An Empirical Investigation of Human-Engaged Computing through Mindfulness-based Mobile Applications

by

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ABSTRACT

An Empirical Investigation of Human-Engaged Computing through Mindfulness-based Mobile Applications

Human-Engaged Computing (*HEC*) (Ren, 2016) aims at creating synergized interaction between humans and computers to enhance human capabilities, emphasizing on human *softer* skills such as focus, mindfulness, and self-control. In this dissertation, we investigate *HEC* through the lens of *mindfulness* as it is a valuable salient human skill.

Mindfulness practices are well-known for their benefits to mental and physical well-being. Nevertheless, the practice of mindfulness is difficult in particular for novices and practitioners with insufficient attentional capabilities. Technological aids still meet the design challenges, e.g. biofeedback devices require dedicated accessories and mobile applications cannot support well attention regulation due to lack of feedback. This dissertation presents a theory-based overarching interactive framework - *Attention Regulation Framework* (*ARF*) for Mindfulness-based Mobile Applications (MBMAs) which composes of three components (detection, feedback, regulation). Following *ARF*, two design cases were developed for *static* and *kinetic* meditations. Four studies were conducted to evaluate *ARF*. A further study was also conducted to understand the effect of human senses in interactive practices. We found that: (i) Users could succeed to train mindfulness in both static and kinetic forms. (ii) In the static meditation, the design case has a unique advantage for practicing in a busy environment, while an existing application lacks the support. (iii) In the kinetic meditation, the design case allows users to train in different postures according to their preferences. (iv) Users can achieve significant improvements on different aspects after short-term interventions with the design cases. (v) The effectiveness of human senses can be defined by their respective roles in maintaining the balance between relaxation and focus.

The main contributions of this dissertation are: (i) Providing the first-ever framework for self-regulated mindfulness technologies including detection, feedback, and regulation

mechanisms. (ii) Proposing smartphones as a subtle approach to support self-regulation in everyday life. (iii) Demonstrating the first rigorous investigation of mindfulness apps. (iv) Providing theoretical and practical implications for the future development of self-regulated mindfulness technologies.

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DEDICATION

to my dear wife, **Mitra**

&

to our beloved friend, **Hannah** who is no longer with us

CHAPTER 1

PREFACE

1.1. Human-Engaged Computing

The relationship between Humans and Computers has been the significant debates of the Human-Computer Interaction (HCI) community. HCI pioneers criticized the prevailing human-technology paradigm for focusing on making technological progress rather than on realizing human potential through technological progress. The debate first has been proposed in 60's by Licklider called Man-Computer Symbiosis (Licklider, 1960). Later Douglas Engelbart introduced Augmented Human Intellect (Engelbart, 1962). This thinking and paradigm shift continued by HCI experts (Farooq, Grudin, Shneiderman, Maes, & Ren, 2017; Shneiderman & Maes, 1997) emphasizing on utilizing the human body through augmented technologies (Maes, 2017) or proposing a symbiotic partnership between human and computer (Farooq et al., 2017). Nevertheless, despite past work, researchers still have not adequately explored the use of information technology to fully develop the user's human capabilities and human capacities in general.

To address the above concern, Xiangshi Ren proposed *Human-Engaged Computing* (*HEC*) framework (Ren, 2016) aiming to leverage the synergy between humans and computers (see Figure 1). The framework aims to exploit various eastern and western notions of *Engagement* so as to integrate both holistic and analytical approaches into wider interaction design potentials. Engagement is "*a state of consciousness in which one is fully* *immersed in and aligned with the activity at hand*" (Ren, 2016), similar to mindfulness or 'achieving flow' which is an 'optimal holistic sensory experience' (Csikszentmihalyi & Csikszentmihalyi, 1988).

On the other hand, in *HEC* overview, human capabilities are not only the physical and cognitive ones. Users' *softer* skills such as focus, mindfulness, self-control, self-motivation, empathy, and trust are equally important to the actual skills. Consideration of human softer skills by new applications and technologies would lead to greater human fulfillment and self-actualization.

In the age of ubiquitous computing, efficiency via the integration of fully developed and developing human capacities and device affordances is not only required, it is progressively achievable. Meanwhile, an interpretive approach advocates 'meaningful engagement' through which computing technology not only 'transforms people and systems' but also elevates 'prosaic experience' into 'aesthetic experience' (McCarthy & Wright, 2004) and thus into human fulfillment beyond mere utility. In this dissertation, we seek to explore *mindfulness* as a valuable salient skill which it can empower humans to survive in the fast-paced, stressful, and distracted world. We aim at developing subtle technological approaches to support mindfulness using Mindfulness-based Mobile Applications (MBMAs).

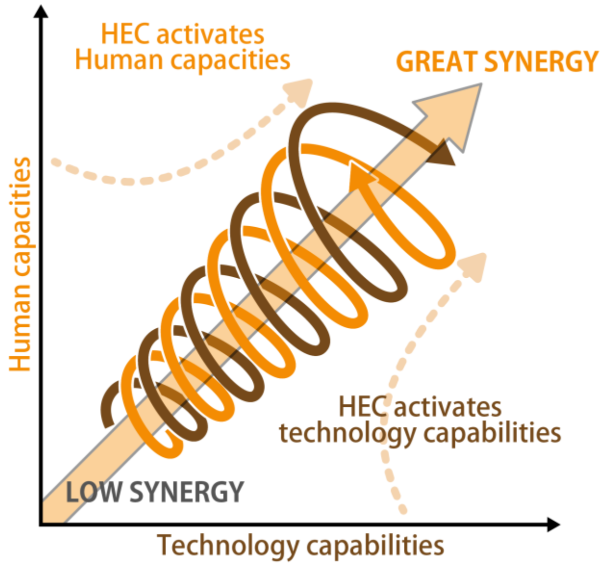

Figure 1. The concept of Human-Engaged Computing (HEC)
Synergizing human capacities and technological capabilities. Synergized interaction between human and computer helps human to realize their capacities and enhance their capabilities. The figure has been taken from the author (Ren, 2016).

1.2. Structure of the Dissertation

The dissertation is organized as follows (see Figure 2). Chapter 2 describes the motivation, contribution, and significance of the work as well as gaps in the previous research. Next, in Chapter 3, we review the related work. In chapter 4, we describe a framework called *Attention Regulation Framework* (*ARF*) focusing on the challenges of designing technologies for self-regulated mindfulness technologies. Chapter 5 elaborates the design goals. Chapter 6 describes a design case (Design 1) for static meditations. Chapters 7 and 8 includes two studies (Studies 1-2) to evaluate the design case 1. Similarly, chapter 9 discusses a design of an app for kinetic meditations (Design 2), and chapters 10 and 11 show how two experiments (Studies 3-4) support the design case. We discuss the framework, in chapters 12. Next, in Chapter 13 we explain a further study (Study 5) for better understanding the role of human senses in interactive MBMAs. Finally, in Chapter 14 and 15 we further discuss the framework, our contributions, future directions, and conclude the thesis.[1]

[1] We also conducted further studies supporting the theme of engagement including understanding individual differences on human engagement (Study 6) and developing motion video games for enhancing cognitive capabilities of the elderly (Studies 7, 8, 9). Nevertheless, considering the scope of thesis (i.e., mindfulness), we did not include them in the dissertation.

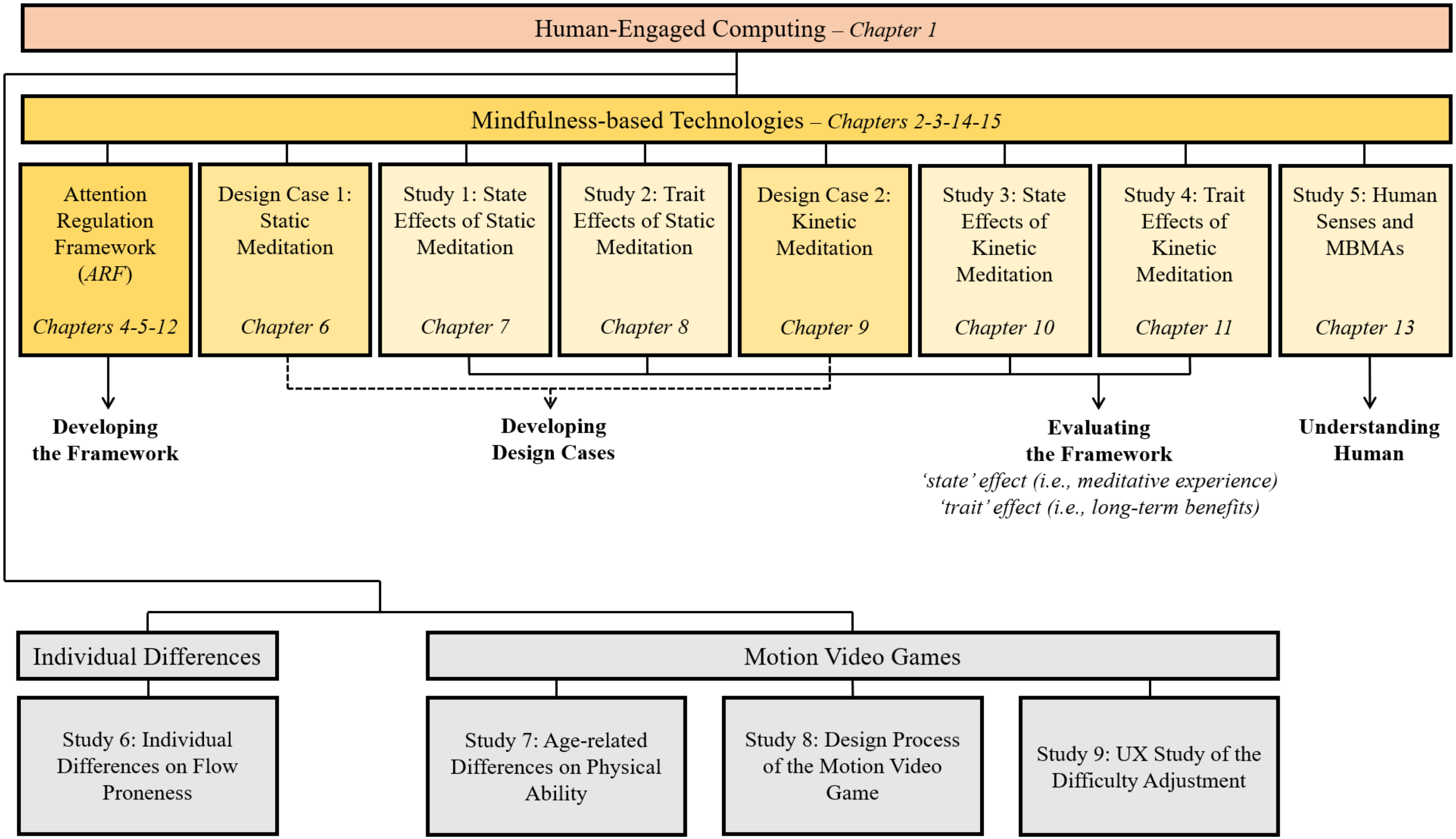

Figure 2. Dissertation Outline

CHAPTER 2

INTRODUCTION

Mindfulness practice has attracted growing interest. Scientific research demonstrates the benefits of mindfulness practice on stress (Caldwell, Harrison, Adams, Quin, & Greeson, 2010), emotional state (Zeidan, Johnson, Gordon, & Goolkasian, 2010), attention (Tang et al., 2007), and positive attitudes such as compassion (Lim, Condon, & De Steno, 2015). Broadly speaking, there are two forms of mindfulness practices (Nash & Newberg, 2013), static meditations (e.g., Zazen) and kinetic meditations (e.g., Tai Chi) where kinetic meditations can induce additional physical benefits such as balance (Jacobson, Ho-Cheng, Cashel, & Guerrero, 1997). One key component of mindfulness practice is *self-regulation* (Lutz, Slagter, Dunne, & Davidson, 2008), the ability to self-evaluate one's own progress and constantly redirect the attention back to the mindful state. For example, in walking meditation, practitioners are asked to walk slowly but consistently. When practitioners realize that they are mind-wandering off since they are walking too fast, practitioners could quickly redirect their attention back to the present moment. For another example, using meditation beads, practitioners are asked to count the beads slowly but consistently. When practitioners realize that they are wandering or snoozing off since they have lost counts of the beads, practitioners could quickly bring their attention back. The ability to detect the current state by evaluating from the contextual feedback, and to consistently bring the attention back is crucial towards the success of any mindfulness practice. As we can see, many traditional mindfulness masters are aware of this importance and thus have leveraged many kinds of mediums for this purpose.

Regardless of the importance, current technologies cannot well support such self-regulation. The current mainstream technologies come in the form of guided meditation (Roquet & Sas, 2018). Nevertheless, this approach suffers from the lack of contextual understanding of users' current state (i.e., no detection and feedback). Therefore, many users may not be able to effectively self-regulate their attention, that is, the one-way guidance could prove too fast or too slow for each user (Nash & Newberg, 2013). To support self-regulation, three key challenges remain to be addressed: (1) The first challenge is about the design of a proper detection mechanism. Technologies should be able to monitor the user's current state. One promising solution is using psychophysiological sensors (e.g. EEG, respiration (Chen, Bowers, & Durrant, 2015; Kosunen et al., 2016; Shaw, Gromala, & Seay, 2007)), where user's state can be detected in real-time. Nevertheless, such devices have an intrusive nature (Gillespie & O'Neill, 2014) that might interrupt users' meditative state (i.e., an altered state of consciousness). In addition, these devices are hardly accessible and thus defeat the whole purpose of wide distribution to daily users. (2) The second challenge is about giving the right feedback to inform users regarding their current states. The key here is that the right feedback should not induce any "judgmental" thoughts during meditation (e.g. right or wrong) (Baer, 2003; Kabat-Zinn, 2009), and thus we have to be cautious regarding the design of feedback. (3) The third challenge is regarding the regulation technique. There are many possible "interaction" techniques and in which we can learn from traditional approaches, such as performing gross-motor movements (e.g. walking meditation, Yoga, Tai-Chi, Qigong), fine-motor movements (e.g. Tibetan singing bowl, Buddhist prayer beads), and using meditative mediums (e.g. breathing, mantra). The key here is to choose suitable techniques that are compatible with current technologies, and that could fit well with challenge 1 (i.e., the progress of the technique can be detected) and 2 (i.e., audio/visual/haptic feedback is technologically appropriate and non-intrusive for that particular technique).

In sum, there are three research questions to be addressed: (1) How technology can detect the user's attentional states, and without using any dedicated accessories? (2) What is the appropriate feedback that would not induce judgmental thoughts? (3) What are the possible interactions techniques for regulation?

This dissertation presents a novel framework for self-regulated mindfulness technologies - *Attention Regulation Framework (ARF)* (see Figure 3 for the high-level description). *ARF* is developed in particular to address our three aforementioned research questions. *ARF* is a closed-loop process and is theoretically grounded. To demonstrate and evaluate *ARF*, two design cases were developed (Chapters 6 and 9) based on two common mindfulness practice scenarios (i.e., static and kinetic). On the other hand, given the pervasiveness of smartphones, we focused on mobile applications as a platform for design cases (a.k.a, Mindfulness-Based Mobile Applications (MBMAs)).

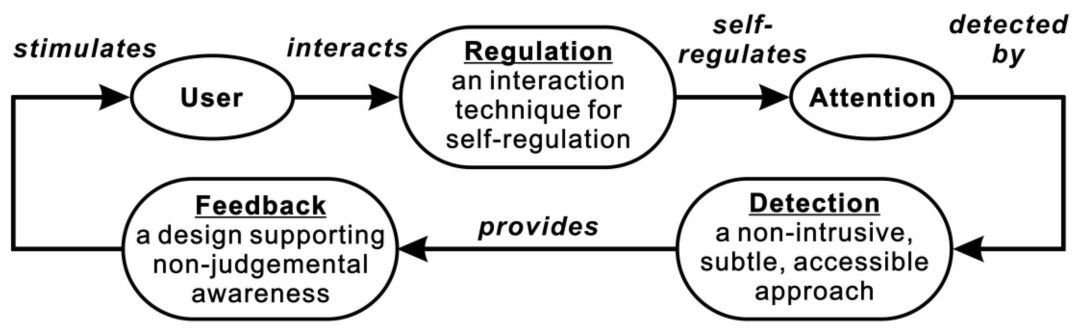

Figure 3. Schematic diagram of *ARF* (a high-level description)
Technology detects user's attention and provides a feedback which stimulates user awareness. Then, user regulates the attention through the proposed interaction. The cycle continues during the practice.

Four studies (Studies 1-4) were conducted to assess 'state' effect (i.e., meditative experience) and 'trait' effect (i.e., long-term benefits) of *ARF* (Cahn & Polich, 2006; Nash & Newberg, 2013). We compared the design cases with state-of-the-art guided meditation MBMAs to understand how the design cases with the use of *ARF* perform against the MBMAs without the use of *ARF*. Some key findings include: first, we found that the design case had a better performance in a busy environment. This is a very interesting result as it suggests that our framework is quite robust against noises and distractions (which are considered by some the biggest enemies of mindfulness practice). Second, our results demonstrated that our kinetic design case allowed participants to self-regulate using various postures (i.e., different interactions). The findings are notable because it helps to support users with different interaction preferences (i.e., users with mobility differences). Third, we found that after an intervention, our static design case had a better performance in improving attention and had achieved similar improvements in mood and general well-being. Our kinetic design case also offers significant improvements in both mental (e.g., mindfulness) and physical (e.g., balance) aspects. In addition, we conducted a further study (Study 5) to understand the relationship between human senses (e.g. touch, audio, and vision) and interactive meditation. Overall, we found that *ARF*, as investigated through the design cases, is a beneficial approach to develop self-regulated mindfulness technologies.

To conclude, this dissertation integrates mindfulness into people's everyday lives by leveraging the interactivity capability of smartphones and it provides theoretical and practical implications for the future development of MBMAs.

CHAPTER 3

RELATED WORK

This chapter provides an overview of traditional mindfulness practices and different approaches of technology-mediated mindfulness systems.

