A Framework for Interactive Mindfulness Meditation Using Attention-Regulation Process

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ABSTRACT
We are often overwhelmed by everyday stressors. Mindfulness meditation can help slow things down and bring one's attention into the present moment. Given the prevalence of smartphones, mindfulness-based mobile applications (MBMAs) have received much attention. Current MBMAs mainly use the guided meditation method which may not be always effective, e.g., users may not be able to follow the pace of instructions and they need a private environment. This paper presents a framework for interactive MBMAs which allows users to self-regulate their attention according to their abilities and conditions. The framework is described by an *Attention-Regulation Process* and has two components: (1) *Relaxation Response* and (2) *Attention Restoration Theory*. The framework is validated by our experiment. It also informs future development for interactive meditation and has broad implications for designing mindfulness and well-being.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous.

Author Keywords
Framework; mindfulness; meditation; interactivity; attention-regulation process; mobile applications; relaxation response; attention restoration theory.

INTRODUCTION
As our world becomes increasingly fast-paced, we occasionally need to disconnect and refresh ourselves. Mindfulness meditation is a helpful technique which can bring one's attention back to the present moment [19]. Mindfulness practice [47] is defined as a "*family of self-regulation practices that focus on training attention in order to bring mental processes under greater voluntary control and thereby foster general mental well-being and development and/or specific capacities such as calm, clarity and concentration.*" The benefits of mindfulness practice have been confirmed as enhancement of human well-being [28], increased attention span [18], stress reduction [38], and improved cognitive abilities [7]. On the more qualitative side, literature shows its effectiveness on empathy, compassion, altruism [25], enlightenment [34], and spiritual health [46]. Given the prevalence of smartphones [9], there are a lot of opportunities for mindfulness-based mobile applications (MBMAs).

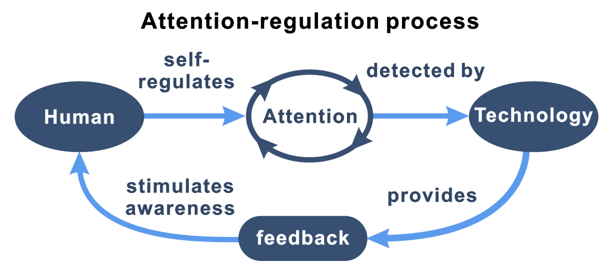

Figure 1. Technology-mediated attention-regulation process [15, 16]. Technology detects the current state of the user's attention and provides real-time feedback to support self-regulation. Our work provides a framework which shows how technology can detect human attention without the use of dedicated sensors, and what kind of feedback can effectively support attention-regulation process.

However, current MBMAs mainly use the *guided meditation* method [31, 49] which follows the tradition of users following instructions from a meditation teacher. Nevertheless, this technique may not always be effective considering that users should be able to follow the pace of instructions. Furthermore, participation requires a dedicated private environment [37, 48]. Given these limitations, researchers have been exploring *attention-regulation process* [15, 16] which describes a cycle of self-regulation supported by technology-mediated detection and feedback mechanisms (see Figure 1). However, this approach also suffers from the need of dedicated accessories (e.g., respiration sensors, EEG).

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In this paper, we present a framework that uses a simple, practical attention-regulation process by leveraging the interactive capabilities of mobile devices. To describe how technologies can detect the user's attention without any extra accessories and provide meaningful feedback, the framework is grounded upon two components: *Relaxation Response* (RR) and *Attention Restoration Theory* (ART). This framework can help inform how to design interactive MBMAs that allow users to self-regulate their attention according to their expertise, without any extra accessories, anywhere and at anytime.

We demonstrated the framework through the development of a case study application called *Pause*[1]. Two studies were conducted to evaluate how our case study performs against an existing MBMA. To understand how Pause compares with traditional meditation, we selected Headspace [26][2] which uses the traditional guided meditation method. Study 1 investigated the intervention effects through a longitudinal study. The results showed that our case study outperformed Headspace in attention improvement and that it achieves similar improvements in mood and general well-being. Study 2 investigated the effect of different environments on the level of relaxation and mindfulness. The results showed that our case study outperformed Headspace in a busy environment, but not in a calm environment, indicating the unique scenario where our framework is particularly effective. Overall, experimental results demonstrated the effectiveness of our proposed framework.

