = 0.16, control: p = 0.26), 10–20 seconds (*MM*: p = 0.46, control: p = 0.35), and 20–30 seconds (*MM*: p = 0.51, control: p = 0.68). As expected, for the *eyes open* condition, analysis showed no difference between the post-test and pre-test in all of the groups: 0–10 seconds (*SWAY*: p = 0.36, *MM*: p = 0.91, control: p = 0.59), 10–20 seconds (*SWAY*: p = 0.38, *MM*: p = 0.87, control: p = 0.69), and 20–30 seconds (*SWAY*: p = 0.59, *MM*: p = 0.21, control: p = 0.76).

Normalized *balance time* results in the *eyes closed* condition are shown in Figure 16(a). The results showed that in the *SWAY* group, average *balance time* increased (Z = −2.72, $p < 0.01$, r = 0.47) in the post-test (M = 0.29, SD = 0.05) compared to the pre-test (M = 0.19, SD = 0.07). There was no significant improvement in the other two groups (*MM*: p = 0.18, control: p = 0.19). We also found a significant improvement in the *SWAY* group for maximum *balance time* (Z = −2.25, $p < 0.05$, r = 0.39) in the post-test (M = 0.53, SD = 0.14) compared to the pre-test (M = 0.36, SD = 0.15), but not for the other groups (*MM*: p = 0.43, control: p = 0.83). Further, we used the Kruskal–Wallis non-parametric test to investigate the effect of *App* on the improvement of *balance time*. However, we could not find a significant *App* effect for average ($\chi^2(2) = 4.09$, p = 0.13) and maximum ($\chi^2(2) = 4.26$, p = 0.12) *balance time*. We also used the Friedman non-parametric test to analyze potential learning effects in the trials of the *SWAY* group only. There was no significant learning effect over the six trials in the pre-test ($\chi^2(5) = 4.29$, p = 0.51) and the post-test ($\chi^2(5) = 5.87$, p = 0.32).

In general, *postural sway* findings revealed the effectiveness of *SWAY* training on postural stability in the eyes closed condition while the training did not influence the stability in the eyes open condition. The results for *balance time* showed that training with *SWAY* can lengthen the time of sustained balance in the eyes closed condition. This is somehow consistent with the results regarding *mood*, which show the effectiveness of *SWAY* training on physical aspects of mood such as *vigor-activity* and *fatigue-inertia*. The *MM* and control groups did not show any effect on either metric. To sum up, *SWAY* as a kinetic mobile application can help users improve in physical aspects similar to the traditional meditation approaches.

6.3.3 Summary. To conclude, we found that: (i) *ARF* and the kinetic design case can be effective for both mental (e.g., mood) and physical (e.g., balance) aspects of health. (ii) The kinetic design case outperformed the guided meditation app (state-of-the-art).

7 GENERAL DISCUSSION

This article presents an overarching framework (*ARF*) for self-regulation mindfulness practices. *ARF* is a theory grounded framework and its main contributions are as follows: (1) The demonstration of a subtle approach for the detection of user attention without the need for dedicated accessories, (2) suggestions regarding appropriate feedback design that will help users avoid to recall judgments and evaluations during mindfulness practice, and (3) recommendations regarding pace (slowness) and steady continuity of movement that can be self-regulated. *ARF* attempts to answer a high-level question: "*to what extent can technology support mindfulness without interrupting the natural progressive meditative states of the user?*" [85]. *ARF* was described through the development and demonstration of two design cases (*PAUSE* and *SWAY*). Overall, our design cases demonstrated the usefulness of the framework. Furthermore, our validation for the static meditation determined where the framework is particularly useful (i.e., in busy environments) and which specific group of users can benefit most (i.e., people who are easily distracted or who have low confidence/motivation to meditate). In addition, the results of kinetic meditation reveal that the framework can be useful for a wide range of users who have different movement preferences. Metrics of the intervention studies consistently demonstrated improvement after 5 days of practice with *PAUSE* and *SWAY*.

In the following sections, we will discuss our findings and will argue the efficiency of the detection, feedback, and regulation mechanisms of *ARF*.