3.1 Traditional Mindfulness Practices

Mindfulness practice could be broadly categorized into static meditations (i.e., stationary body but not necessarily immobile) and kinetic meditations (i.e., usually movement of the extremities) according to the level of physical exertion required (Nash & Newberg, 2013). Some examples of static meditation are Samatha, Vipassana, and Zazen practices where practitioners pay attention to their breath, repeating a mantra, or visualizing an object. There is abundant evidence regarding the benefits of static meditation toward increasing attention span (Jha, Krompinger, & Baime, 2007), regulating mood (Tang et al., 2007), and enhancing well-being (Nyklícek & Kuijpers, 2008). On the other hand, for people who are restless and vigorous (Stout, 2017), 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 (Larkey, Jahnke, Etnier, & Gonzalez, 2009). Tai Chi, Yoga, Qigong, Feldenkrais method, and Walking Meditation are various forms of the kinetic meditation. A growing body of literature demonstrates that kinetic meditation not only has similar effects to static meditation (e.g. mood (Johansson, Hassmén, & Jouper, 2011; Lavey et al., 2005; Prakhinkit, Suppapitiporn, Tanaka, & Suksom, 2014), mindfulness (Curtis, Osadchuk, & Katz, 2011; Schure, Christopher, & Christopher, 2008), body awareness (Dittmann & Freedman, 2009; Mehling et al., 2011), well-being (Rani et al., 2011; Sandlund Erica & Norlander, 2000), quality of life (Gard et al., 2012)) but it can also yield additional physical improvements such as proprioception (Xu, Hong, Li, & Chan, 2004), stability (Hart & Tracy, 2008), balance (Jacobson et al., 1997), and postural adjustment (Forrest, 1997). Based on this information, the design cases were developed according to these two common categories of mindfulness practice.

3.2 Technology-mediated Static Meditations

Using technology for mindfulness has attracted much recent attention. A large part of the literature is based on static meditation. The most common approaches used 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) (Kosunen et al., 2016) or physiological sensors such as skin conductance (Gromala, Tong, Choo, Karamnejad, & Shaw, 2015; Shaw et al., 2007; Snyder et al., 2015), heart rate (HR) (Roo, Gervais, Frey, & Hachet, 2017), respiration (Hao & Chan, 2017; Pisa, Chernyshov, Nassou, & Kunze, 2017; Roo et al., 2017; Ståhl et al., 2016; Vidyarthi & Riecke, 2014) and pulse-rate (Shaw et al., 2007).

For "feedback", previous studies proposed integrating *biofeedback* into *dedicated rooms* (e.g. MoodLight (Snyder et al., 2015), Breathing Light (Ståhl et al., 2016), Sonic Cradle (Vidyarthi & Riecke, 2014)), *immersive VR* (e.g. RelaWorld (Kosunen et al., 2016), Virtual Meditative Walk (Gromala et al., 2015), Meditation Chamber (Shaw et al., 2007)), and *spatial augmented reality* (e.g., Inner Garden (Roo et al., 2017)). While most of the methods developed a soothing audio-visual feedback (Gromala et al., 2015; Kosunen et al., 2016; Roo et al., 2017; Shaw et al., 2007), few studies focused only on visual feedback (e.g., lighting (Snyder et al., 2015; Ståhl et al., 2016)), and some studies used audio feedback (e.g. user's own breathing sound (Pisa et al., 2017), relaxing sound (Vidyarthi & Riecke, 2014)).

For "regulation", most of the studies proposed focusing on objects as mediums to support self-regulation such as breath (Gromala et al., 2015; Pisa et al., 2017; Roo et al., 2017; Ståhl et al., 2016; Vidyarthi & Riecke, 2014), a 3D virtual object (Kosunen et al., 2016; Shaw et al., 2007), or a bubble light (Snyder et al., 2015). Few studies used *tangible artifacts* as interaction techniques. For example, Inner Garden (Roo et al., 2017) has been 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 (Ståhl et al., 2016) 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" mechanism, most of the biofeedback and wearable devices have an intrusive nature (Gillespie & O'Neill, 2014) which they might increase the user's burden and that might thus interrupt user's meditative state (i.e., an altered state of consciousness). In addition, the user requires special access to these devices which is not commonly available. Second, regarding the "feedback" design, none of the earlier studies provide an overarching explanation or design guidelines on how to tackle the challenges of feedback design. Third, regarding the "regulation" technique, these approaches may not support self-regulation in different scenarios. For example, it may be difficult to implement the biofeedback methods (e.g., EEG) in kinetic meditation due to motion artifact in the bio-signal. Moreover, they may not support the required mobility in conducting movement practices. Our study aims to mitigate this limitation by proposing an alternative method, without the use of any dedicated biofeedback devices.

3.3 Technology-mediated Kinetic Meditations

A number of platforms have been proposed for kinetic meditation. Some of these platforms (Han, Chen, Zhong, Wang, & Hung, 2017; Iwaanaguchi, Shinya, Nakajima, & Shiraishi, 2016; Portillo-Rodriguez et al., 2008) were designed based on imitation process that users can practice gross-motor movements through mimicking the instructor. For example, an earlier study (Portillo-Rodriguez et al., 2008) 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 (Han et al., 2017) developed an augmented reality Tai Chi trainer using an HMD and a drone to provide appropriate visual guidance using redundant augmented instructors from different angles.

On the other hand, there is a paucity of studies (Chen et al., 2015; Yu, Wu, Lee, & Hung, 2012) which have focused only on walking meditation. Breathwalk-Aware (Yu et al., 2012) is a closed loop system which provides an audio-visual feedback according to footsteps and breath patterns. The system helped users to reduce their gait speed and decrease incorrect 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), or Tibetan prayer wheels (e.g., Channel of Mindfulness (Wang, 2012)). Both use technology to sense the particular pattern of movement (i.e., fine-motor movement) required by the associated meditation artifact and augment them with meaningful digital experiences such as rewards when a user achieves the right movement pattern.

As it is implied in this and previous section, although many promising approaches have been developed, because of the requirements of these “dedicated” accessories, they are hardly accessible to daily users, and consequently, the adoption rate suffers. Our idea is to propose a framework that would enable the development of “widely” accessible technology that would not require dedicated accessories.

3.4 Mindfulness-Based Mobile Applications (MBMAs)

The increasing prevalence of smartphones has created a unique opportunity for Mindfulness-Based Mobile Applications (MBMAs). There are many examples of mobile applications available on application stores which were developed for static (Headspace[2],

[2] https://goo.gl/Df3qqB

Buddhify[3], Calm[4], and Smiling Mind[5]) and kinetic meditations (e.g., Meditation Moves[6], 7-Minute CHI[7], Tai Chi Fundamentals[8], Pocket Yoga[9]). These mobile applications primarily used the guided meditation method which requires users to listen and/or watch instructions. In static mobile applications users usually close the 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*") (Headspace meditation limited, 2016). In particular, for the static meditation, guided mobile applications require users to find a quiet spot (E. Shapiro & Shapiro, 2012; Watkins, 2015). Nevertheless, a lack of expertise and personalized guidance could prevent practitioners from following all instructions in a precise way. That is, the pace could prove to be way too slow or too fast for certain users.

Similarly, in the kinetic mobile applications, users watch and imitate the movements conducted by an instructor while listening to instructions (e.g., "*raise your hands gently in front of your chest as if you were about to start playing the accordion*") (PPL Development Company LLC, 2010). However, guided meditation as a non-interactive passive approach (i.e., no feedback) does not take into account users' expertise, users' mobility differences and preferences. For examples, it may not work well in particular circumstances such as for practitioners who function at a slower pace (e.g., novices) or for practitioners who cannot learn and explore complex techniques.

Besides the MBMAs in the market, there are very little studies in academia exploring the design space of MBMAs. Mole and his colleagues developed MindfulBreather (Mole TB, Galante J, Dawson A, Hannah L, Walker I, Mackeith P, Ainslie P, 2017), 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). At the same moment, users have to tap the screen in the right time during inhalation to receive relaxing audio feedback. Although this work proposed the detection, feedback, and regulation

[3] https://goo.gl/2sihSq
[4] https://goo.gl/JvKRwP
[5] https://goo.gl/zmSZrd
[6] https://goo.gl/mwk489
[7] https://goo.gl/1bpW8K
[8] https://goo.gl/RaQTfw
[9] https://goo.gl/xUYHwg

elements, the technique is difficult to perform for users as it requires users practice only in lying position.

Our work aims to integrate "self-regulation" as the key component in the design of mindfulness technologies, that is, users can self-evaluate their own progress, and then adapt accordingly based on their own capabilities. In a way, one can imagine our work as a personalized approach. Our philosophy is that users know what is best for themselves, and this is a very important philosophy, as people differ vastly in their abilities and expertise.

3.5 Human Senses and MBMAs

Given their prevalence, smartphones provide viable platforms to support meditation with more than 300 meditation relaxation apps in app stores. Since attention and relaxation are mediated through the human senses, meditation apps can be categorized according to the human senses (Calvert, 2001; Scott, 2017). Here, we focus on the three most commonly used senses applied in smartphone meditation apps: audio, vision, and touch.

Audio-based meditation comes in many forms. For example, in Mantra meditation, practitioners repeatedly chant a mantra (Boswell & Murray, 1979). Nature sounds and singing bowl sounds have also been used (Alvarsson, Wiens, & Nilsson, 2010; Guzzetta, 1989; Laurie & Blandford, 2016; Monteiro et al., 2016; Schmid & Ostermann, 2010). *Vision-based* meditation comes mainly in the form of gazing at the shape of neutral visual stimuli such as nature scenes (Valtchanov, Barton, & Ellard, 2010), calming visualizations (Snyder et al., 2015; Vacca, 2016), a burning candle, or a lava lamp (Chowdhary, 2015). This has since been verified by Attention Restoration Theory (S. Kaplan, 1995) which states that spending time with soft cognitive stimuli such as a forest or an ocean can lead to a state of meditation. *Touch-based* (sometimes called body-based) meditation exploits the principle of relaxation response theory (Benson, Beary, & Carol, 1974) which states that slow deliberate movement can stimulate heightened attention. This principle is reflected in many traditional meditation methods such as Tai Chi, Yoga and Qigong (Schure et al., 2008). One example of touch-based meditation apps is to focus on finger tap on the smartphone screen as described in Section 3.4 (Mole TB, Galante J, Dawson A, Hannah L, Walker I, Mackeith

P, Ainslie P, 2017). Moreover, several meditation apps also leverage combinations of audio, vision, and touch to support meditation.

Prior studies reveal that little evaluative work has been done on the effects of the various human senses in meditation relaxation applications. The main goal of our study in Chapter 13 is to understand how different human senses affect relaxation experience while using meditation apps. How does vision-only compare with audio-only meditation? Do combinations of senses, e.g., vision and audio together facilitate relaxation better than single sense apps e.g., vision-only? How do subjective preferences affect relaxation? Our findings will allow designers to better exploit the senses in meditation apps and also in multi-modal interaction in general.

CHAPTER 4

ATTENTION REGULATION FRAMEWORK

We developed an overarching framework to support self-regulation in mindfulness practices, called *Attention Regulation Framework* (*ARF*, see Figure 4a). *ARF* is a closed-loop attention regulation process through detection-feedback-regulation mechanisms. By discussing the theoretical principles, we describe features of mindfulness and explains how to incorporate such features into the interaction design. We also discuss the characteristics of feedback design to help users sustain attention while avoiding self-judgment in the practice. As a reminder, our *ARF* addresses three key questions in the theoretical level: (1) How to *detect* user mindful states? (2) What are some suitable *feedback* elements that are mindfulness-friendly, and (3) What are some suitable *regulation techniques* for regulating ones' mindfulness?

4.1 Detection

ARF aims to address the challenge of detection without using dedicated accessories. This is initially a difficult problem because without any bio-tools, it is quite unimaginable how we can detect user current states. To this end, we found *Embodied Cognition* (Stern, 2015; Wilson, 2002) as a very useful theory in addressing this challenge. Theories of embodied cognition simply pointed out that our mind and body are remarkably intertwined, and the way that we perceive the world is highly influenced by our body and vice versa. This implies that any change in our body 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) (Lucas, Klepin, Porges, & Rejeski, 2016) of the movement, moving the body creates interoceptive (i.e., organ-based), kinesthetic (i.e., movement-based), and proprioceptive (i.e., spatially-based) senses. The generated senses can act as an immediate, continuous, and distinguished feedback (Clark, Schumann, & Mostofsky, 2015) that stimulate the awareness (Salmon, Hanneman, & Harwood, 2010) and support self-regulation. Indeed, in the eastern form of meditation, there are many use-cases of embodied cognition such as Buddhist prayer beads, Tibetan prayer wheel, Chinese meditation balls, and Tibetan singing bowl which all use tangible artifacts to direct attention to the body and movement.

Putting the pieces together with detection, embodied cognition can enlighten us that it is actually possible to detect users' state through their bodily behaviors 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 where instead of directly detecting user states using physiological tools which could be obtrusive, embodied cognition suggests us that we could unobtrusively assess users' state through their bodily behaviors. Indeed, this approach is not new and is long-known by century-old meditation masters where they have exploited various bodily mediums for training mindfulness. It becomes now our HCI goal to integrate this principle into our detection design.

4.2 Feedback

Feedback is another important component of self-regulated mindfulness practice, where the goal of feedback is to inform users to bring their attention back to the present moment. The challenge lies in the constraints where the feedback design should inform users yet without inducing any judgmental thoughts (i.e., evaluating the experience as a right or wrong) or causing any heightened emotional changes (e.g., become frustrated or sad) (Baer, 2003; Kabat-Zinn, 2009). 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.

4.2.1 Soft Fascinations

Attention Restoration Theory (S. Kaplan, 1995) 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 landscape (Berman, Jonides, & Kaplan, 2008; R. Kaplan, 2001) or listening to a birdsong or sound of a waterfall (Alvarsson et al., 2010; Ratcliffe, Gatersleben, & Sowden, 2013). 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 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.

4.2.2 Feedback Modality

Our exploratory study of static meditation presented that while audio modality is an effective element for relaxation, visual modality can help for better focus (Study 5, see Chapter 13). The study concluded integration of those modalities in different states of the user to achieve a better user experience. Consistently, the findings of the Breathwalk-Aware study (Yu et al., 2012) demonstrated that using audio-visual feedback is more effective for correct footsteps than using only visual or only audio. On the other hand, there were few attempts to use haptic feedback in mindfulness applications. For example, researchers developed atmoSphere (Tag et al., 2017), a haptic sphere ball which combined audio and haptic feedback based on users' breathing rhythms. Another work (Bumatay & Seo, 2015) 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 on the efficacy of haptic on self-regulation and mindfulness experience. In addition, earlier studies (Bumatay & Seo, 2015; Tag et al., 2017) used haptics as a regulation technique and not as a feedback mechanism.

There is also a wealth of studies in rehabilitation (Hatzitaki, 2015; Rosati, Rodà, Avanzini, & Masiero, 2013; Vogt, Pirrò, Kobenz, Höldrich, & Eckel, 2010) and sports training (Kleiman-Weiner & Berger, 2006; Schaffert, Mattes, & Effenberg, 2010; Spelmezan & Daniel, 2012) demonstrating the use of multimodal feedback to facilitate attention to the movement. Notably, most of the literature suggested the use of audio feedback. For example, in physiotherapy (Vogt et al., 2010), audio feedback of motion including music and speech could increase body movement awareness. In the rowing sport (Schaffert et al., 2010), sonification (i.e., perceptualizing each motion and transferring it to users in a form of sound) improved motor performance of the rowers and increased the boat's speed. Furthermore, more recent studies (Singh et al., 2016; Singh, Bianchi-berthouze, & Williams, 2017; Tajadura-Jiménez et al., 2015) have utilized the latest wearable technology, and demonstrated the effectiveness of audio feedback on increasing sense of control in daily movements (Singh et al., 2017) and changing users' emotional valence, perceived body weight and gait patterns in walking (Tajadura-Jiménez et al., 2015). Besides, there is evidence showing the beneficial effects of haptic feedback and tangible interactions on leveraging motor performance including higher precision and better learning (Lee & Choi, 2010; Mott, Donahue, Poor, & Leventhal, 2012). Although the mentioned methodologies did not focus on mindfulness per se, they can guide our framework for a better feedback design.

To conclude, *ARF* informs technology to select multimodal feedback. Audio feedback could be implemented in design in the forms of soothing music, verbal instructions or alert sounds. 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 (Schönauer, Fukushi, Olwal, Kaufmann, & Raskar, 2012). Nevertheless, designers have to be cautious about using haptic feedback as it may interrupt users' mindfulness experience. Furthermore, designing a promising haptic feedback usually requires dedicated accessories which is out of the scope of our two design cases. Consequently, our two design cases use a combination of audio and visual feedback as soft-cognitive stimuli.

4.2.3 Instructions

To support self-regulation in bodily movements, it is necessary to provide proper instructions to the user. 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. During a movement, based on the direction of attention, the attentional focus has been categorized into internal focus and external focus (Moran, 2016; Nideffer & Sagal, 1993). Internal focus is paying attention to inner, vestibular and proprioceptive cues, while the external focus is paying attention to environmental cues. Meditation experts usually have a higher awareness of internal focus compared to external focus (Fiori, David, & Aglioti, 2014). 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 mindfulness experience (Pantano & Genovese, 2016).

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 text feedback could guide users to focus internally and eventually 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, which would well foster mindfulness.

4.3 Regulation Techniques

Here we ask the question that what kinds of interaction techniques could be applied to mindfulness practice. To answer this, we refer to the *Relaxation Response* principle (Benson et al., 1974). "*Relaxation Response is a physical state of deep rest ... and the opposite of the fight or flight response*" (Benson et al., 1974). 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. Relaxation response can be elicited through the slow repetition of a word, a sound, breathing or a *movement*.

As mentioned in Section 4.1 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 (Salmon et al., 2010). This reflects the common properties of Tai Chi, Yoga, Qigong, and Walking Meditation which are slow, continuous and gentle movements.