RELATED WORK

This section summarizes three approaches to designing technology-mediated mindfulness training products: (1) biofeedback, (2) physical artifacts, and (3) MBMAs.

Biofeedback

The first approach focuses on biofeedback. Electroencephalography (EEG)[3], pulse-rate [39], respiration [5, 39], heart rate variability[4], skin conductance [39, 40], and blood volume [39] are common body properties which have been used in this approach to provide users with real-time audio, visual, or audiovisual feedback to help self-regulate the state of mindfulness. All these products support and motivate users to sustain their attention. However, they require dedicated accessories or special devices to measure the user's physiological state because access to these accessories may be limited.

Physical Artifacts

The second approach borrows the physical forms of traditional meditation artifacts, such as a Chinese meditation balls (e.g., Philips Mind Spheres concept), or Tibetan prayer wheels (e.g., Channel of Mindfulness[5]). Both use technology to sense the particular pattern of 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. This approach also requires special physical devices that are often expensive and necessitate private space for their use.

MBMAs

The third approach is to use mobile applications which are more accessible in daily life. The most common approach is guided meditation [31]. Practitioners meditate according to instructions provided by a meditation teacher e.g., Headspace, Buddhify[6], Calm[7], and Smiling Mind[8]. However, they have certain drawbacks. Guided meditation apps require users to find a quiet spot which may be difficult for those who are in busy public places [48]. Moreover, a lack of previous expertise could prevent practitioners from following all instructions in a precise way [37]. Instead of using guided meditation, our work exploits the interactivity capabilities of smartphones following the attention-regulation process.

ATTENTION-REGULATION FRAMEWORK

Figure 2a illustrates the process of the attention-regulation framework. Our framework describes an attention-regulation process which can be separated into two key mechanisms: Detection and Feedback. The technology first detects the user's attention and then provides real-time feedback to stimulate user awareness so that the user can self-regulate his/her attention accordingly. The key challenge of this work is how to detect user attention without the use of any dedicated biofeedback devices. In addition, we asked how technologies could provide an appropriate amount of feedback while not interrupting the natural process of self-regulation. In the following two subsections we discuss two components that help inform these questions: *Relaxation Response* and *Attention Restoration Theory*.

Relaxation Response (RR)

Relaxation response (RR) [2] stems from physiology and is defined as our physiological ability to release chemicals and brain signals to make our muscles and organs slow down and increase blood flow to the brain. There are many methods to elicit RR, all such methods containing two aspects: *Repetition* and *Slowness*. In RR, practitioners repeat a word, sound, phrase, prayer or movement to cultivate attention through passively disregarding everyday thoughts that inevitably come to mind and then return to the repetition. The pace of repetition is another significant factor. All RR methods are slow-paced. The slow pace keeps users away from daily habitual processing and trains them to have heightened awareness of their minute actions. Good examples of RR include walking meditation, Yoga, and Tai Chi, all exploiting slow, repetitive patterns to cultivate mindfulness.

RR is a well-established principle [12, 30] and it is relevant to the attention-regulation process. First, RR informs what user actions can be exploited to support the self-regulation process. Second, RR informs how we can use technology to detect the user's attention without the use of sensors. In other words, by exploiting slowness and repetitiveness parameters of user

[1] www.pauseable.com

[2] http://www.headspace.com. Headspace is one of the most downloaded MBMAs with around 5 million users in January 2016.