7.1 Detection Mechanism of *ARF*

The detection mechanism is essential and critical because it allows technologies to "be aware of" a user's current state and to prompt technologies to react appropriately without interrupting mindfulness practice. It is important to distinguish between "detecting" attention and "guiding" attention. Although human beings have the capacity to self-regulate their attention, the technological detection of deviations from voluntary attention provides meaningful feedback from moment to moment to support and motivate users to sustain self-regulation. On the other hand, any overreach in guiding and disciplining user attention by technology could diminish the natural human capacity to self-regulate by allowing technology to dominate the whole process. This consideration nature leads to limited digital expression of the design as it follows the specific rhythm and patterns from pre-designed self-regulation process. The Breathe app[11] is an example of a recently developed product for the Apple Watch that uses visual and haptic feedback to guide the user to breathe slowly. Nevertheless, our framework informs that without a proper detection mechanism, the digital experience is inflexible and limited by predefined rhythms and patterns, which may interrupt the practitioner's inner process and overall progress in mindfulness practice (i.e., each user has his/her own pace). *ARF* contributes by grounding the detection mechanism with embodied cognition theories, which enables detection on mobile devices without the need for dedicated accessories. In addition, *ARF* contributes to design guidelines and features by showing precisely

[11] https://goo.gl/LWvCw7.

how to detect body movements. Being able to detect attention opens up a new creative space for designing digital experiences with feedback regarding human-focused attention.

Kinetic meditation techniques such as Tai Chi or Yoga usually have different styles, each of which requires practitioners to precisely conduct specific movements in the correct sequential order. Therefore, designing technology for kinetic meditation is relatively challenging. Previous attempts exposed varying pros and cons. For example, biofeedback systems could only measure user psychophysiological states in static postures and thus offered no movement detection. By adding motion detectors to dedicated accessories (e.g., Microsoft Kinect motion sensor) they could precisely detect the practitioner's body movement, but such sensors could not be used as or with mobile devices or in outside environments (e.g., for walking meditation in the street); furthermore, they could not be easily accessed by most people. Considering the prevalence of smartphones, interactive mobile applications could be a proper, convenient, and productive choice that would bring the benefits of mindfulness to daily life.

7.2 Non-Judgmental Awareness: Challenge of the Feedback Design

Feedback is the other essential component that is important to support self-regulation. Intuitively, slow movements (either fine or gross movements) permit discernible inner feedback, which stimulates body awareness. However, natural inner feedback is often too subtle for novices to recognize precisely because they are not used to dwelling in such mindful states. Technology can facilitate this process by providing instant and pertinent feedback. Although the necessity of feedback is obvious, it is essential to consider what kinds of feedback should be designed such that it provides adequate feedback but not so overwhelming that it disrupts the users' smooth transition into deeper meditative states. Feedback must be designed in such a way that it does not cause the practitioner to judge his/her own performance during mindful practice. There are two key obstacles when learning meditation: first, it takes time for a beginner to become aware that the mind has already been distracted by thoughts. Second, when the practitioner becomes aware that the mind has been distracted, it is natural for the mind to apply self-critical judgments (e.g., "Am I performing well or badly?"). In traditional meditation, non-judgmental awareness (i.e., an attitude of acceptance toward the present moment [2, 42]) is relatively hard to achieve by novice practitioners and it requires a lot of practice. Thus, designing proper feedback is challenging. For example, emWave2 [24] detects HR variability and provides visual feedback using a light bar. However, our framework informs us that a light bar may not be appropriate because users may be enticed into constantly interpreting the meaning of the bar (am I high or low?) as a judgment on their performance and this might prevent users from entering into deeper states of mindfulness.

To address this challenge, for the static design case (*PAUSE*), we developed the feedback mechanism to stimulate meta-awareness. As soon as the mind is distracted, feedback is provided. Because of the simple interaction design, everyone can easily resume slow, continuous finger movements. So, even though self-judgment may arise, finger interaction helps users to quickly disengage from mental self-judgments. Thus, *PAUSE* can help develop a new healthy relationship with the judgmental mind and contribute to the development of non-judgmental awareness. Similarly, for the kinetic design case (*SWAY*), the feedback mechanism informs users as soon as their slow, continuous, and regular movements show signs of being disrupted or diverted. This may cause users to be self-critical, but simple intuitive feedback prompts the user to spontaneously bring the attention back to the present moment and to sustain slow, continuous body movement. Although our design promotes non-judgmental awareness during practice, the review of our results for *non-judging of inner experience* facet reveals that the mechanism does not readily transfer to the daily behavior of practitioners after only 5 days of practice (p-value = 0.19).