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

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

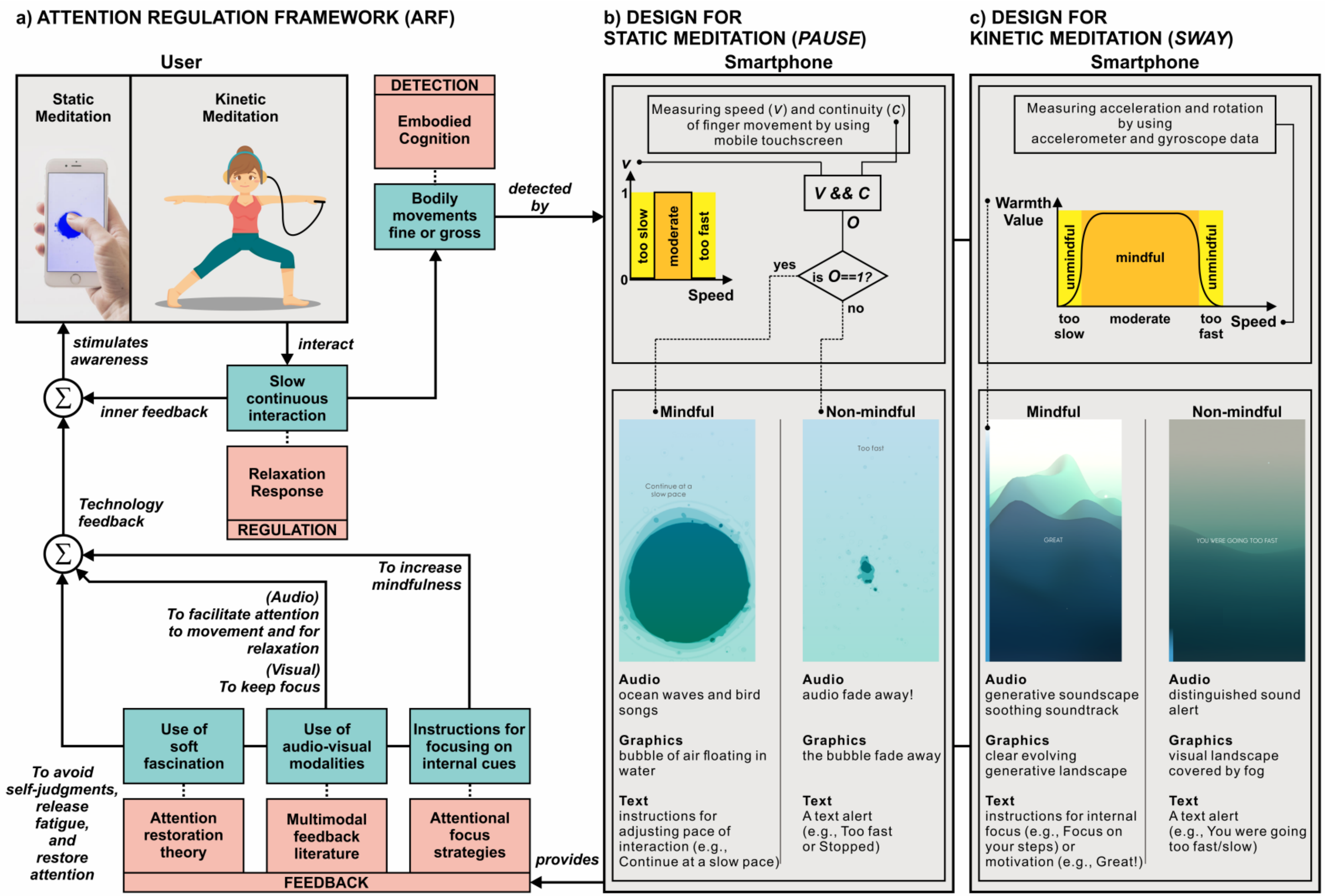

Figure 4. Overall framework and design
(a) The Attention Regulation Framework (*ARF*) (b) design elements of *PAUSE* (static meditation) (c) design elements of *SWAY* (kinetic meditation)

CHAPTER 5

DESIGN GOALS

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

To demonstrate *ARF*, two design cases were developed under two common meditation scenarios, called *PAUSE* for static meditation (Figure 4b) and *SWAY* for kinetic meditation (Figure 4c). Given the pervasiveness of the mobile platforms, the two design cases are implemented as mobile applications (MBMAs). The following two chapters describe how the two design cases can achieve the design goals at the practical level.

CHAPTER 6

DESIGN CASE 1 - STATIC MEDITATION

Here we explain the design mechanisms for static meditations including the interaction mechanism, the pace of interaction, audio feedback, and visual feedback (Figure 4b). A static meditation MBMA (*PAUSE*[10]), has been developed to demonstrate the *ARF*. *PAUSE* has been developed through an iterative process (Cheng, Lucero, & Buur, 2016). However, in this chapter, we only present the final design.

PAUSE adopts repetitive, slow touch movements from embodied cognition and relaxation response which states that such movement can lead to heightened awareness and mindfulness. According to the literature in multimodal feedback, audio and visual modalities have been chosen as feedback elements. Following the attention restoration theory which 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.

Touch interaction was chosen 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 5a). To move the finger slowly, continuously and repeatedly, sustained attention is required. Soft audio-visual cognitive stimuli were also designed. The amorphous image of a bubble of air floating in water combined with randomly displayed gradients and variations of motion were used to provide a feeling of

[10] http://www.pauseable.com/

something organic, random, minimalistic and airy which promotes effortless reflection. The sound of ocean waves and bird songs with a sweeping sound around one chord were used. This provides an un-intrusive repeating and soothing loop which allows the practitioner to focus within the required parameters of the slow repetitive finger movement. To adjust the pace of the interaction, text guidance was used to train users through the slow mindful interaction. Also, 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 interaction mechanism was implemented such that the phone generates sound and audio feedback only when it detects slow, continuous and repetitive finger movements (Figure 5b). The sound is the mechanism in the feedback loop that effectively calms the mind. The visual part works as an anchor to engage the mind. If the finger moves too fast, or stops, or is lifted from the screen, the amorphous audio-visual feedback fades away immediately to inform the user that they have lost control of the steady, deliberate movement. The moment the user returns to attention within the required movement parameters, the feedback fades back in. Visual feedback gradually transitions to a sound-only experience (Figure 5f), when people close their eyes. By confining the interaction to strict parameters, sustained mindful attendance is proactively encouraged.

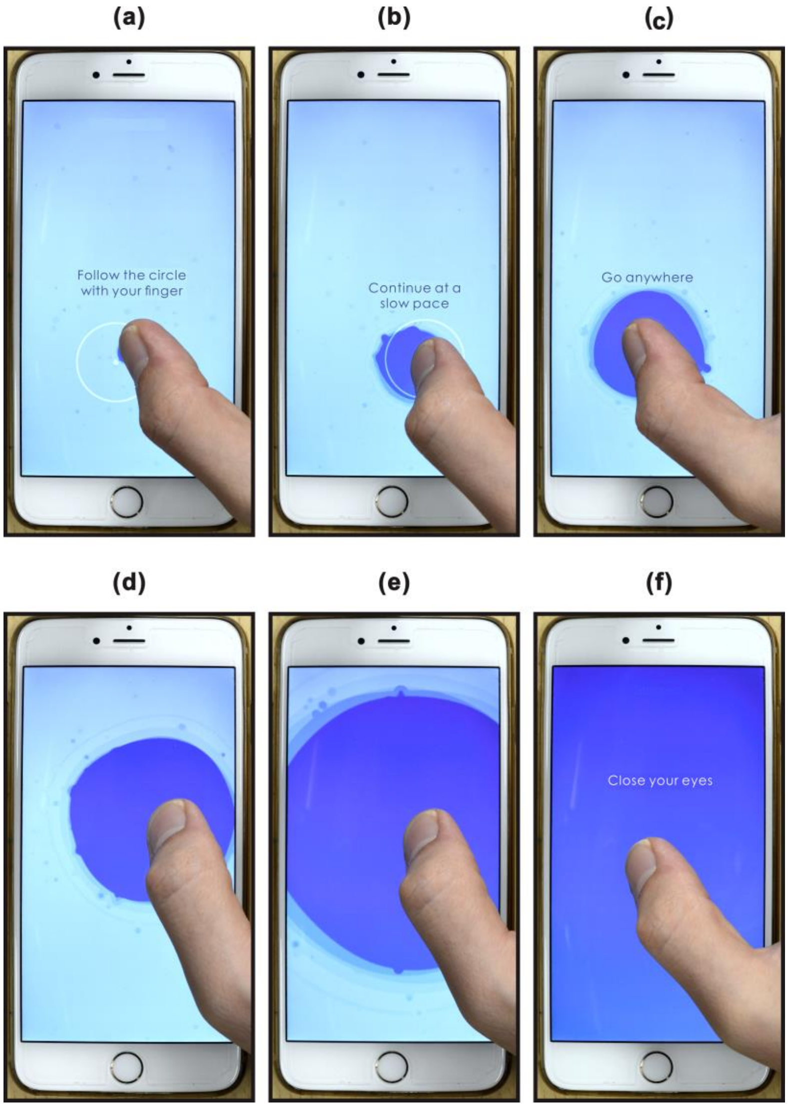

Figure 5. Interaction steps with the static design case (*PAUSE*)
(a). First, the user starts to follow the white circle with the finger on the screen. The audio is playing. (b) An amorphous floating air-bubble appears. *PAUSE* prompts the user to move the finger slowly. (c) The user freely moves the finger over the whole screen repetitively, continuously, and slowly. (d) *PAUSE* keep on generating feedback while there is slow, continuous and repetitive finger movement. The floating bubble of air gets bigger. The audio continues playing. (e) The bubble size increases provided the user does not stop moving the finger and does not move it too fast. If movement is not sustained within these parameters, the bubble will fade away to remind the user to return to and maintain necessary attention. In case of lost attention, the user needs to repeat the process from step b to return to a properly attended interaction. (f) Finally, the floating bubble of air covers the whole screen, and *PAUSE* asks the user to close the eyes and to continue with the finger movement. Users should keep on moving in a slow and repetitive manner. Otherwise, the feedback will fade out to remind the user to bring the attention back.

CHAPTER 7

STUDY 1: ENVIRONMENTAL STUDY

Study 1 aims to investigate how well the static design case can perform (state effects) compared to an existing mobile application in different environmental settings. We selected *Headspace* which uses the traditional guided meditation method[11]. Since *ARF* emphasizes attention regulation, can *PAUSE* outperform *Headspace* in busy environments (i.e., noisy)? And how does *PAUSE* perform in calm environments (i.e., no noise) compared to *Headspace*?

7.1 Methodology

7.1.1 Experimental Design

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

7.1.2 Participants

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[11] *Headspace* is one of the most downloaded Apps with around 11 million downloads and 400,000 paying subscribers in the last five years (Chaykowski, 2017).

Eleven individuals (3 females) participated (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. Participants were compensated with $10.

7.1.3 Apparatus

An iPhone 6 Plus and its original headphones were used for running the mobile applications. The *Headspace* app was downloaded from the Apple App Store. Heart rate was measured using a Polar H7 heart rate sensor. To measure EEG, a g.SAHARA dry electrode system and a g.USBamp USB biosignal amplifier were used. MATLAB 2010a and g.BSanalyze software were used for recording and analysis. All processes were run on Intel(R) Core(TM) i7-2620M 2.7 GHz CPU on DELL Precision M6600 laptop with Windows 7. Participants were provided with a desk and table for training mindfulness in a quiet room and in a cafeteria respectively. A Sound Level Analyzer Lite - Simple dB Meter was used to check and record sound levels.

7.1.4 Task and Procedure

Participants were asked to sign a letter of consent. Background information including daily stress and meditation experience was gathered. Participants were introduced to both apps. For this purpose, they were allowed to use each app for five minutes. Participants were trained in a total of four conditions including *PAUSE*-Calm, *PAUSE*-Busy, *Headspace*-Calm, *Headspace*-Busy (Figure 6). Conditions were counterbalanced using a Latin square to minimize the learning effect. Each condition was conducted in one day and included four 10-minute blocks with five minutes breaks between them. The experiment for the Calm was run in a quiet meeting room with 28.7 - 36.5 decibel (dB) range. During training, only the experimenter and the participant were in the room (see Figure 6a). However, the experiment in the Busy was conducted in the university cafeteria during lunchtime (i.e., rush hours) with a background noise range of 52.5 - 75.1 dB (see Figure 6b). The noise mainly included conversations of students, the sound of moving chairs on the floor, general ambient noise, and cafeteria music. In addition, some of the participants reported perceiving a feeling of pressure because many students were watching them during their practice.

The heart rate 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, they 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 one 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. 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%. During rest time, the experimenter casually talked with the participant about different topics to restore her/him to the normal mental state. After the fourth day of training, a semi-structured interview was conducted. The whole experiment was video recorded.

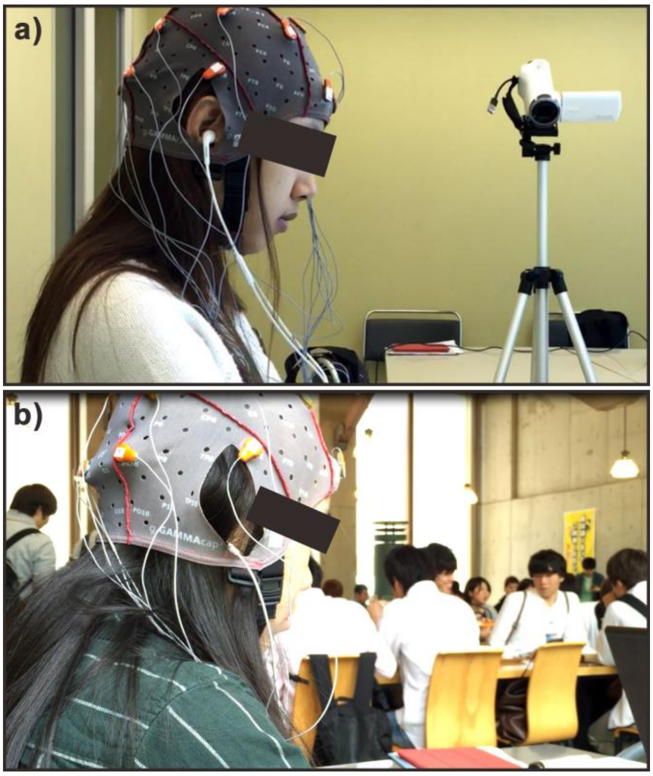

Figure 6. Experiment setup of Study 1
A participant meditating (a) in a room (calm environment), (b) university cafeteria (busy environment).

7.1.5 Measures

Mindfulness practice can impact users' autonomic nervous system (Tang et al., 2009) which unconsciously regulates bodily functions. Therefore, we gauged the performance of *PAUSE* and *Headspace* by measuring physiological and electrophysiological metrics. Previous work reported the effect of relaxation on heart rate, breathing rate, skin conductance and EEG (Tang et al., 2009). 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 (Zeidan et al., 2010) showed that a brief mindfulness meditation session can reduce the heart rate, which is counted in beats per minute (bpm). To measure the heart rate of participants, a heart rate sensor was used. The signal was recorded at 1 Hz sampling frequency. Mean heart rate and delta heart rate were extracted for analysis. Delta heart rate equals to the subtraction of minimum from maximum heart rate during practice. A decrease in mean heart rate and increase in delta heart rate correspond to better relaxation (Zeidan et al., 2010).

EEG. Spectral analysis of the EEG signal using Fast Fourier Transform (FFT) is correlated with the mindfulness state (Cahn & Polich, 2006). The power of the signal ($\mu Volt^2$) is usually studied in five main frequency bands: delta (0.5-4 Hz), theta (4-7 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-45 Hz). Among the frequency bands, theta and alpha are correlated with the mindfulness state (Sanei & Chambers, 2013). An increase in theta band activity is associated with meditative concentration, while an increase in alpha band activity indicates relaxation. Previous work (Takahashi et al., 2005) also studied low alpha (8-10 Hz) and high alpha (11-13 Hz) band activity. Takahashi et al. reported an increase in theta and low alpha band activities during Zen meditation. A review of over 60 papers (Cahn & Polich, 2006) 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 which 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 (Grummett et al., 2015). 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) which are close to the anterior cingulate cortex (ACC) and prefrontal cortex (PFC) areas, the most active areas of the brain during mindfulness meditation (Tang, Hölzel, & Posner, 2015). EEG signals were amplified and digitized through the amplifier. Signals were recorded at 256 Hz sampling frequency and filtered using a 0.1 to 100 Hz bandpass filter. EEG signals were preprocessed before analysis. Signals were passed through a 60 Hz notch filter (to remove noise in the electrical power line) and a 1-30 Hz Butterworth (12 dB/Octave) band-pass filter (to select appropriate frequency bands). 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. Theta and low alpha band activities were then analyzed.

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

7.2 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.

7.2.1 Heart Rate

There is an interaction effect in *App*×*Environment* ($F_{1,43}=5.870$, $p < 0.05$, $\eta^2=0.120$) on Delta (Figure 7). In the Calm, simple main effect analysis revealed that *Delta* for *Headspace* (M=15.15, SD=6.94) is significantly ($p<0.05$) higher than that for *PAUSE* (M=13.29, SD=5.83). Moreover, *Delta* 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 heart rate.

The results revealed that participants successfully reduce their heart rate in the Busy using *PAUSE* rather than *Headspace*. On the other hand, *Headspace* shows better performance in the Calm than *PAUSE*. The results may be grounded in our framework design. Our results suggest that *PAUSE* is particularly effective in the Busy as *PAUSE* emphasizes attention regulation and thus trains users to remain focused in the midst of everyday distractions.

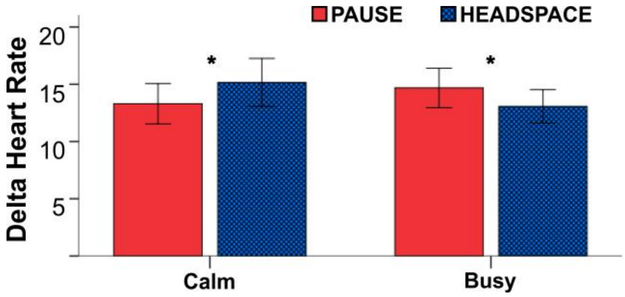

Figure 7. Delta heart rate (bpm)
The error bars indicate ±SE.

7.2.2 EEG

Figure 8a summarizes theta band activity results. Statistical analysis of theta band activity of Fp1 channel showed a higher power ($Z=-2.490$, $p<0.05$) for *Headspace* in the Calm ($M=16.54$, $SD=8.69$) than in the Busy ($M=11.61$, $SD=4.09$). Moreover, the power in the Busy for *PAUSE* ($M=14.96$, $SD=2.66$) is higher than ($Z=-2.624$, $p<0.01$) for *Headspace*. Similarly, theta band activity of Fp2 channel is higher ($Z=-2.134$, $p<0.05$) for *Headspace* ($M=16.36$, $SD=7.46$) in the Calm rather than Busy ($M=11.81$, $SD=3.92$). We also found that in the Busy, *PAUSE* ($M=22.55$, $SD=18.75$) is higher ($Z=-2.934$, $p<0.01$) than *Headspace*. Surprisingly, we found that the theta band activity of *PAUSE* in the Busy is higher than ($Z=-2.223$, $p<0.05$) in the Calm ($M=12.59$, $SD=3.00$). Results of Fp1 and Fp2 show that in the Busy deeper mindfulness was achieved using *PAUSE* compared with *Headspace*. Additionally, participants experienced a deeper mindfulness state using *Headspace* in the Calm compared to the Busy.