[3] Muse headband, http://www.choosemuse.com

[4] emWave2, http://www.heartmath.com

[5] http://cargocollective.com/yufan/Channel-of-Mindfulness

[6] http://buddhify.com

[7] https://www.calm.com

[8] http://smilingmind.com.au

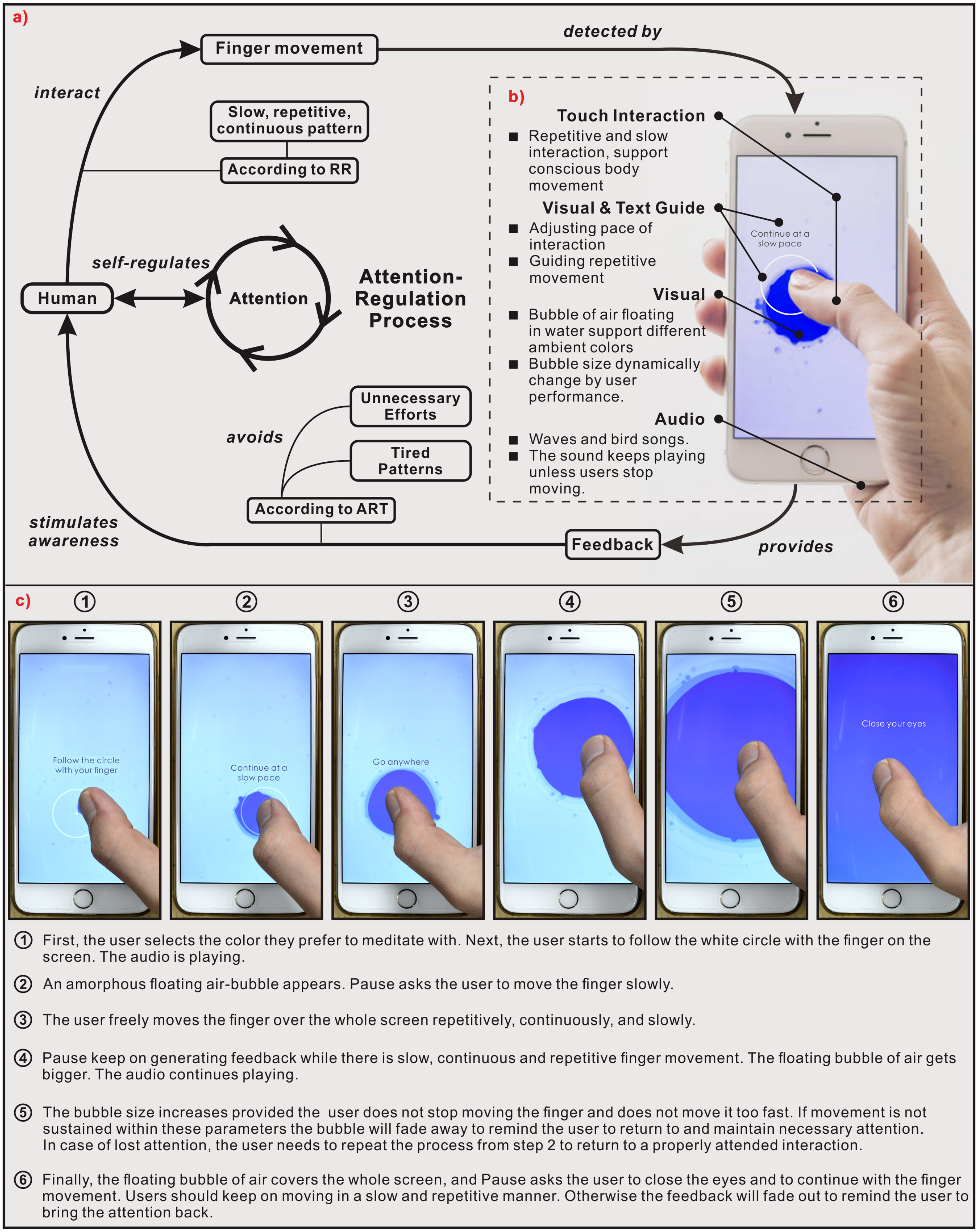

Figure 2. (a) Attention-regulation framework, (b) Overview of case study (Pause), (c) Interaction steps with Pause.

actions, the technology can assess whether the user's mind is wandering or whether it is one with the task and then can provide appropriate real-time feedback to users, without the need to attach any sensors.