More work needs to be done to assess how well the habit and benefits of various mindfulness applications transfer into daily and professional tasks and into overall satisfaction in life.

Finally, the use of proper instruction to encourage users to develop their internal focus was recommended. Achieving significant improvement in different facets of mindfulness and body awareness demonstrates that practitioners can achieve mindfulness by paying attention to the bodily movements.

7.3 Slow and Continuous: Regulation Techniques of *ARF*

The challenge is to design a suitable interaction that serves as an effective regulation technique. The interaction should be compatible with the detection mechanism (i.e., bodily movements) and the feedback mechanism (i.e., audio-visual feedback). To achieve this compatibility, *ARF* suggested a subtle solution based on identifying the underlying mechanisms of practices in the relaxation response principle. *ARF* recommended detecting slowness and endurance via the movement detection capabilities of the technologies to sense whether users are in a mindful state or not. *ARF*'s regulation technique makes the following contributions: First, by identifying principles of mindful movements beyond any particular form, it helps users practice self-regulation without requiring them to learn the complex movements of some traditional methods (e.g., Tai Chi). Second, by detecting the quality of movements, the framework turns every bodily movement into an opportunity for mindful practice.

7.4 Efficiency of Self-regulation

To determine the effectiveness and efficiency of our spontaneous self-regulation approach, we revisited the findings of the intervention studies. We also compared our results to previous studies that had almost the same amount of training time.

SWAY can help in increasing two facets of mindfulness (*observing* and *acting with awareness*). *Observing* is the ability to sense and notice internal (e.g., body) and external (e.g., aromas) stimuli, which is *what* to do to be mindful. *Acting with awareness* is the ability to pay attention to the present moment and that it is *how* to be mindful [3]. *SWAY* training as a self-regulation approach, by heightening awareness to the body movement and as a result, by redirecting attention to the present moment can help improve these two facets. On the other hand, *MM* training cannot affect any of these mindfulness facets. We speculate that this difference may be hinge on the issue of self-regulation. The self-regulation approach specifically develops the participant's own faculties of attention and control in the present moment, while in the non-self-regulation approach, the user merely imitates the process, which is contrary to the objectives of mindfulness practice. Indeed, in the latter case, the user is expected to multitask by observing movement instructions and simultaneously mimicking those movements. Although this type of technology can be helpful for precisely performing the movements, it does not maximize the potential to cultivate true subject driven mindfulness.

Our results demonstrate that *SWAY* can boost four items of mood (lower *fatigue-inertia*, greater *vigor-activity*, lower *confusion-bewilderment*, and lower *anger-hostility*), where *MM* can increase two items (i.e., lower *anger-hostility* and lower *depression-dejection*). An interesting outcome of training with *SWAY* is the improvement regarding *confusion-bewilderment*. This result shows the effectiveness of *SWAY* on attention-related capabilities such as the capacity for concentration. Similarly, *PAUSE* induced improvement with regard to *confusion-bewilderment*. This similarity seems to show that *ARF* aligns with Kabat-Zinn's definition of mindfulness [42], i.e., paying attention, on purpose, in the present moment, non-judgmentally. To lead users to pay attention in the present moment, *ARF* uses slow, continuous movement that requires sustained voluntary attention that can enhance the user's capacity to focus. This is also proven by the ANT, showing that *PAUSE* can improve directed attention after 5 days of training. Those practices that do not use the self-regulative guided meditation approach cannot improve *confusion-bewilderment*. For example, a *traditional* 5-day training program called Integrative Body-Mind Training (IBMT) [117] showed improvement in all factors of mood except *confusion-bewilderment*. IBMT originated from an ancient eastern tradition and includes both *static* and *kinetic meditation* techniques. Congruently, in our intervention studies, *Headspace* and *MM* did not affect this factor either.