Analysis of F3, Fz, and F4 channels revealed similar results. In the Busy, the F3 channel had higher theta band activity ($Z=-2.134$, $p<0.05$) in *PAUSE* ($M=21.87$, $SD=4.02$) than in *Headspace* ($M=17.02$, $SD=5.83$). Also, *PAUSE* ($M=23.35$, $SD=4.94$) had higher theta band activity in the Fz channel in the Busy ($Z=-2.765$, $p<0.01$) compared to *Headspace* ($M=16.55$, $SD=4.00$). In addition, theta band activity for *PAUSE* in the Busy was surprisingly higher ($Z=-2.223$, $p<0.05$) than in the Calm ($M=19.40$, $SD=3.96$). We found a significant increase in theta band activity in the Busy for F4 channel ($Z=-2.124$, $p<0.05$) for *PAUSE* ($M=23.35$, $SD=4.94$) compared to *Headspace* ($M=16.55$, $SD=4.00$). Finally, we found higher theta band activity for *PAUSE* in the Busy ($Z=-2.934$, $p<0.01$) by comparison with the Calm (M=14.45, SD=3.32). To summarize, F3, Fz, and F4 results indicated that the users were in a deeper meditation state when using *PAUSE* compared with *Headspace* in the Busy.

Figure 8b summarizes low alpha band activity results. Analysis of Fp1 channel showed higher low alpha band activity ($Z=-2.578$, $p < 0.01$) for *PAUSE* (M=27.84, SD=16.82) than for *Headspace* (M=15.61, SD=6.38) in the Busy. We did not find any significant results on Fp2. In addition, F3, Fz, and F4 analyses showed greater low alpha band activity for *PAUSE* rather than for *Headspace* in the Busy. Low alpha band activity of F3 in the Busy for *PAUSE* (M=28.65, SD=15.90) is greater ($Z=-2.134$, $p<0.05$) than for *Headspace* (M=18.01, SD=6.85). Low alpha band activity of Fz in the Busy (M=26.40, SD=15.32) is greater ($Z=-1.965$, $p<0.05$) for *PAUSE* compared to *Headspace* (M=17.00, SD=7.24). We did not find any effect on low alpha-band activity in F4. Low alpha band activity analysis revealed that participants experienced more relaxation using *PAUSE* in the Busy.

We found consistent results between EEG and heart rate indicating that *PAUSE* helps users achieve deeper mindfulness and better relaxation in the Busy. On the other hand, in the Calm *Headspace* was as effective as *PAUSE* in the same condition. As discussed for heart rate, *ARF* leads users to ignore distractions in the Busy and to experience deeper mindfulness and better relaxation in the Busy. On the other hand, earlier studies (Paek, Agashe, & Contreras-Vidal, 2014; Xiao & Ding, 2015) showed that spectral analysis of EEG signals during finger movement affects the delta, alpha, and beta band activities. However, consistency of our results between EEG, heart rate, and interviews confirm the validity of our findings.

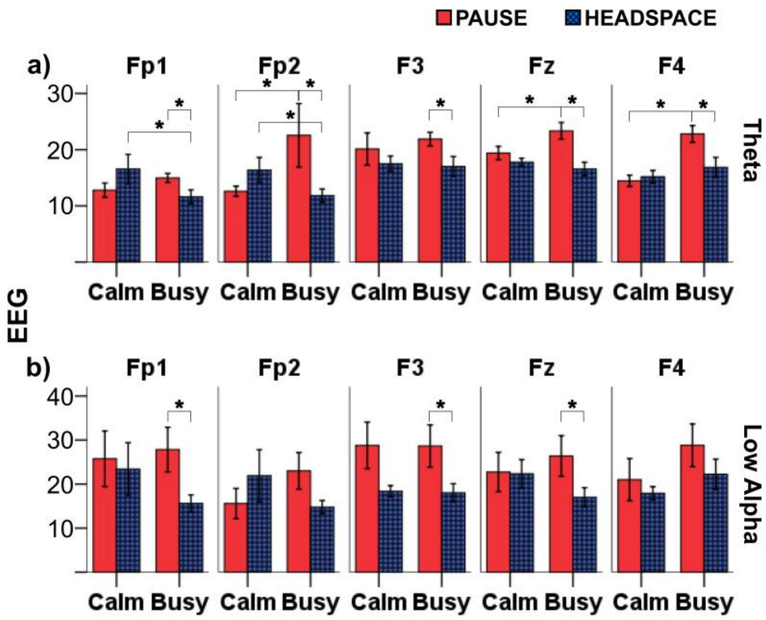

Figure 8. EEG power

(a) Theta band (4-7 Hz), (b) Low alpha band (8-10 Hz) for *PAUSE* and Headspace in the calm and busy environments. Each column represents Fp1, Fp2, F3, Fz, and F4 EEG electrodes. The error bars indicate ±SE.

7.2.3 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 (busy). 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 public place (busy). 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, through 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 said,

[P3]: "*Headspace helps me meditate similar to what I did before without a phone. I think Headspace is good enough. Cafeteria (busy) noise cannot disturb my meditation.*"

CHAPTER 8

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* which was already investigated in a qualitative way (Laurie & Blandford, 2016) for long-term use, showing that *Headspace* can lead participants to improve emotion and mood states.

8.1 Methodology

8.1.1 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 five days training because earlier studies (Mahmood, Hopthrow, & De Moura, 2016; Tang et al., 2007; Yu et al., 2012; Zeidan et al., 2010) showed that as little as three to five days of training can significantly enhance attention and mood regulation.

8.1.2 Participants

Eighteen university students and staff members (8 females) were recruited (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. Each participant was paid $10.

8.1.3 *Apparatus*

Similar phones and headphones were used as in Study 1. The Psychology Experiment Building Language (PEBL 0.14)[12] was used to run cognitive tests. PEBL ran on a 2 GHz Intel Xeon CPU PC with Windows 8. A 21" LCD display with a resolution of 1920 by 1080 was used. All questionnaires were filled in on a paper-based system.

8.1.4 *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 65 cm 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. Training was repeated over five 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.

8.1.5 *Measures*

As mentioned, traditional mindfulness practices improve attention (Tang et al., 2007), mood (S. L. Shapiro, Astin, Bishop, & Cordova, 2005), and well-being (Nyklícek & Kuijpers, 2008). Therefore, we measured the trait effects of mindfulness practice using the following methods.

[12] http://pebl.sourceforge.net

Attention. To measure attention, the *Attentional Network Test* (ANT) (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) is the most used method. An earlier work (Tang et al., 2007) showed that directed attention significantly improved after long-term meditation. Our study used ANT to measure pre-test and post-test attentional abilities of the practitioners. ANT included four blocks and 312 trials. ANT used three cue conditions (no cue, center cue, spatial cue) and two target conditions (congruent and incongruent). For details see (Fan et al., 2005). Mean accuracy, mean response time, alerting, orienting and conflict effects (directed attention) were measured using ANT. Alerting, orienting and conflict effects were calculated by subtracting the response times (RT) of different cues and targets (Equations 1, 2, 3).

$$\textit{Alerting effect} = RT_{\textit{no cue}} - RT_{\textit{center cue}} \quad \ldots\ldots\text{Equation 1}$$

$$\textit{Orienting effect} = RT_{\textit{center cue}} - RT_{\textit{spatial cue}} \quad \ldots\ldots\text{Equation 2}$$

$$\textit{Conflict effect} = RT_{\textit{incongruent}} - RT_{\textit{congruent}} \quad \ldots\ldots\text{Equation 3}$$

Mood. A 65-item *Profile of Mood State* (POMS) (Douglas M McNair, Droppleman, & Maurice Lorr, 1992) 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 (for more detail see Supplementary Material 1). POMS is a well-established metric to assess mood. Several studies used POMS. For example, a studying the effect of an 8-week Mindfulness-based Stress Reduction (MBSR) program on cancer patients (Garland, Tamagawa, Todd, Speca, & Carlson, 2013) showed a correlation between an increase in mindfulness and decreased stress and negative moods. In another work (Tang et al., 2007), the intervention effects of a newly developed meditation method (integrative body-mind training) showed that five days of training can improve mood.

Well-being. General Well-being was measured using a 22-item *Psychological General Well-being* (PGWB) index (Dupuy, 1984). The PGWB index asked for ratings on a 6-point

Likert-scale from 0 to 5 (for more detail see Supplementary Material 2). PGWBI is a well-known inventory which was used in an earlier work (Chiesa, Mandelli, & Serretti, 2012) to evaluate the effect of an eight-week Mindfulness-based Cognitive Therapy (MBCT) program on the well-being of patients with a major depression problem. Using PGWBI they found significant improvement in the well-being of MBCT group.

Happiness. The 4-item *Subjective Happiness Scale* (SHS) (Neff & Germer, 2013) was used to measure happiness. SHS questionnaire was rated on a 7-point Likert-scale from 1 to 7 (for more detail see Supplementary Material 3). Other studies measured happiness (Neff & Germer, 2013) as an indication of emotional well-being.

8.2 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 0.880, 0.933, and 0.808 for POMS, PGWBI, and SHS, respectively.

8.2.1 Attention

Results are shown in Figure 9. There is an interaction effect in *Training*×*App* ($F_{1,16}$=5.481, $p<0.05$, η^2=0.255) 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), however, there was no significant difference for *Headspace*. The results indicate that five days training improved response times with *PAUSE*, but not with *Headspace*. There are also main effects for *Training* on *conflict effect* for all responses ($F_{1,16}$=5.224, $p<0.05$, η^2=0.246) and on *conflict effect* for only correct responses ($F_{1,16}$=10.804, $p<0.005$, η^2=0.403). 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 *conflict effect* of all responses. Similarly, for *conflict effect* of correct responses, in both groups post-test (M=89.0, SD=20.2) significantly improved compared to the pre-test (M=108.3, SD=21.2). However, there is no difference in improvement between *PAUSE* and

Headspace groups. In other words, both apps help 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 five days of training with the mobile application, 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.

8.2.2 Mood

Results are summarized in Figure 10. There are main effects in *Training* on *total mood disturbance* ($F_{1,16}$=13.972, $p<0.01$, η^2=0.466), *confusion-bewilderment* ($F_{1,16}$=5.441, $p<0.05$, η^2=0.254), *depression-dejection* ($F_{1,16}$=7.455, $p<0.05$, η^2=0.318), *fatigue-inertia* ($F_{1,16}$=14.676, $p<0.001$, η^2=0.478), and *tension-anxiety* ($F_{1,16}$=11.184, $p<0.01$, η^2=0.411). However, there is no effect on *anger-hostility*, and *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. These results may have stemmed from guided meditation. In *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.

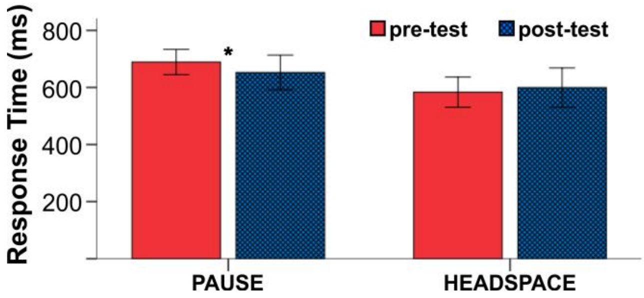

Figure 9. Response time
The figure shows a significant reduction in response time after five days of training with *PAUSE*. The error bars indicate ±SE.

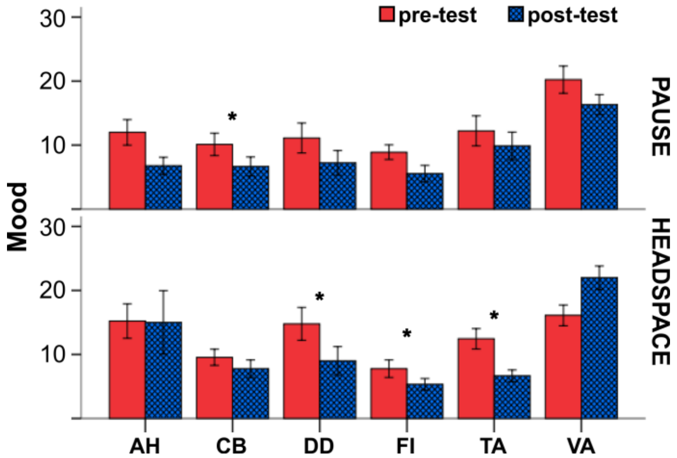

Figure 10. Intervention effect on mood
Using *PAUSE* helped participants reduce the *confusion-bewilderment* scale while Headspace reduced *depression-dejection*, *fatigue-inertia*, and *tension-anxiety*. The error bars indicate ±SE.

8.2.3 Well-being

There is a main effect in *Training* on *General Well-being* ($F_{1,16}$=29.448, p<0.001, η^2=0.648). 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(Nyklícek & Kuijpers, 2008; Peters, Benson, & Porter, 1977), training in mindfulness through mobile applications can increase the well-being of users.

8.2.4 Happiness

There is a main effect in *Training* on *Happiness* ($F_{1,16}$=4.448, $p<0.05$, η^2=0.219). 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 regarding the happiness subscale. 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.

CHAPTER 9

DESIGN CASE 2 – KINETIC MEDITATION

This chapter explains the design mechanisms for Kinetic meditations (Figure 4c). A kinetic meditation MBMA (*SWAY*[13]), has been developed to demonstrate the *ARF*.

To recognize slowness and endurance of mindful movement, *SWAY*'s detection mechanism requires the user to move at a relatively constant speed, making sure that rotation and acceleration are slow and continuous (Figure 4c). This is done by measuring the average accelerometer and gyroscope input over a given period of time and checking if those values are within given bounds. Only when the rotation and acceleration are within the given bounds can the movement be considered mindful. The upper and lower bounds were set through an iterative process in pilot studies.

Mindful movement causes an increase in a *warmth value* (i.e., a visual sidebar which is built up after detecting the mindful movement, see Figure 4c) while a non-mindful movement causes a decrease. The *warmth value* was designed to distinguish intended mindful movements from other 'accidental' slow movements which often last a very short time. This approach allows *SWAY* to detect any mindful movements regardless of the movement pattern from tiny wrist movements (Figures 11f, 11g) to larger arm movements (Figures 11a, 11b, 11d). It can also be carried in the user's pocket for use in mindful walking (Figures 11c). The *warmth value* works as a buffer, allowing the user to make small mistakes

[13] http://www.pauseable.com/

as they attempt to master the movements. This value is what triggers a mindful state in the *SWAY*.

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. When the user moves mindfully, s/he hears a continuous and real-time generated soothing soundtrack to motivate continuous mindful movements. 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 the pocket (Figures 11c, 11e). In these circumstances, the sound is the primary feedback mechanism in *SWAY*.

SWAY's soft stimuli *graphical feedback* is an ever-evolving generative landscape. At the start of the session, the landscape is covered by fog (Figures 12a, 12b). When the user starts mindful movements, the *warmth value* (i.e., a visual sidebar) builds up, the fog clears and reveals the landscape while the visual perspective lifts up giving the user the feeling of flying over an endlessly evolving landscape (Figure 12c). When non-mindful movements are detected, the perspective drops, and fog returns and progressively covers the landscape (Figure 12d).

To promote mindfulness, *SWAY*'s *text feedback* was purposefully designed to direct the user's attention towards the internal focus. Text feedback is a trigger point of the closed-loop framework. At the beginning of the training, text 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 to let the audio 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 12d).

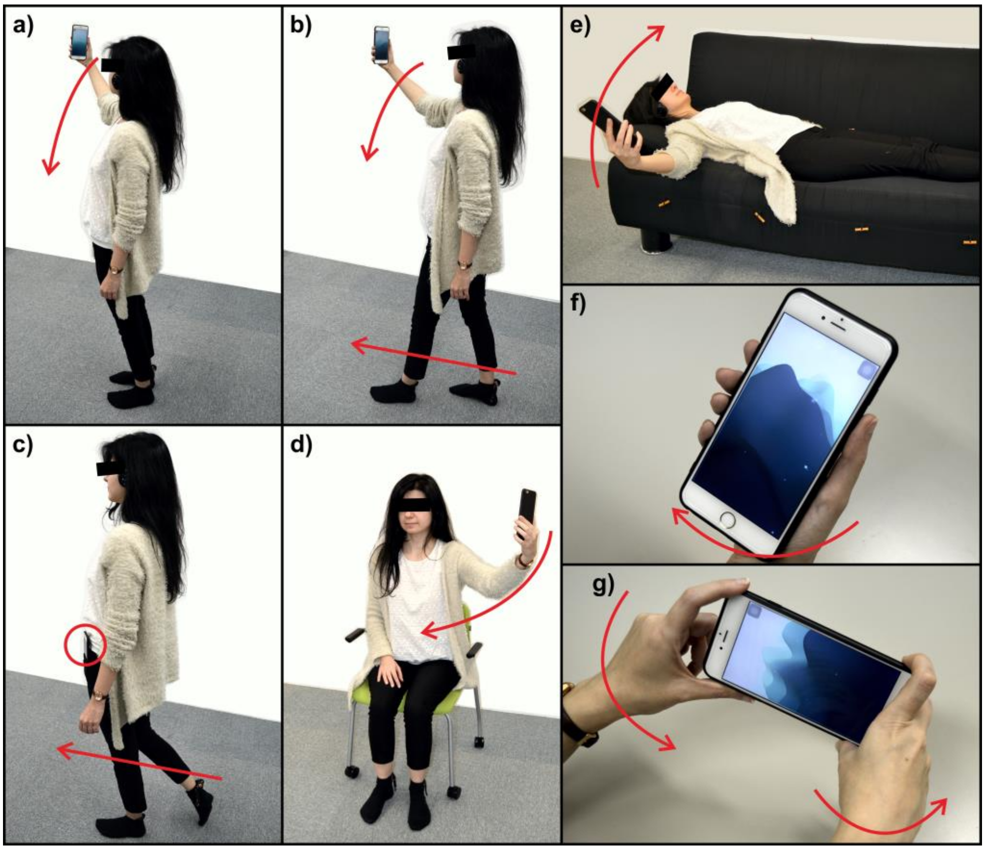

Figure 11. Participant's movement patterns in using the kinetic design case (*SWAY*) (a) moving the arm in standing position (b) moving the arm while walking (c) walking with eyes closed while the phone is in her pocket (d) sitting and moving the arm (e) lying down on a couch and moving the arm (f) sitting and rotating her wrist with open eyes (g) sitting and rotating her both wrists with open eyes.

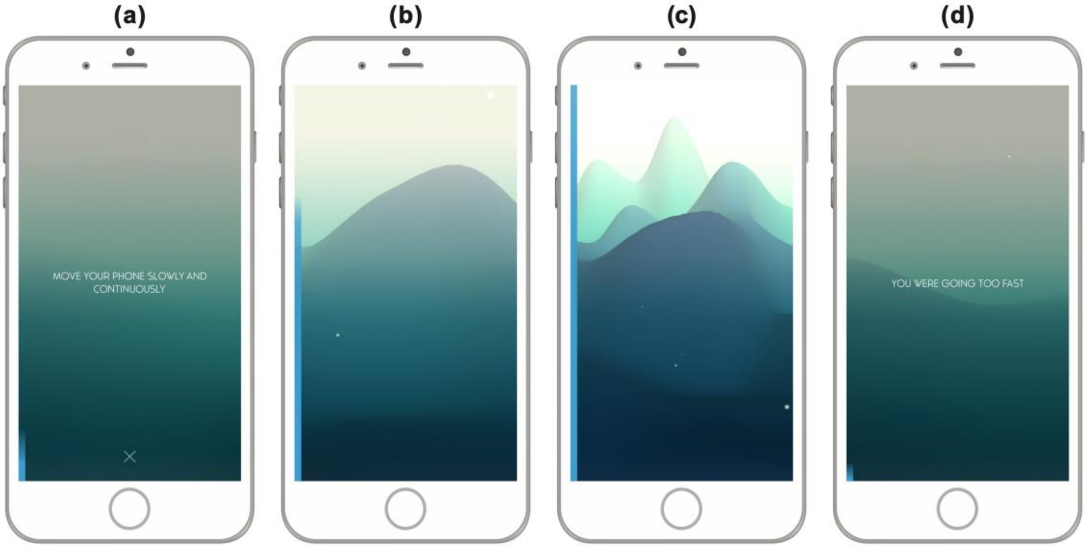

Figure 12. Interaction steps of the kinetic design case (*SWAY*)
(a) First, *SWAY* instructs the user to move the phone slowly and continuously. (b) Next, the user moves the phone slowly. The visual sidebar (warmth value) is filled after a couple of seconds of continuous slow movement. Audio and visual feedback is being generated. The visual feedback (landscape) is still covered by fog. (c) The user moves the phone mindfully. The landscape becomes clear. The user's continuous slow movement while watching the visual feedback gives the feeling of flying over endless mountains. The phone instructs the user to focus on the quality of the movement and steps. Now the user can close the eyes, put the phone in the pocket and continue with mindful movement. This continuous slow and gentle body movement stimulates user awareness and helps the user sustain attention in the present moment. (d) If the user becomes distracted, stops the movement or moves too fast, audio-visual feedback fades away. A distinguished sound alert and text feedback remind the user to bring the attention back to the present moment.

CHAPTER 10

STUDY 3: USER EXPERIENCE OF MINDFUL MOVEMENT

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

10.1 Methodology

10.1.1 Participants

Thirteen university students and researchers including 5 females (M=28.5, SD=4.9, range=23-36) were recruited. None of the participants were expert in kinetic meditation. Participants were paid $10.

10.1.2 Apparatus

An iPhone 6 Plus with a TaoTronics TT BH03 Bluetooth headset was used for training with *SWAY*. A 7-meter×7-meter area in the laboratory was provided for *SWAY* training.

10.1.3 Task and Procedure

After getting the informed consent from the participant, they were introduced to *SWAY*. They were asked to use the application in a creative way and explore different approaches to interacting with *SWAY*. Participants practiced with barefoot or only with socks. They were asked to practice kinetic meditation with *SWAY* in three 10 minutes sessions. Participants had 5 minutes rest after each session. After the third session, an interview was conducted. The interviews were lasted 20 – 30 minutes and were audio recorded for later analyses. The whole experiment was conducted in a quiet space.

10.1.4 Measures

Semi-structured interviews including several open-ended questions were conducted assessing the mindfulness experience of the users and the way that they interacted with *SWAY*.

Next, two questions were asked of the participants. The first question investigates the affective state of the participants using Russell's two-dimensional circumplex space model (Russell, 1980). The model annotates and demonstrates different human emotions based on arousal and valence dimensions. Participants were asked to carefully study the arousal-valence emotional chart (Paltoglou & Thelwall, 2013) that it was printed on a paper sheet (for more detail see Supplementary Material 4). They were asked to *select three most close affective states considering all sessions*. The second question measured feedback preference of the users considering usefulness and effectiveness of the feedback type (audio, graphics, and text) in all sessions. Participants were asked to *rank the most important, the second choice, and the least important feedback type*.

10.2 Results

This section describes the main findings of the 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 illustrated by heat mapping the emotions that have been selected by participants. Last, to investigate a possible effect of feedback type on preference, Friedman non-parametric test was used. Wilcoxon Signed-Rank tests were also used for pairwise comparisons between the feedback types. P-values were Bonferroni corrected.

10.2.1 Participants' background

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

10.2.2 Overall engagement

In general, most of the participant (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.*"

10.2.3 Detection

SWAY detects users' movements and warns them if they are not in 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 received a few ones.

> [P8]: "*At the beginning of the first session, I got many interruptions because I was faster, but later almost it didn't happen.*"
>
> [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 those [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, a 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.*"

10.2.4 Feedback

Audio, graphics, and text are the main elements of the *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 that disrupted my experience. I recommend using a smoother sound for notification.*"

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 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.*"

Where 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.*"

10.2.5 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.

10.2.6 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 with 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 the only walking is too habitual. I need something more for focus, that 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 without combining the leg and arm 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], infinite (∞) [P4], and back and forth [P12]. Six participants performed the training with eyes open which 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*".

10.2.7 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] compared *SWAY* against 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.*"

10.2.8 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.

10.2.9 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, camping fire) [P1], make a tutorial about the app use [P4], or providing 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.

10.2.10 Affective State

We asked participants to select three affective states that they felt during the practices. Figure 13 shows that the majority of the answers are in the high-valence and low-arousal area. The most answered emotions are 'Peaceful', 'Relaxed', 'Calm', 'Amused' with 7, 5, 4, and 3 repetitions, respectively. 'Delighted', 'Feel well', and 'Interested' were two times repeated. Other mentioned words were: 'At ease', 'Attentive', 'Confident', 'Contemplative', 'Convinced', 'Expectant', 'Glad', 'Lighthearted', 'Melancholic', 'Pensive', 'Serious', 'Sleepy', 'Startled', and 'Taken aback'.

10.2.11 Feedback Preference

We also asked participants to rank the most effective and useful feedback element. There is a main effect of feedback type on participants' preference ($\chi^2(2)=19.54$, $p<0.001$). The results indicated that audio feedback is preferable to graphics ($Z=-3.27$, corrected $p<0.01$). Also audio is preferable to text ($Z=-3.27$, corrected $p<0.01$). Where there is no significant difference between graphics and text (corrected $p=1.00$). Figure 14 shows that notably, all participant selected audio feedback as the most important feedback type. This result is congruent with the interview results.

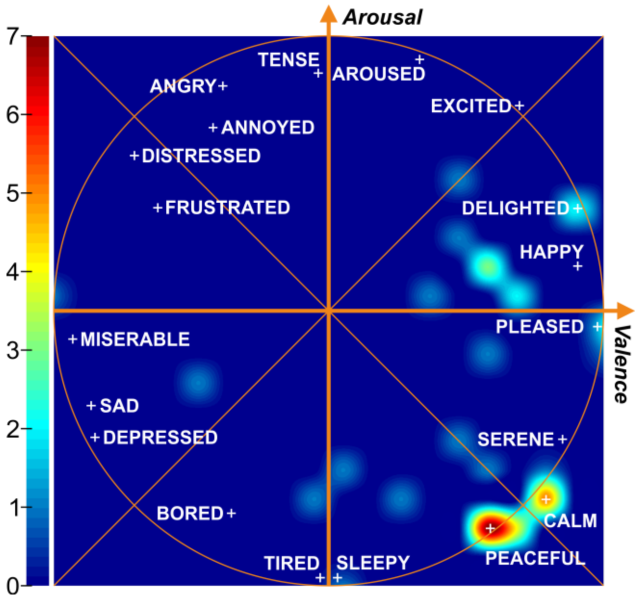

Figure 13. Emotion ratings on arousal (y-axis) and valence (x-axis)
Most of the participants experienced high-valence and low-arousal. The most answered states are *Peaceful*, *Relaxed*, *Calm*, *Amused* with 7, 5, 4, and 3 repetitions, respectively.

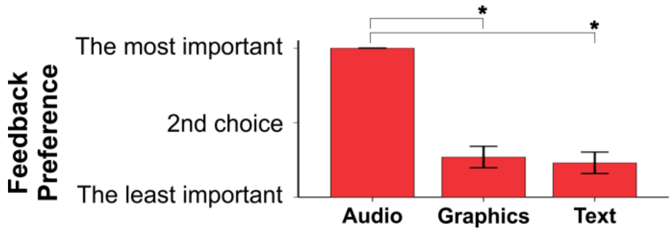

Figure 14. Feedback preference
The figure shows that all participants selected Audio as the most useful and effective feedback type. Audio is significantly preferable to other feedback types. However, graphics and text do not have any significant difference. The error bars indicate ±SE. Significant effects are indicated by an '*' symbol.

10.3 Discussion

We assessed the usability and state effects of training with *SWAY*. To sum up, most of the participants could successfully practice kinetic meditation. Our findings revealed that *SWAY* can promote slow continuous movement and can facilitate focus on the body movements. We also found that audio feedback is the most effective and favorite feedback type during the practice. Moreover, for the majority of cases, graphics and text are remarkably important for the learning process, but they can be disregarded for the rest of the practice. Our findings also demonstrated that *SWAY* allows participants with different interaction and movement preferences (i.e., users with mobility differences) to train kinetic meditation in different postures according to their preferences. Finally, we found that most of the participants noted experiencing high relaxation and pleasure during the training.

CHAPTER 11

STUDY 4: INTERVENTION STUDY (II)

To investigate the effectiveness of *SWAY* on mental and physical health 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 five days of practice for our experiment.

11.1 Methodology

11.1.1 Experimental Design

A mixed design experiment was conducted. The *intervention* was within-subject comparing pre-test and post-test results. The *group* was between-subject comparing the *SWAY* group with the *MM* group and the control group.

11.1.2 Participants

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

11.1.3 Apparatus

Similar smartphone and headset used in Study 3 were used for training with *SWAY* and *MM*. We downloaded *MM* application from iTunes into the smartphone. A VICON Motion Capture System including a twelve Bonita B10 camera system (frame rate: 250 fps, resolution: 1 megapixels, lens operating range: up to 13 m, angle of view wide (4mm): 70.29°×70.29°, angle of view narrow (12mm): 26.41°×26.41°) was used for balance tests. Nexus 2.6.0 software was used to record the motion and extract the balance data. A Q&Q HS-45 electronic stopwatch was used to record balance time. MATLAB R2017a and IBM SPSS 23 were used for motion analysis and statistical analysis, respectively. Questionnaires were completed in the laboratories using Google Forms. *SWAY* and *MM* trainings were performed in the same environment as Study 3. A smartphone holder attached to a camera tripod was used for *MM* group training. *MM* group used only a 2-meter×2-meter area as they required to stand behind the smartphone and watch the screen.

11.1.4 Task and Procedure

Consent forms were gathered from the participants. Demographic information including health background, meditation and exercise experience were collected. Later, 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 of the participants were explicitly instructed that "*do not 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 particular instruction and only attended pre-tests and post-tests. 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 the 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 70 cm away from the smartphone and follow the guides from the instructor through watching and listening to the application.

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 did not use any application or smartphone and just took a seat on a chair. 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. Moreover, they took 5-minute rest after finishing each questionnaire. Post-tests were conducted for each participant at the same time of the day that the pre-tests were conducted.

11.1.5 Measures

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

Mindfulness. A 39-item *Five Facet Mindfulness Questionnaire* (FFMQ) (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006) 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 (Carmody & Baer, 2008): *observing* (attending to or noticing internal and external stimuli), *describing* (noting or mentally labeling these stimuli with words), *acting with awareness* (attending to one's current actions), *non-judging of inner experience* (refrain from evaluations), and *non-reactivity to inner experience* (allowing thoughts and feelings to come and go). The negative items of *acting with awareness* and *non-judging of inner experience* factors were reversed before factor analysis (for more detail see Supplementary Material 5). Recent studies used

FFMQ to show the effectiveness of yoga and mindful movement in achieving mindfulness (Caldwell et al., 2010; Gard et al., 2012).

Body Awareness. To assess *body awareness*, we adopted a 6-item questionnaire from an earlier study (Mehling et al., 2009). The list of questions is provided in Supplementary Material 6. 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 previous studies, body awareness has been assessed in kinetic meditation (Daubenmier, 2005) and it has been seen as the common principle of such practices (Mehling et al., 2011).

Well-being. We measured General Well-being using the PGWB index as described in Study 2. The PGWB index previously has been used to ascertain the effectiveness of yoga practice in improving well-being (MehtaPriti Taneja, 2013; Rani et al., 2011).

Mood. To measure mood POMS was used as described in Study 2. It has been used in earlier studies (Lavey et al., 2005; Mills, Allen, & Carey Morgan, 2000) to demonstrate the impact of kinetic meditation on mood enhancement.

Balance. Proper body balance is a necessary factor to a high quality of life and, in particular, it is vital and particularly relevant to elderly people (Siqueira Rodrigues, Ali Cader, Bento Torres, Oliveira, & Martin Dantas, 2010) and patients (Cameron & Lord, 2010) (e.g., multiple sclerosis) in order to decrease the risk of falls and increase life expectancy. Many intervention studies have demonstrated that long-term kinetic meditation training can improve balance function (Jacobson et al., 1997), proprioception (Xu et al., 2004) and postural stability (Hart & Tracy, 2008). Thus, we used a *Single-Leg Stance* (SLS) task (Kee, Chatzisarantis, Kong, Chow, & Chen, 2012; Riemann, Myers, & Lephart, 2003) to assess *postural sway* and *balance time* in a balanced performance. 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. They were asked to position the other leg on the posterior side of the knee of the standing leg and cross the 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., at least 30 sec rest. For longer trials the rest time was equal to half of the trial time). 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 look at a marker approximately 2 meters away and stand as stably as possible for only 30 seconds.

Postural sway (Shumway-Cook, Anson, & Haller, 1988) 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. Considering individual differences between participants and to eliminate fatigue effects, 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 (Collins & De Luca, 1995), we expect 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. Since there were considerable individual differences in balance time, it was normalized across participants.

11.2 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 intervention 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 (Pallant, 2007). Cronbach's-α were 0.77, 0.94, 0.88, and 0.52, for FFMQ, POMS, PGWBI, and body awareness, respectively.

11.2.1 Mindfulness

Figure 15 illustrates the results. There is a main effect in *intervention* for *observing* of 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 *intervention* 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* (i.e., the ability to attend to internal/external stimuli) and *acting with awareness* (i.e., the ability to pay attention to the present moment). Our finding is consistent with a previous study (Carmody & Baer, 2008) showing that traditional kinetic meditation has a greater effect on observing and acting with awareness.

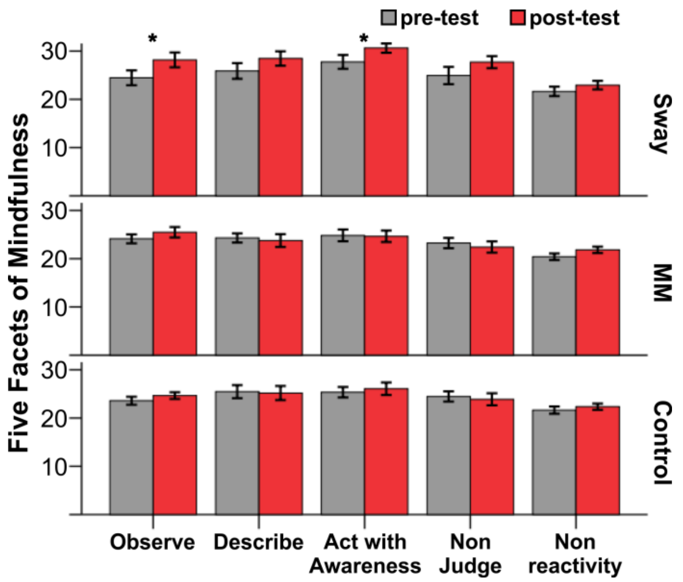

Figure 15. Effect on mindfulness
The figure shows a significant improvement in *observing* and *acting with awareness* only for the *SWAY* group. The error bars indicate ±SE. Significant effects are indicated by an '*' symbol.

11.2.2 Body Awareness

Figure 16a shows the results. There is a main effect in *intervention* 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 *intervention* 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 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 *intervention* on *quality of attention* for the *SWAY* group (Z=-2.96, p<0.01, r=0.51). Pairwise comparisons showed that for the *SWAY* 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 which have been significantly improved by *SWAY* training. However, the results should be interpreted with caution due to the low internal consistency of the body awareness questionnaire.

11.2.3 Well-being

Figure 16b summarizes the well-being results. There is a main effect in *intervention* on well-being in the *SWAY* group (Z=-2.77, p<0.01, r=0.47). The well-being rate for *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* in 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 (Nyklícek & Kuijpers, 2008), traditional kinetic meditation (Rani et al., 2011), and technology-mediated static meditation (the results of Study 2).