Finally, the intervention experiment confirmed the effectiveness of *SWAY* in enhancing the user's ability to balance. Clark and colleagues [16] discussed the underlying mechanisms behind motor improvement after mindful movement practice. They shed light on the inner bodily feedback that can enable practitioners to monitor changes in their body sensations and improve their motor skills through training. In addition, they show that slow and mindful movements can help practitioners predict the sensory consequences of their movements [124]. On the other hand, a previous work [69] showed that motor performance associative focus (e.g., listening to an adaptive tone, which varies based on performance) improves motor learning compared to dissociative focus (e.g., listening to an irrelevant song). The finding revealed the effectiveness of feedback in improving motor learning. Our evaluations demonstrated a positive impact from our task-relevant feedback, which enhances motor learning and promotes better balance skills. Our results showed that *SWAY* can increase the stability of balance when eyes are closed but not with eyes open. This result might arise from the human balance system. Proper or steady balance is the result of processing information from different sensory modalities: the visual system (i.e., eyes), the vestibular system (i.e., inner ear), and the somatosensory system (i.e., muscles and joints) [17]. Closing the eyes turns off the flow of information from the visual system to the brain and causes difficulty in balance control. Our findings suggest that *SWAY* training might have further clinical implications for patients with balance impairments caused by impediments in the visual system such as Strabismus (i.e., eye muscle imbalance) [82]. By contrast, *MM* training did not lead to any improvement with eyes open or eyes closed. One possible reason for these results might be the different uses of body parts. Similar to other existing mobile applications, *MM* does not allow mobility as the user is required to stand behind the smartphone and continuously watch the screen. As a result, they only move the upper body. By contrast, *SWAY* allows the user to move and focus on their footsteps and/or arm movements. Our findings for *SWAY* training also reveal greater improvement in stability in the initial seconds of the balance test compared to the later period. It is likely that training with *SWAY* yields an improvement in balance rather than in physical power (i.e., leg power) and the effect persists until participants feel fatigued.

7.5 *ARF* vs. Biofeedback and Guided Meditation

Our findings revealed that our design cases are effective in promoting attention regulation, and these results are consistent with earlier biofeedback studies. For example, MeditAid [95] and RelaWorld [48], which used neurofeedback, effectively promote attention regulation and enhance concentration. However, those studies only used subjective evaluations to measure attention during practice, while our study used an analytic method (ANT cognitive test) to measure changes in attention skills. Another example of biofeedback devices is Sonic Cradle [118], which was created using the chamber of darkness and respiration feedback. Subjective evaluations showed the potential of Sonic Cradle to act as a stress therapy device. However, there are no concrete results reflecting the long-term use of Sonic Cradle.

We did not use biofeedback because our work primarily focused on merging the prevalence of smartphones together with the concept of a spontaneous self-regulation process; we wanted to mitigate the limitations inherent in the guided meditation method. We recognize that although guided meditation has been proven to be effective in past work, there are many situations and many kinds of users that together render this approach unsuitable. We therefor propose a framework and design cases that address this challenge. This is consistent with traditions of meditation where meditation masters provide various approaches (e.g., breathing, walking) to support different types of users and environments, but with the single goal of training mindfulness. Designers and innovators can and should tailor their mobile application designs to suit the wide variety of people according to their cultures, tastes, abilities, and lifestyles.

7.6 Limitations and Future Work

Our research is subject to several limitations: First, the sample sizes in Study 1 (11 people, within-subject) and Study 2 (18 people, between-subject) are relatively small and this may affect the generalizability of the findings. To address this limitation, we reported effect sizes besides the p-values. Second, neurophysiological sensors (EEG, HR) were used in Study 1 to measure the mindfulness state. Despite many types of research that used these metrics for reporting the mindfulness state, it remains debatable whether these metrics can properly measure the mindfulness state compared to related states such as relaxation or light sleep. Thus, to validate the findings, it is always necessary to use self-report mindfulness questionnaires. In future investigations, we plan to evaluate our framework using expert meditators to understand how these apps support users experience the true mindfulness state. Third, In Study 2, we did not include a no-contact control group as a third group. This may raise a question whether mentioned effects are due to the mindfulness practice or they are influenced by the self-regulation factor. Fourth, in Study 3, we did not compare our approach with a rival app. Such comparisons in future work could enlighten us regarding how our qualitative insights are different from existing kinetic mobile applications. Fifth, our data in Study 4 were non-parametric and we could not check inter-group effects using post-hoc analysis. This may potentially cause false positive findings. Given these points, the results should be interpreted with caution. We believe that future work can clarify many research questions focusing on the mentioned limitations.