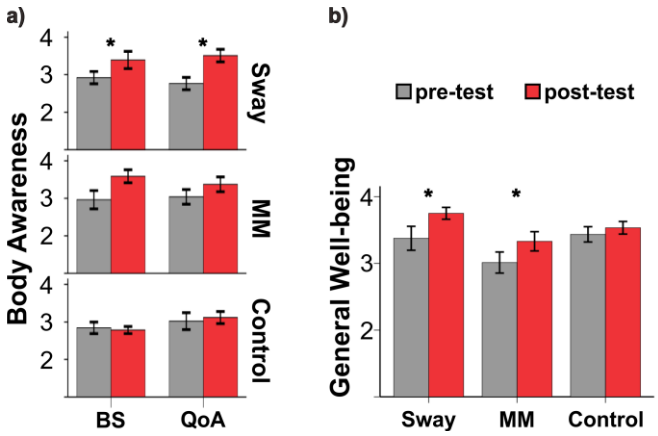

Figure 16. Effect on (a) body awareness and (b) well-being
Figure a shows significant enhancement in *body sensation* (BS) and *quality of attention* (QoA) for the *SWAY* group. Figure b shows significant enhancement of well-being for the *SWAY* and MM groups. The error bars indicate ±SE. Significant effect and marginal effect are indicated by '*' and '**' symbols, respectively.

11.2.4 Mood

Figure 17 summarizes the mood results. There is a main effect in *intervention* on *total mood disturbance* in the *SWAY* group (Z=-2.58, p<0.01, r=0.44). Participants in the *SWAY* group rated significantly lower *total mood disturbance* 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 *intervention* 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 *intervention* 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 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 *intervention* 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. There are no effects on *confusion-bewilderment* for the other groups (*MM*: p=0.31, control:

p=0.15). In the *MM* group, there is a main effect in *intervention* on *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 to the pre-test (M=24.47, SD=12.61). The *SWAY* and control groups did not show any significant effect on the *depression-dejection* (*SWAY*: p=0.17, control=0.41). There is a main effect in *intervention* 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). *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 *intervention* 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 the *MM* training on *anger-hostility* and *depression-dejection*. Whilst *SWAY* can affect both physical and psychological aspects, *MM* only influences psychological facets. Last, *SWAY* could not significantly improve *depression-dejection* and *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 a potential improvement.

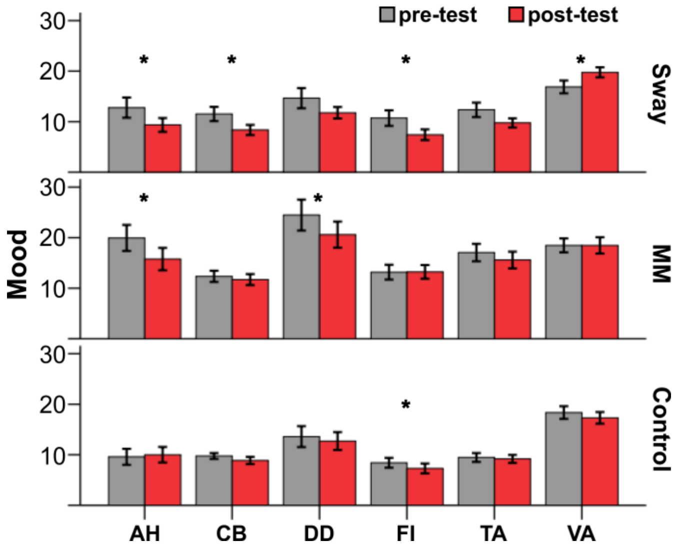

Figure 17. Mood
The figure shows a significant reduction of the *SWAY* training on *anger-hostility* (AH), *confusion-bewilderment* (CB), and *fatigue-inertia* (FI) and improvement in *vigor-activity* (VA). MM training demonstrated a significant effect on *anger-hostility* (AH) and *depression-dejection* (DD). *Tension-anxiety* (TA) did not show any effect in all groups. The error bars indicate ±SE. Significant effects are indicated by an '*' symbol.

11.2.5 Balance

Figure 18 summarizes *postural sway* results. Statistical analyses of the *eyes closed* condition for the *SWAY* group indicated lower fluctuation in 0-10 secs (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 *SWAY* group in 10-20 secs was lower (Z=-2.67, 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 secs for *SWAY* group (p=0.069). Analyses for *MM* and control groups showed no difference between the pre-tests and the post-tests in 0-10 secs (*MM*: p=0.16, control: p=0.26), 10-20 secs (*MM*: p=0.46, control: p=0.35), and 20-30 secs (*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 secs (*SWAY*: p=0.36, *MM*: p=0.91, control: p=0.59), 10-20 secs (*SWAY*: p=0.38, *MM*: p=0.87, control: p=0.69), and 20-30 secs (*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 19. 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 Kruskal-Wallis non-parametric test to investigate the effect of *group* on the improvement of *balance time*. However, we could not find a significant group 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 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 affect 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 metrics. To sum up, *SWAY* as a kinetic mobile application can help users improve in physical aspects similar to the traditional approaches.

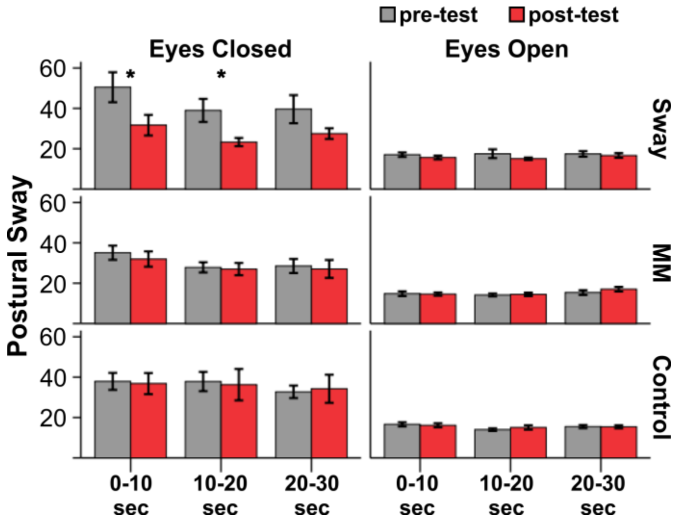

Figure 18. Postural sway
The figure shows significant improvement (i.e., reduction) in postural sway in millimeters (mm) for the eyes closed condition in 0-10 secs and 10-20 secs time portions for the *SWAY* group. The error bars indicate ±SE. Significant effects are indicated by an '*' symbol.

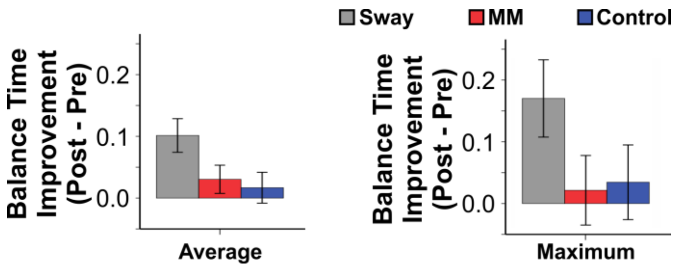

Figure 19. Balance time improvement (post-pre)
The figure shows significant improvement for *SWAY* group between the pre-test and post-test normalized mean balance times (sec) and maximum balance times (sec). However, we could not find a significant group difference in balance time improvement. The error bars indicate ±SE.

CHAPTER 12

GENERAL DISCUSSION ON *ARF*

This dissertation presents an overarching framework (*ARF*) for self-regulation practice. *ARF* is a theory grounded framework and its main contributions are: (1) demonstrating a subtle approach to detect user's attention without the need of dedicated accessories, (2) suggesting an appropriate feedback design to avoid users to recall judgments and evaluation during the practice, and (3) suggesting slowness and continuity of the movement for regulation through understanding features of mindful movement. Indeed, *ARF* attempts to answer the high-level question "to what extent can technology support mindfulness without interrupting the natural progressive meditative state of the user? (Ren, 2016)".

ARF was described through the development and demonstration of two design cases (*PAUSE* and *SWAY*). Overall, the design cases demonstrated the usefulness of the framework. Furthermore, our validation for static meditation revealed where the framework is particularly useful, i.e., in busy environments, and with a specific group of users, i.e., people who are easily distracted or who have low confidence in their ability to meditate and/or who are less motivated to meditate. In addition, the results of kinetic meditation revealed 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 five days of practice with *PAUSE* and *SWAY*.

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

12.1 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 allows technologies to react appropriately without interrupting the process of mindfulness practice. It is important to distinguish between 'detecting' attention and 'guiding' attention. Detecting attention recognizes that human beings already have the capacity to self-regulate attention. Detecting voluntary attention allows technology to provide meaningful feedback from moment to moment to support and motivate users to sustain self-regulation. On the other hand, guiding attention may diminish the human capacity to self-regulate by allowing technology to dominate the whole process. This nature leads to limited digital expression of the design as it follows specific rhythm and patterns of pre-designed self-regulation process.

The Breathe app[14] is an example of a recently developed product for the Apple Watch which 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 limited by predefined rhythms and patterns which may interrupt the progressive process of 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, it contributes to the design features by showing how to precisely 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 the kinetic meditation is relatively challenging. Previous attempts have different pros and cons. For example, biofeedback systems could only measure user psychophysiological states in static postures and thus with no movement detection. By adding motion detectors to dedicated accessories (e.g.,

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

Microsoft Kinect motion sensor) they could precisely detect the practitioner's body movement, but such sensors could not be easily accessed by everyone, and they could not be used as mobile devices or in outside environments (e.g., for walking meditation in the street). Considering the prevalence of smartphones, interactive mobile applications could be a proper choice to bring the benefits of mindfulness to the daily life.

12.2 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) provides inner feedback which stimulates body awareness. However, this inner feedback is too subtle to be recognized by novices. Thus, the technology could facilitate this process by providing proper feedback. Although the necessity of feedback is obvious, the key question is what kinds of feedback should be designed such that it provides adequate feedback but not so overwhelming that it constantly disrupts users from moving into deeper meditative states or in the other words interrupts non-judgmental awareness of the practitioners in the mindful state.

There are two key challenges for 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 towards the present moment (Baer, 2003; Kabat-Zinn, 2009)) is relatively hard to achieve by novice practitioners and it requires a lot of practice. For this reason, designing proper feedback is challenging. For example, emWave2 (emWave2®, 2012) detects heart rate 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 constantly judge the meaning of the bar (am I high or low?) and this might prevent users from entering into deeper states of mindfulness.

To address this challenge, for the static design case (*PAUSE*), the feedback mechanism was developed 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, the 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 mobile application (*SWAY*), the feedback mechanism informs users immediately after their slow and continuous movement is interrupted. This may cause users to be self-critical, but a simple intuitive feedback prompts the user to quickly bring the attention back to the moment and to sustain slow, continuous body movement. Although this mechanism supports non-judgmental awareness during practice, the review of the *non-judging of inner experience* facet results reveals that the mechanism does not readily yet transfer to the daily behavior of practitioners after only five days of practice (p-value=0.19).

Last, the use of proper instruction was suggested to encourage users to develop their internal focus. Achieving significant improvement in aspects of mindfulness and body awareness demonstrates that practitioners can achieve mindfulness through paying attention to the bodily movements.

12.3 Slow and Continuous: Regulation Techniques of *ARF*

The last critical 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 alleviate this problem, *ARF* suggested a subtle solution based on identifying the underlying mechanisms of practices in 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 complex movements of the 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.

12.4 Efficiency of Self-regulation

To understand the effectiveness and efficiency of our self-regulative approach, we revisit the findings of the intervention study. We also compared our results to previous studies which had almost the same amount of the training time.

SWAY can help in increasing two facets of mindfulness (i.e., *observing* and *acting with awareness*). *Observing* is the ability to sense and notice internal (e.g., body) and external (e.g., aromas) stimuli which indeed it 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 (Baer et al., 2006). *SWAY* training as a self-regulative 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 as a non-self-regulative approach cannot affect any of the mindfulness facets. We speculate that this difference may be due to the issue of self-regulation. The self-regulative approach allows the user to self-regulate the attention and practice to be in the present moment, while in the non-self-regulative approach, the user does the imitation process which it is on the contrary with mindfulness. Indeed, in the latter case, the user does multitasking by watching movement instructions and simultaneously mimicking those movements. Although this type of technology can be helpful for precisely performing the movements, it may decrease the likelihood of cultivating mindfulness.

Our results demonstrated that *SWAY* can boost four items of mood (i.e., 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 *SWAY* is the improvement on *confusion-bewilderment*. This result shows the effectiveness of *SWAY* on attention-related capabilities such as the ability for concentration. Similarly, *PAUSE* induced improvement on *confusion-bewilderment*. This similarity may stand to reason that *ARF* draws upon Kabat-Zinn's definition of mindfulness (Kabat-Zinn, 2009), 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 which requires sustained voluntary attention that can enhance the user’s focus capability. This is also proven by the attentional network test, showing that *PAUSE* can improve response time and conflict effect after five days of training. Surprisingly, those practices that use the non-self-regulative guided meditation approach cannot improve *confusion-bewilderment*. For example, a *traditional* five-day training program called Integrative Body-Mind Training (IBMT) (Tang et al., 2007) showed improvement in all factors of mood except *confusion-bewilderment*. IBMT originated from an ancient eastern tradition and includes the *static* and *kinetic meditation*s. Congruently, in our intervention studies, *Headspace* and *MM* could not affect this factor either.

The intervention experiment demonstrated the effectiveness of *SWAY* in enhancing balance ability of users. Clark and colleagues (Clark et al., 2015) discussed the underlying mechanisms behind the motor improvements after mindful movements. They shed light on the inner bodily feedback that can enable practitioners to monitor changes in their body sensation and improve their motor skills through training. In addition, they clarified that slow and mindful movements can help practitioners to predict sensory consequences of their movements (Wolpert, Diedrichsen, & Flanagan, 2011). On the other hand, a previous work (Neumann & Brown, 2013) showed that in 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 interestingly, *SWAY* can increase the stability of balance when eyes are closed but not with open eyes. This result might arise from the human balance system. A proper balance is the result of processing information from different sensory modalities: visual system (i.e., eyes), vestibular system (i.e., inner ear), and somatosensory system (i.e., muscles and joints) (Collins & De Luca, 1995). 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) (Przekoracka-Krawczyk, Nawrot, Czaińska, & Michalak, 2014). By contrast, *MM* training did not lead to any improvement with either open or closed eyes. One possible reason for these results might be the different use of body parts. Similar to other existing mobile applications, *MM* does not allow mobility as the user requires to stand behind the smartphone and continuously watch the screen, and as a result, only move the upper body, whilst *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 the sense of balance rather than physical power (i.e., leg power) and the effect persists until participants feel fatigued.

12.5 *ARF* vs. Biofeedback and Guided Meditation

Our findings revealed that the design cases are effective in promoting attention regulation and these results are consistent with earlier biofeedback studies. For example, MeditAid (Sas & Chopra, 2015) and RelaWorld (Kosunen et al., 2016) 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 (Vidyarthi & Riecke, 2014) 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 the 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 kinds of users who may not be able to meditate using this approach, thus we propose a framework and design cases to 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 should tailor their mobile application designs to suit the wide variety of people according to their cultures, tastes, abilities, and lifestyles.

CHAPTER 13

STUDY 5: HUMAN SENSES AND MBMAS

MBMAs exploit various senses, e.g., touch, audio, and vision, but the relationship between human senses and interactive meditation is not well understood. Study 5 empirically evaluates the effects of single and combined human senses on interactive meditation. This study is the first to attempt to understand these relationships. The findings have broad implications for the field of multi-modal interaction and interactive meditation applications.

Meditation is a complex construct and has various theoretical underpinnings which we cannot cover at length in a note. Instead, this study looks at meditation from the perspective of *Concentrative Meditation* (CE). CE is a popular form of meditation asking practitioners to focus on one object (e.g., audio, a visual image, a body action) and sustain it over a period of time (Valentine & Sweet, 1999). CE can be further described in two phases: analytical and placement (Gyatso, 2009). In the analytical phase, users reflect on an object of meditation to help introduce or restore their attention. In this phase, the judgmental effort is still involved. When users feel calm and still, they gradually enter the placement (or the actual meditation) phase. In this phase, users experience a state of non-judgmental awareness, i.e., they are just aware of their thoughts coming and going. Whenever users become distracted, they repeat the analytical phase to restore the meditative state. Our study was grounded upon these definitions.

The main goal of this study is to define how human senses affect meditation experiences. We compared the effects of audio, vision, touch and their combinations (see Figure 20) using a within-subject design. Our experiment was based on *PAUSE* as the static design case which supports three modalities of meditation and has also been shown to be an effective tool for meditation.

13.1 Methodology

13.1.1 Conditions

Touch (T). The Touch condition (*T*) required participants to slowly and continuously perform circular movements with one finger on the touchscreen. One finger was preferred over multi-touch movement because it allows users to focus the attention on one point and to minimize effort. Participants were instructed to close their eyes when they wanted to, while maintaining finger movement.

Vision (V). The Vision condition (*V*) used amorphous visual feedback using floating bubbles with a wide range of calming colors (Manav, 2007). Each participant was free to choose the color they preferred. We did not choose a nature view e.g., the sea or a waterfall, because scene preferences vary greatly from person to person. Instead, we chose more neutral visual stimuli that nevertheless had calming and soothing effects. Participants were asked to focus on the dynamic changing shape of the floating bubbles. Participants were instructed to close their eyes when they wanted to, and when they did so, they were asked to sustain their attention by visualizing the floating bubbles in their minds.

Audio (A). The Audio condition (*A*) combined instrumental music with background nature sounds. We did not choose guided or mantra meditation given the possible confounding effect of the teacher's guidance. In addition, guided or mantra meditation requires prior training and this was not considered to be suitable for our experiment. Participants were simply instructed to listen to the audio, and close their eyes whenever they wanted to.

Touch and Visual (T+V). *T+V* is an interaction mechanism using both touch and vision. When users touch and move a finger slowly and gently on the screen, the floating bubble slowly increases in size until it fills the whole screen. On the other hand, whenever the finger movement is interrupted (e.g., by lifting the finger or when the movement was too fast or stalled), the floating bubbles slowly decrease in size.

Touch and Audio (T+A). *T+A* is an interaction mechanism combining touch and audio. When users move a finger slowly, gently and continuously on the screen, the audio keeps playing, otherwise, the audio stops to alert the participants.

Audio and Visual (A+V). Participants were simply asked to reflect on the floating bubbles while listening to the background audio.

Touch, Audio, and Visual (T+A+V). Participants were asked to gently perform the finger movement while the floating bubbles and audio served as feedback mechanisms.

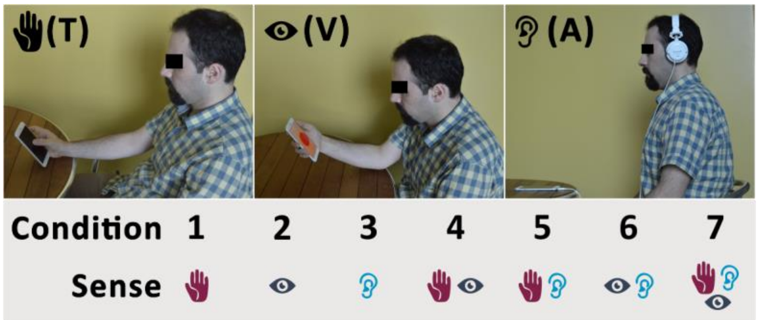

Figure 20. Experiment conditions
Mobile apps exploit different senses for interactive meditation. This study investigates the effects of touch (T), vision (V), audio (A) and their combinations on meditation app use.

13.1.2 Participants

Seventeen university students (10 females, M=28.6, SD=4.0, range=24-35) volunteered for the study. One participant had prior experience in meditation, while the rest of the participants had never experienced meditation. A power analysis indicated that our sample size has a 95% chance of detecting a moderate effect (d = 0.5) with power set at 0.8.

13.1.3 Apparatus

We allowed users to choose their preferred smartphone sizes in order to promote comfortable interaction. We provided a 4-inch (Fleaz F4s+), a 4.5-inch (Alcatel OneTouch POP C5 Dual 5036D), a 4.65-inch (Samsung Galaxy Nexus I9250) and a 5.7-inch (Samsung Galaxy Note 3). We used a Polar H7 heart rate sensor to measure heart rate.

13.1.4 Task and Procedure

First, we explained the study procedure to participants. Then participants were asked to choose their preferred smartphone sizes. A heart rate sensor was fixed around the participant’s chest and the quality of the signal was checked. Participants were asked to choose a comfortable sitting posture and to breathe deeply and slowly for two minutes. Then they were taught how to practice meditation using the assigned condition. They were asked to meditate using the assigned condition for 10 minutes. After each condition, participants took a rest for five minutes while answering questionnaires. All seven conditions were completed in two days, three conditions on the first day and the rest on the second day. The order of intervention was completely randomized across participants. At the end of the second day, we conducted a semi-structured interview. We also asked participants to rank their preferences and ease of use for each of the seven conditions.

13.1.5 Measures

We reviewed and identified common evaluation methods described in prior studies. The effectiveness of meditation can be measured by psychological metrics such as questionnaires and interviews and physiological metrics via quantitative measuring tools such as heart rate sensors. We applied the following metrics: *Relaxation Technique Rating Scale (RTRS)* is commonly used to measure the level of relaxation (Greenberg, 2017) (for more detail see Supplementary Material 7). To understand how the human senses affect user motivation, we used the *Intrinsic Motivation Inventory (IMI)* (McAuley, Duncan, & Tammen, 1989) containing three subscales - importance, enjoyment, and usefulness (for more detail see Supplementary Material 8). To understand how participants prioritize each of the senses, we asked the participants to order the seven conditions according to their preferences and ease of use. To understand each participant's rationale, we conducted a *semi-structured interview*. We also measured *Delta Heart Rate* as a physiological measurement of relaxation, where delta means the difference between the maximum and minimum heart rates while practicing meditation (Hjortskov et al., 2004; Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012; Vrijkotte, Van Doornen, & De Geus, 2000).

13.2 Results

To analyze IMI, RTRS, and heart rate results, we used Repeated Measures Analysis of Variance (RM-ANOVA) and we used Mauchly's test for correcting the data. Post hoc comparisons with Bonferroni correction were used. The order of user preferences and ease of use were analyzed using the Friedman test and Wilcoxon signed-rank tests for pairwise comparisons. The correlations between user preferences and IMI, RTRS and delta heart rate were analyzed via a Spearman's rank-order correlation test.

13.2.1 Quantitative

Table 1 summarizes the quantitative results. There is a main effect on *enjoyment* ($F_{4.5,72.2}$=4.145, p<0.01, η^2=0.206, Mauchly not sig). Post hoc tests reveal significant differences between *V* and *A* (p<0.001), between *T+V* and *V* (p<0.05), between *A+V* and *V* (p<0.01), and between *T+A+V* and *V* (p<0.05). There is also a main effect regarding the *usefulness* of human senses in the practice of meditation ($F_{4.8,76.9}$= 5.155, p<0.001, η^2=0.244, Mauchly not sig). Post hoc tests revealed significant differences between *V* and *A* (p<0.01), between *V* and *T+A+V* (p<0.05), and between *A* and *T+V* (p<0.01).

There is a main effect on *RTRS* ($F_{4.0,64.1}$=2.933, p<0.05, η^2=0.155). Post hoc comparisons reveal significant differences between *A* and *V* (p<0.01), between *A+V* and *V* (p<0.05), and between *T+A+V* and *V* (p<0.05).

There is a main effect on *delta heart rate* ($F_{4.1,65.5}$=2.01, p<0.05, η^2=0.112, Mauchly not sig). Post hoc comparisons revealed significant differences between *T+A* and *T* (p<0.05).

There is a main effect on *user preference* (χ^2(6)=38.521, p<0.001). Post hoc analyses revealed significant differences between *T+A* and *T* (p<0.01), between *A* and *T* (p<0.001), between *A+V* and *T* (p<0.05), between *T+A+V* and *T* (p<0.01), between *T+A* and *V* (p<0.01), between *A* and *V* (p<0.001), between *T+V* and *V* (p<0.05), between *A+V* and *V* (p<0.001), and between *T+A+V* and *A* (p<0.01). We also found a main effect on *easiness* (χ^2(6)=22.921, p<0.001). Post hoc analysis showed significant differences between A+T and *T* (p<0.05), between *A* and *T* (p<0.001), and between *A* and *V* (p<0.001).

A Spearman's rank-order correlation was conducted to determine the relationship between *user preferences* and *IMI*. There was a moderate positive correlation between *user preferences* and *enjoyment* (r_s(119)=0.339, p<0.001), a strong positive correlation between *user preferences* and *usefulness* (r_s(119)=0.524, p<0.001), and a strong positive correlation between *user preferences* and *RTRS* (r_s(119)=0.414, p<0.001). These results suggested that preferences affect the effectiveness of meditation.

In general, all measures provide consistent results. We found that *A* generally performed better than *V* and T. In addition, when *V* and *T* were combined with *A* respectively, the performance of *V* and *T* improved, suggesting that *A* is a significant component. Conversely, we found that when *A* was combined with other senses, performance was less effective than with *A* alone. Indeed, this was clearly reflected in user preferences and ease of use. To understand why this was so, we further analyzed our interview results using an open coding process.

Table 1. Results summary for human senses
Results of IMI (Enjoyment, Usefulness, and Importance), RTRS, HR Delta (Max-Min), and user preferences and ease of use. The characters (a to i) refer to significant differences between pairs.

Senses	IMI						RTRS		HR Delta		Preference		Easiness	
	Enjoyment		Usefulness		Importance									
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T	27.59	4.43	27.29	4.01	19.29	1.99	42.41	6.98	14.23[a]	3.86	3.35[a,b,c,d]	1.80	3.25[a,b]	1.80
V	26.47[a,b,c,d]	4.40	25.18[a,b]	7.16	19.06	1.92	38.76[a,b,c]	8.30	17.12	6.89	3.41[e,f,g,h]	2.29	3.25[c]	2.26
A	31.06[a]	5.38	33.18[a,c]	6.39	20.12	2.23	46.23[a]	8.71	15.41	5.71	6.18[b,f,i]	1.51	6.12[b,c]	1.54
T+V	28.47[c]	4.68	27.29[c]	5.99	19.71	3.10	41.47	7.32	17.59	7.79	3.41[g]	1.66	3.50	1.67
T+A	29.82	5.01	31.29	7.28	20.12	2.69	44.41	8.53	17.76[a]	5.42	4.41[a,e]	1.62	4.44[a]	1.67
A+V	29.06[b]	4.64	28.59	7.17	19.41	3.52	44.53[b]	8.12	16.59	4.42	3.70[c,h]	1.61	3.75	1.65
T+A+V	29.29[d]	3.87	30.53[b]	5.66	19.76	2.95	45.18[c]	7.64	18.23	5.98	3.59[d,i]	2.03	3.75	1.98

13.2.2 Qualitative

Interviews provide a rationale for our quantitative results, particularly on why *A* was strongly preferred, but also revealed that our quantitative results may not fully depict the complete understanding of *V* and *T*. In the interview, all participants reported that, because *A* is simple and it relaxes them easily, *A* was strongly preferred. Nevertheless, some participants mentioned that *A* easily caused them to feel sleepy or their minds to wander. Conversely, most participants reported that both *T* and *V* were difficult to practice and required extra effort and thus were not preferred. For example, a participant said,

> [P4]: "*Vision is helpful at the beginning to help me focus, but I started to feel tired after a while. Thus, I choose to close my eyes but during that time there is literally nothing to keep my attention.*"

Similarly, another participant said that,

[P15]: "*Using touch is a useful technique to keep me focused and attentive but doing it continuously could be tiring. Instead, I prefer touch for several minutes, then I close my eyes once I feel I want to and I can stop/restart the finger movement anytime.*"

To further understand when *T* and *V* start to feel tiring, we asked participants at what stage they wanted to close their eyes and stop watching or touching the screen. On average, participants preferred to stop after 4 minutes for vision and after 2 minutes for touch. Participants preferred to close their eyes while maintaining finger movements for a short while; when they felt they were 'in the zone', they wanted the option to stop finger movement altogether, so they could enter a deeper mindfulness zone.

These qualitative results contradict our quantitative results, i.e., they indicate that *V* and *T* may be actually useful but not preferred, most likely because they promote attentiveness rather than relaxation which can sometimes feel tiring and tense especially for meditation novices. One participant mentioned,

[P14]: "*Everyone strongly preferred audio because audio is easy to practice. Meanwhile, touch and vision require practice and initial effort to train the attention, and they make me feel fatigued, tired and it's hard to relax.*"

Consistent with our quantitative results, we found that participants mostly focused on the relaxation aspect of meditation, while few appreciated the attentiveness aspect of meditation. This is a very surprising result indicating that lack of participant preferences for certain senses may not mean that these senses are unimportant. Instead, it may suggest the need for users to practice more to enhance their attentive skills. Furthermore, it suggests that perhaps certain senses may be more useful for certain purposes. Specifically, this result indicates that there are two components for meditation. One is relaxation and the other is the focus. On the one hand, some interaction conditions (i.e., *T* and *V*) lead to focus (but are tiring after a period of time), while on the other hand, some interaction conditions (i.e., *A*) make people relax (but may lead to drowsiness and a wandering mind).

The interaction between the two components was further observed when participants were asked about combinations of senses. For example, several participants commented that combining *T* with *A* or *V* with *A* was particularly effective. A participant said,

[P2]: “*Combining touch with audio is better than using touch or audio individually. Touch helps me focus but feels tiring after a long time while audio makes me feel sleepy after a certain period of time. Using both senses addresses both limitations.*”

We found similar comments for the *A+V* condition.

Overall, this is an interesting result because, (1) it indicates the difference between using human senses for either focus or relaxation, (2) it suggests that *V* and *T* are effective for focusing, (3) *A* is useful for states of relaxation, and (4) both relaxation and focus need to be developed in parallel and eventually integrated, in order to lead users to reach the mindfulness zone.

13.3 Discussion and Conclusion

Our findings raised a conflict in the experience of the participants, but this conflict helps us understand more precisely the interaction between human senses and meditation. As opposed to our original expectation that certain senses are more effective, we found that the effectiveness of human senses can be defined by their respective roles which are based on the two components of meditation: relaxation and focus (see Figure 21).

When users wander or get sleepy, *V* and *T* can be helpful to trigger focus. On the other hand, when users feel stress, it may be beneficial for users to stop using *V* and *T* and use *A* instead. Careful configuration and situational application should aim at leading the practitioner into the mindfulness zone, i.e., a state in which relaxation and focus are not in opposition to each other. We suggest that an informed meditation app design must include awareness of various outcomes: relaxation, focus, and mindfulness.

Study 5 is predominantly exploratory but also provides initial design insights. For example, since users may switch between wandering and stress, the effectiveness of a meditation app could be enhanced if it supports a dynamic understanding of the user states (e.g., through biofeedback devices). Another good example is that it may not always be wise to design a dependent interaction mechanism. For example, the dependent mechanism between *T* and *A* may prevent users from entering into a more mindful state.

One limitation of Study 5 is the choice of participants, i.e., primarily university students. Our study is also based on a specific prototype thus further study may need to be conducted to confirm our results. Another possible limitation is the limited physiological metric being used. EEG is a common metric for measuring meditation, but we decided not to use EEG as there was evidence that finger movements may affect the results of EEG (Paek et al., 2014), and thus such EEG results may confound meditation effects and results between our seven conditions. Heart rate and respiratory dynamics are generally similar during the relaxation state (Peng et al., 2004), thus we decided to stick with heart rate while complementing it with qualitative results.

Due to recent evidence regarding the effectiveness of meditation, many developers became excited and applied meditation practice to smartphones but perhaps without adequate understanding. In particular, meditation is an activity that has to account for the human senses where the aim is to reach a mindful state. Thus, we intended to scrutinize how human senses affect meditation experiences. Our evaluation approach centered around interactions and multi-modalities (individual and combined) and therefore our findings have significance beyond meditation apps to interactions and interfaces in general. Study 5 has also opened a discussion regarding how passive interaction such as audio and active interaction such as touch affects the meditation process. This study can serve as a stepping stone towards understanding the relationship between the human senses and interactive meditation in particular, and multi-modal interactions in general.

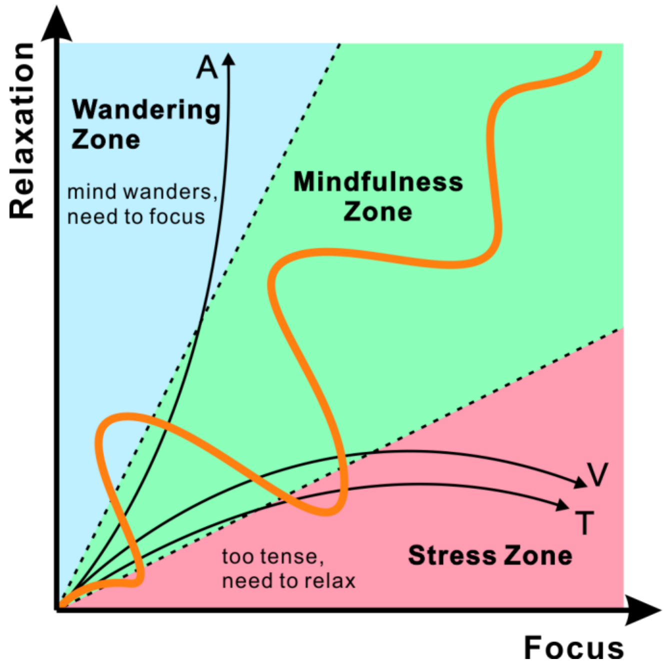

Figure 21. Hypothetical framework for human senses

We found that the effectiveness of human senses can be described by their role in maintaining the balance between relaxation and focus. For example, *A* is useful for relaxation but may easily lead to sleepiness or a wandering mind. On the other hand, *V* and *T* are useful for promoting focus but they may cause stress after a period of time. Thus, it is important to know how to use the different human senses situationally to maintain both relaxation and focus.

CHAPTER 14

RELATIONSHIP BETWEEN TECHNOLOGY AND MINDFULNESS

14.1 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 technologies can introduce users to the benefits of meditation. It needs to be noted that the state of mindfulness is a natural and intrinsic human capacity. Though mindfulness capacity is intrinsic to human consciousness, it is generally ignored in the rush of our daily schedules. Therefore, the primary purpose of our framework is to develop a product that introduces users to what is potentially the first time to a deliberate and conscious experience of mindfulness. People simply need to experience it, for example, through such an app and practice it with a view to making mindfulness habitual and natural. 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 and the 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.

14.2 Smartphones and Mindfulness in Daily Life

There is a growing body of evidence indicating detrimental effects of smartphones. A recent investigation (Stothart, Mitchum, & Yehnert, 2015) 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 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 are habitually fast and non-mindful. When we are moving, our mind usually wanders, and the body moves in autopilot mode. Technology enables us to practice mindful movement anytime, anywhere such as 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.

14.3 Future Implications

Mobile phones are one of the popular, everyday embodied objects. Even though our framework is developed for mobile phones, the implications of the framework could be applied to any objects in our lives. 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, but the input/output interface can also be well separated: what if we mindfully move a mobile phone, 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.

In essence, if our interactive framework can turn a mobile phone into a mindfulness tool which means 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 actually encourages 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 the digital design to augment every object to encourage mindful interactions. Our work on smartphones could be an initial step for the conscious living.

CHAPTER 15

CONCLUSION

A holistic consideration of our human capacities and technological hindrances to those capacities is essential to achieving greater synergy between humans and computers and more edifying outcomes for a human experience beyond interactions with devices.

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 (movement) and sheds light on the generic features of mindfulness for regulation (slow, continuous). *ARF* also proposes the appropriate feedback design for mobile applications (soft stimuli). Through developing two design cases, and conducting several evaluation studies, we demonstrated that the framework can achieve positive results in improving mindfulness, mood, well-being, etc. 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 preference (for kinetic meditation). Due to ease of access and lower cost compared 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.

SUPPLEMENTARY MATERIAL 1

PROFILE OF MOOD STATE (POMS)

The following are 65 items of *Profile of Mood State* (POMS) (Douglas M McNair et al., 1992). The online version of POMS is available at https://www.brianmac.co.uk/poms.htm.

Instruction. Read each item and select your feeling regarding each item in the past 5-day. Rate the items by choosing Not at All, A Little, Moderately, Quite a Bit, and Extremely.

Items. 1- Friendly, 2- Tense, 3- Angry, 4- Worn Out, 5- Unhappy, 6- Clear Headed, 7- Lively, 8- Confused, 9- Sorry for things done, 10- Shaky, 11- Listless, 12- Peeved, 13- Considerate, 14- Sad, 15- Active, 16- On Edge, 17- Grouchy, 18- Blue, 19- Energetic, 20- Panicky, 21- Hopeless, 22- Relaxed, 23- Unworthy, 24- Spiteful, 25- Sympathetic, 26- Uneasy, 27- Restless, 28- Unable to Concentrate, 29- Fatigued, 30- Helpful, 31- Annoyed, 32- Discouraged, 33- Resentful, 34- Nervous, 35- Lonely, 36- Miserable, 37- Muddled, 38- Cheerful, 39- Bitter, 40- Exhausted, 41- Anxious, 42- Ready to Fight, 43- Good Natured, 44- Gloomy, 45- Desperate, 46- Sluggish, 47- Rebellious, 48- Helpless, 49- Weary, 50- Bewildered, 51- Alert, 52- Deceived, 53- Furious, 54- Efficient, 55- Trusting, 56- Full of Pep, 57- Bad Tempered, 58- Worthless, 59- Forgetful, 60- Carefree, 61- Terrified, 62- Guilty, 63- Vigorous, 64- Uncertain about things, 65- Bushed.