8 CONSIDERATIONS FOR DAILY USE AND IMPLICATIONS

8.1 The Role of Technology

Our original question asks why users need technologies when everyone can just freely meditate anywhere and at anytime. One answer is that the ubiquitous availability and attractive character of technologies can be used to introduce all kinds of people to the benefits of meditation, i.e., they can make these benefits widely and readily accessible for the first time. It is important to note that the state of mindfulness is a natural and intrinsic human capacity. Though mindfulness capacity is intrinsic to human consciousness, it is generally neglected in the rush of our daily schedules. Therefore, the primary purpose of our framework is to develop a product that introduces users for what is likely the first time to a deliberate and conscious experience of mindfulness. People simply need to know that it is an innate potential, experience it, and practice it with a view to making mindfulness habitual and natural. The proposed appropriately designed apps can contribute to that process. In a maturing person, techniques and devices will and should fall away, but a conscious initiation into the awareness that mindfulness is a natural capacity can be realized through the application of this framework via a device. The hypothesis is that, as users practice with the app, they become better at controlling their own attention and ultimately, they may not need the app anymore. So, this becomes a training exercise, which develops voluntary attention and wiser, personal sovereign engagement in life.

8.2 Smartphones and Mindfulness in Daily Life

There is a growing body of evidence indicating some significant detrimental effects of smartphones. A recent investigation [110] showed that smartphones can disrupt our attention even when we are not using them. Then, it might seem counterintuitive at first that against the basic principle of meditation our framework requires a user to hold a smartphone while practicing meditation. Nevertheless, "mindfulness" should be considered to be distinct from 'time-out' meditation practice. Mindfulness is, ideally, a disposition of attention in any and all circumstances of life and it is available whether one has a smartphone, a hammer or a cup of tea in one's hand. Mindfulness is practiced in "time-out" situations so that the practitioner recognizes the innate capacity for mindfulness for the whole of life and may realize mindfulness in daily discourse. Thus, a digital device—appropriately devised, developed and applied—is not against the principles of applied mindfulness. "Time-out" mindfulness practice is best taught and practiced with a view to 'mindfulness in all the tasks of life and in association with all the things (including human artefacts) in daily living'. In addition, many activities in normal life are performed while "on the move" where mindfulness would seem to be even more necessary and beneficial. Our body movements have become habitually fast and non-mindful. When we are moving, our mind usually wanders, and the body moves in autopilot mode. Technology can enable us to practice mindful movement anytime, anywhere - when walking in a shopping mall or standing in a queue to enter a museum. *ARF* creates a valuable opportunity to turn our daily habitual bodily movements into mindful practices and mindful living.

8.3 Design Implications

Mobile phones are very popular, everyday objects. Even though our framework is developed for mobile phones, the implications of the framework could be applied to any human artifacts. The reason we started with a mobile phone is that it unites both the input interface and output interface in a compact form, which fits in everyone's pocket offering easy accessibility and portability. The input/output interface can also be well separated: what if we mindfully move a wearable device, the lighting in the room changes, or the TV starts displaying engaging digital effects. In addition, different kinds of sensors (e.g., motion, pressure, vision) could be integrated into everyday objects as the input interface.

Since our interactive framework can turn a mobile phone into a mindfulness tool, this approach can turn every daily object into an agent that can guide attention into the present moment. This is significant, as almost all objects in our lives are designed with a focus on utility (i.e., usefulness), which encourage mindless and automatic behaviors. But there is also the 'existential' aspect of everyday objects, which is that they are part of the here and now. Our framework could enable digital design to augment every object to encourage mindful interactions. Our work on smartphones could be an initial step for conscious holistic living.

9 CONCLUSION

Our motivation is to use mindfulness practice as a tool to enhance human well-being. We present a new interactive framework (*ARF*) for self-regulated mindfulness technologies, which allows users to self-regulate their attention through static and kinetic meditations. *ARF* presents a subtle approach to detect attention (via movement) and sheds light on generic features of mindfulness for spontaneous self-regulation (via attention to pace and continuity). *ARF* also proposes appropriate feedback design for mobile applications (soft stimuli). By developing two design cases, and conducting several evaluation studies, we demonstrated that the design cases can achieve positive results in improving mindfulness, mood, well-being, and so on, and can be comfortably used in busy environments like public places (for static meditation). The framework also provides an opportunity to practice mindfulness in different postures based on user preferences (within kinetic meditation practice). Due to the ease of access and lower cost compared with apps that use biofeedback devices, our work creates the opportunity for mobile applications to be more widely adopted and more useful, and this may lead to greater well-being in society.

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