Scoring information. The detail of scoring for POMS is described at https://www.brianmac.co.uk/pomscoring.htm.

SUPPLEMENTARY MATERIAL 2

PSYCHOLOGICAL GENERAL WELL-BEING INDEX

The following are 22 items of Psychological General Well-being (PGWB) index (Dupuy, 1984). The PGWB index asked for ratings on a 6-point Likert-scale from 0 to 5.

Items.

1. How have you been feeling in general? (During the past 5-day)

5 [ ] In excellent spirits

4 [ ] In very good spirits.

3 [ ] In good spirits mostly

2 [ ] I have been up and down in spirits a lot

1 [ ] In low spirits mostly

0 [ ] In very low spirits

2. How often were you bothered by any illness, bodily disorder, aches or pains? (During the past 5-day)

0 [ ] Every day

1 [ ] Almost every day

2 [ ] About half of the time

3 [ ] Now and then, but less than half the time

4 [ ] Rarely

5 [ ] None of the time

3. Did you feel depressed? (During the past 5-day)

0 [ ] Yes-to the point that I felt like taking my life

1 [ ] Yes-to the point that I did not care about anything

2 [ ] Yes-very depressed almost every day

3 [ ] Yes-quite depressed several times

4 [ ] Yes-a little depressed now and then

5 [ ] No-never felt depressed at all

4. Have you been in firm control of your behavior, thoughts, emotions, or feelings? (During the past 5-day)

5 [ ] Yes, definitely so

4 [ ] Yes, for the most part

3 [ ] Generally so

2 [ ] Not too well

1 [ ] No, and I am somewhat disturbed

0 [ ] No, and I am very disturbed

5. Have you been bothered by nervousness or your "nerves"? (During the past 5-day)

0 [ ] Extremely so-to the point where I could not work or take care of things

1 [ ] Very much so

2 [ ] Quite a bit

3 [ ] Some-enough to bother me

4 [ ] A little

5 [ ] Not at all

6. How much energy, pop, or vitality did you have or feel? (During the past 5-day)

5 [ ] Very full of energy-lots of pep

4 [ ] Fairly energetic most of the time

3 [ ] My energy level varied quite a bit

2 [ ] Generally low In energy or pep

1 [ ] Very low in energy or pep most of the time

0 [ ] No energy or pep at all-I felt drained, sapped

7. I felt downhearted and blue. (During the past 5-day)

5 [ ] None of the time

4 [ ] A little of the time

3 [ ] Some of the time

2 [ ] A good bit of the time

1 [ ] Most of the time

0 [ ] All of the time

8. Were you generally tense-or did you feel any tension? (During the past 5-day)

0 [ ] Yes-extremely tense, most or all of the time

1 [ ] Yes-very tense most of the time

2 [ ] Not generally tense, but did feel fairly tense several times

3 [ ] I felt a little tense a few times

4 [ ] My general tension level was quite low

5 [ ] I never felt tense or any tension at all

9. How happy, satisfied, or pleased have you been with your personal life? (During the past 5-day)

5 [ ] Extremely happy-could not have been more satisfied or pleased

4 [ ] Very happy most of the time

3 [ ] Generally satisfied-pleased

2 [ ] Sometimes fairly happy, sometimes fairly unhappy

1 [ ] Generally dissatisfied, unhappy

0 [ ] Very dissatisfied or unhappy most or all the time

10. Did you feel healthy enough to carry out the things you like to do or had to do? (During the past 5-day)

5 [ ] Yes-definitely so

4 [ ] For the most part

3 [ ] Health problems limited me in some Important ways

2 [ ] I was only healthy enough to take care of myself

1 [ ] I needed some help In taking care of myself

0 [ ] I needed someone to help me with most or all of the things I had to do

11. Have you felt so sad, discouraged, hopeless, or had'so many problems that you wondered if anything was worthwhile? (During the past 5-day)

0 [ ] Extremely so-to the point that I have just about given up

1 [ ] Very much so

2 [ ] Quite a bit

3 [ ] Some-enough to bother me

4 [ ] A little bit

5 [ ] I Not at all

12. I woke up feeling fresh and rested. (During the past 5-day)

0 [ ] None of the time

1 [ ] A little of the time

2 [ ] Some of the time

3 [ ] A good bit of the time

4 [ ] Most of the time

5 [ ] All of the time

13. Have you been concerned, worried, or had any fears about your health? (During the past 5-day)

0 [ ] Extremely so

1 [ ] Very much so

2 [ ] Quite a bit

3 [ ] Some, but not a lot

4 [ ] Practically never

5 [ ] Not at all

14. Have you had any reason to wonder If you were losing your mind, or losing control over the way you act, talk, think, feel or of your memory? (During the past 5-day)

5 [ ] Not at all

4 [ ] Only a little

3 [ ] Some-but not enough to be concerned or worried about

2 [ ] Some and I have been a little concerned

1 [ ] Some and I am quite concerned

0 [ ] Yes, very much so and I am very concerned

15. My daily life was full of things that were interesting to me. (During the past 5-day)

0 [ ] None of the time

1 [ ] A little of the time

2 [ ] Some of the time

3 [ ] A good bit of the time

4 [ ] Most of the time

5 [ ] All of the time

16. Did you feel active, vigorous, or dull, sluggish? (During the past 5-day)

5 [ ] Very active, vigorous every day

4 [ ] Mostly active, vigorous-never really dull, sluggish

3 [ ] Fairly active, vigorous-seldom dull, sluggish

2 [ ] Fairly dull, sluggish-seldom active, vigorous

1 [ ] Mostly dull, sluggish-never really active, vigorous

0 [ ] Very dull, sluggish every day

17. Have you been anxious, worried, or upset? (During the past 5-day)

0 [ ] Extremely so-to the point of being sick or almost sick

1 [ ] Very much so

2 [ ] Quite a bit

3 [ ] Some-enough to bother me

4 [ ] A little bit

5 [ ] Not at all

18. I was emotionally stable and sure of myself. (During the past 5-day)

0 [ ] None of the time

1 [ ] A little of the time

2 [ ] Some of the time

3 [ ] A good bit of the time

4 [ ] Most of the time

5 [ ] All of the time

19. Did you feel relaxed, at ease or high strung, tight, or keyed-up? (During the past 5-day)

5 [ ] Felt relaxed and at ease the whole month

4 [ ] Felt relaxed and at ease most of the time

3 [ ] Generally felt relaxed but at times felt fairly high strung

2 [ ] Generally felt high strung but at times felt fairly relaxed

1 [ ] Felt high strung, tight, or keyed up most of the time

0 [ ] Felt high strung, tight, or keyed up the whole month

20. I felt cheerful, lighthearted. (During the past 5-day)

0 [ ] None of the time

1 [ ] A little of the time

2 [ ] Some of the time

3 [ ] A good bit of the time

4 [ ] Most of the time

5 [ ] All of the time

21. I felt tired, worn out, used up, or exhausted. (During the past 5-day)

5 [ ] None of the time

4 [ ] A little of the time

3 [ ] Some of the time

2 [ ] A good bit of the time

1 [ ] Most of the time

0 [ ] All of the time

22. Have you been under or felt you were under any strain, stress, or pressure? (During the past 5-day)

0 [ ] Yes, almost more than I could bear or stand

1 [ ] Yes, quite a bit of pressure

2 [ ] Yes, some-more than usual

3 [ ] Yes, some-but about usual

4 [ ] Yes, a little

5 [ ] Not at all

SUPPLEMENTARY MATERIAL 3

SUBJECTIVE HAPPINESS SCALE

The followings are 4 items of *Subjective Happiness Scale* (SHS) (Neff & Germer, 2013).

Items.

1. In general, I consider myself:

Not a very happy person   1   2   3   4   5   6   7   A very happy person

2. Compared with most of my peers, I consider myself:

Less happy   1   2   3   4   5   6   7   More happy

3. Some people are generally very happy. They enjoy life regardless of what is going on, getting the most out of everything. To what extent does this characterization describe you?

Not at all   1   2   3   4   5   6   7   A great deal

4. Some people are generally not very happy. Although they are not depressed, they never seem as happy as they might be. To what extent does this characterization describe you?

Not at all   1   2   3   4   5   6   7   A great deal

SUPPLEMENTARY MATERIAL 4

RUSSEL’S TWO-DIMENSIONAL CIRCUMPLEX SPACE MODEL

We used *Russell’s two-dimensional circumplex space model* (Russell, 1980) for measuring affective states of users (i.e., level of arousal and valence). The emotional chart (see Figure 22) has been taken from (Paltoglou & Thelwall, 2013), pp. 119.

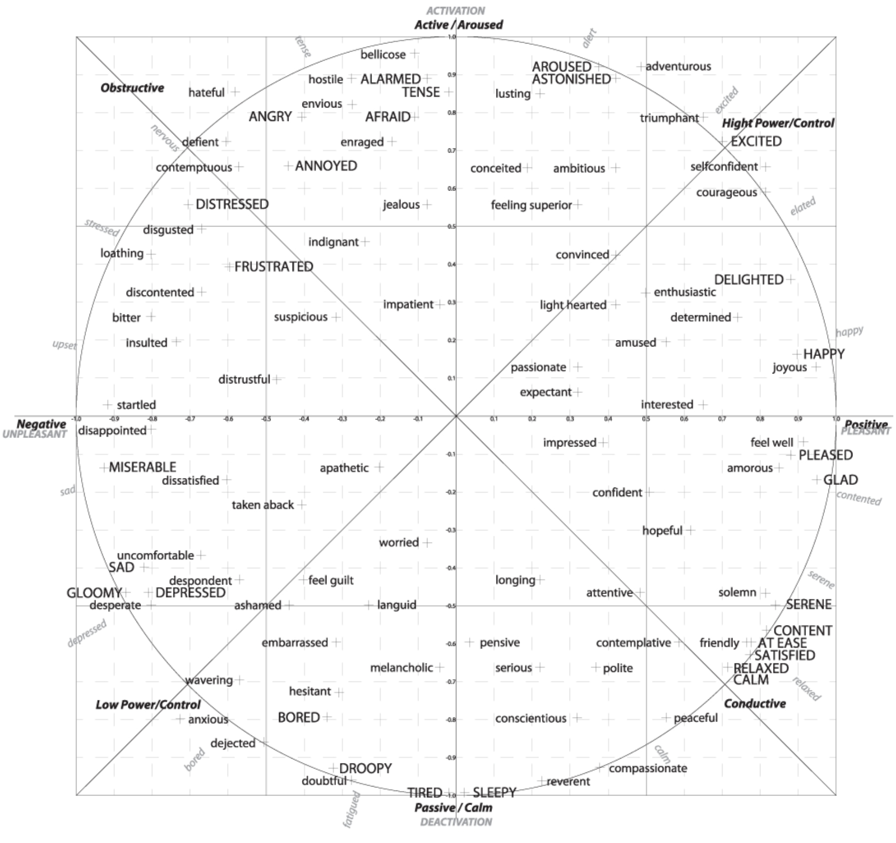

Figure 22. Russell’s two-dimensional circumplex space model
The chart has been taken from (Paltoglou & Thelwall, 2013).

SUPPLEMENTARY MATERIAL 5

FIVE FACET MINDFULNESS QUESTIONNAIRE

The followings are 39 items of *Five Facet Mindfulness Questionnaire* (FFMQ) (Baer et al., 2006).

Instruction. Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you.

1. *Never or very rarely true*
2. *Rarely true*
3. *Sometimes true*
4. *Often true*
5. *Very often or always true*

Items.

1. When I'm walking, I deliberately notice the sensations of my body moving.
2. I'm good at finding words to describe my feelings.
3. I criticize myself for having irrational or inappropriate emotions.
4. I perceive my feelings and emotions without having to react to them.
5. When I do things, my mind wanders off and I'm easily distracted.
6. When I take a shower or bath, I stay alert to the sensations of water on my body.
7. I can easily put my beliefs, opinions, and expectations into words.

8. I don’t pay attention to what I’m doing because I’m daydreaming, worrying, or otherwise distracted.

9. I watch my feelings without getting lost in them.

10. I tell myself I shouldn’t be feeling the way I’m feeling.

11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.

12. It’s hard for me to find the words to describe what I’m thinking.

13. I am easily distracted.

14. I believe some of my thoughts are abnormal or bad and I shouldn’t think that way.

15. I pay attention to sensations, such as the wind in my hair or sun on my face.

16. I have trouble thinking of the right words to express how I feel about things.

17. I make judgments about whether my thoughts are good or bad.

18. I find it difficult to stay focused on what’s happening in the present.

19. When I have distressing thoughts or images, I “step back” and am aware of the thought or image without getting taken over by it.

20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.

21. In difficult situations, I can pause without immediately reacting.

22. When I have a sensation in my body, it’s difficult for me to describe it because I can’t find the right words.

23. It seems I am “running on automatic” without much awareness of what I’m doing.

24. When I have distressing thoughts or images, I feel calm soon after.

25. I tell myself that I shouldn’t be thinking the way I’m thinking.

26. I notice the smells and aromas of things.

27. Even when I’m feeling terribly upset, I can find a way to put it into words.

28. I rush through activities without being really attentive to them.

29. When I have distressing thoughts or images I am able just to notice them without reacting.

30. I think some of my emotions are bad or inappropriate and I shouldn’t feel them.

31. I notice visual elements in art or nature, such as colors, shapes, textures, or patterns of light and shadow.

32. My natural tendency is to put my experiences into words.

33. When I have distressing thoughts or images, I just notice them and let them go.

34. I do jobs or tasks automatically without being aware of what I’m doing.

35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.

36. I pay attention to how my emotions affect my thoughts and behavior.

37. I can usually describe how I feel at the moment in considerable detail.

38. I find myself doing things without paying attention.

39. I disapprove of myself when I have irrational ideas.

Scoring information.

Observe items: 1, 6, 11, 15, 20, 26, 31, 36

Describe items: 2, 7, 12R, 16R, 22R, 27, 32, 37

Act with Awareness items: 5R, 8R, 13R, 18R, 23R, 28R, 34R, 38R

Nonjudge items: 3R, 10R, 14R, 17R, 25R, 30R, 35R, 39R

Nonreact items: 4, 9, 19, 21, 24, 29, 33

Note: R indicates reverse items (i.e., calculated score = 6 – participants' answer)

SUPPLEMENTARY MATERIAL 6

BODY AWARENESS QUESTIONNAIRE

The *Body Awareness Questionnaire* was adopted from an earlier study (Mehling et al., 2009).

Instruction. Please rate each item based on your feeling in the last 5-day. Put the number in the blank space.

1. *Never or very rarely true*
2. *Rarely true*
3. *Sometimes true*
4. *Often true*
5. *Very often or always true*

Items.

1. I am aware of distress, worry, pain, and tension in my muscles.
2. I feel my feet warming up when I relax.
3. I notice changes in how my body feels.
4. I can distract myself from uncomfortable body sensations.
5. I can move my attention to different parts of my body.
6. When I am walking, I deliberately notice the sensations of my body moving.

Scoring information. Questions 1-3 assessed *body sensation* (i.e., the ability to sense the body or notice changes in the body) and questions 4-6 measured *quality of attention* (i.e., the level of attention paid to the body).

SUPPLEMENTARY MATERIAL 7

RELAXATION TECHNIQUE RATING SCALE

The followings are items of *Relaxation Technique Rating Scale (RTRS)* (Greenberg, 2017). The questionnaire retrieved from https://goo.gl/JVtpym, and revised according to purpose of the study.

Instruction. Please rate each item based on your feeling during the last session. Put the number in the blank space.

1. *Very untrue*
2. *Untrue*
3. *Somewhat untrue*
4. *Neutral*
5. *Somewhat true*
6. *True*
7. *Very true*

Items.

1. After I have practiced meditation, it felt me good.
2. It was easy to fit this relaxation technique into my schedule.
3. I handled my daily tasks better than I usually did.
4. It was an easy technique to learn.
5. I was able to isolate from my surroundings while using this input modality.
6. I did not feel tired after practicing this relaxation technique.

7. I became more aware of your body during after using this input modality.
8. Any stress symptoms I had (headache, tense muscles, anxiety) while practicing meditation by using this input modality.
9. When I concluded this technique, my pulse rate was much lower than when I began.

SUPPLEMENTARY MATERIAL 8

INTRINSIC MOTIVATION INVENTORY

The followings are items related to *enjoyment*, *importance*, and *usefulness* subscales of the *Intrinsic Motivation Inventory (IMI)* (McAuley et al., 1989). The original questionnaire was retrieved from http://selfdeterminationtheory.org/intrinsic-motivation-inventory/. The items were revised according to the purpose of the study.

Instruction. Please rate each item based on your feeling during the last session. Put the number in the blank space.

1. *Very untrue*
2. *Untrue*
3. *Somewhat untrue*
4. *Neutral*
5. *Somewhat true*
6. *True*
7. *Very true*

Enjoyment/Interest items.

1. I enjoyed practicing mediation with this input modality.
2. Practicing meditation with this input modality was fun to do.
3. I thought using this input modality was boring. (R)
4. Using this input modality did not hold my attention at all. (R)
5. I would describe using this input modality as very interesting.

6. I thought using this input modality was quite enjoyable.
7. While I was using this input modality, I was thinking about how much I enjoyed it.

Importance/Effort items.

1. I put a lot of effort for using this input modality in meditation.
2. I didn’t try very hard to do well while using this input modality. (R)
3. I tried very hard on using this input modality.
4. It was important for me to do well at this meditation session.
5. I didn’t put much energy into this input modality. (R)

Usefulness/Value items.

1. I believe this input modality could be of some value to me.
2. I think, using this input modality is useful for reducing stress.
3. I think using this input modality is important for meditation because it can enhance my relaxation ability.
4. I would be willing to repeat using this input modality because it has some value to me.
5. I think using this input modality help me to have a clear head.
6. I believe using this input modality could be beneficial to me.

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