Attention Restoration Theory (ART)

Attention Restoration Theory (ART) [22] stems from psychology and it states that by spending time with soft fascinations such as bird songs, random water bubbles, or ocean waves in which gazing is effortless, this process can enable our attention system to recover from mental fatigue [1, 3, 21, 32]. ART is relevant to the attention-regulation process as it informs how we should implement the feedback mechanism while not interrupting the user's progressive meditative state. ART suggests that suitable feedback should follow two characteristics [23]: First, the feedback should avoid calling on tired cognitive patterns such as things related to the everyday environment (e.g., daily music) or complex stimuli that stimulate judgement (e.g., a picture of some known person). Second, the feedback should be a single, soft cognitive stimulus which acts as an anchor to promote effortless reflection.

CASE STUDY

In this section, we demonstrate how we can design an MBMA using our attention-regulation framework. We developed a case study called Pause. Figure 2b provides the overview of Pause. We developed Pause through an iterative process [6]. However, in this work, we only present the final design. We applied what we learned from RR and ART to our design including the interaction mechanism, the pace of interaction, audio feedback, and visual feedback. Pause adopts repetitive, slow touch movements from RR which states that such movement can lead to heightened awareness and mindfulness. Following ART 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.

To implement RR, we chose touch interaction where the speed and continuity of finger movement can be precisely detected by the mobile touch screen itself. Pause asks the user to slowly move one finger on the screen. To move the finger slowly, continuously and repeatedly, sustained attention is required. To implement ART, we designed soft audio-visual cognitive stimuli. We used the amorphous image of a bubble of air floating in water combined with randomly displayed gradients and variations of motion which provide a feeling of something organic, random, minimalistic and airy which promotes effortless reflection. We used the sound of ocean waves and bird songs with a sweeping sound around one chord. This provides an un-intrusive repeating and soothing loop which allows the practitioner to focus within the required parameters of the slow repetitive finger movement. To adjust the pace of the interaction, we used text guidance to train users 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 between RR and ART 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 (see Figure 2c). Sound is the mechanism in the feedback loop that effectively calms the mind. The visual part works as an anchor to engage the mind. As soon as the finger moves too fast, or stops, or is lifted from the screen, the amorphous audio-visual feedback fades away 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, when people close their eyes. By confining the interaction to strict parameters, sustained mindful attendance is encouraged.

STUDY 1 - INTERVENTION EFFECTS

To understand how our case study performs against an existing MBMA in the long-term, we conducted Study 1. We selected Headspace which was already investigated in a qualitative way [26] for long-term use, showing that Headspace can lead participants to improve emotion and mood states.

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-training with post-training states. We selected five days training because earlier studies [44, 51] showed that as little as three to five days training can significantly enhance attention and mood regulation.

Participants

Eighteen university students and staff members (8 females) aged 20-34 (M=27, SD=4.3) were recruited. All were right handed. Only one of the participants had received routine mindfulness training before. None of them had used MBMAs before. Each participant was paid $10.

Apparatus

An iPhone 6 Plus and its original headphone were used for running the MBMAs. The Headspace app was downloaded from the Apple App Store. The Psychology Experiment Building Language (PEBL 0.14)[9] 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.

Task and Procedure

Participants were asked to sign a letter of consent. Background information including daily stress and meditation experience was gathered. Later they were introduced to the procedure of the study. Participants were randomly assigned to either the Pause (5 males and 4 females) or Headspace (5 males and 4 females) groups. Participants were instructed in the use of MBMAs. 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 measure general well-being, mood, and happiness respectively. The three questionnaires took 45

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

minutes to complete. From the next day, participants trained using the MBMA in two sessions. Each session consisted of 10 minutes training with a five minute break between sessions. Training was repeated over five days. All participants used headphones for training. Right after finishing 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.

Measures

As mentioned, traditional mindfulness practices improve attention [44], mood [38] and well-being [28]. Therefore, we measured the intervention effects of mindfulness practice using the following methods:

Attention. To measure the attention, the *Attentional Network Test* (*ANT*) which was developed by Fan et al. [13] is the most used method. Tang et al. [44] showed that directed attention significantly improved after long-term meditation. Our study used ANT to measure pre-training and post-training 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 [13]). 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 (Equation 1).

$$\begin{aligned} Alerting\ effect &= RT_{no\ cue} - RT_{center\ cue} \\ Orienting\ effect &= RT_{center\ cue} - RT_{spatial\ cue} \\ Conflict\ effect &= RT_{incongruent} - RT_{congruent} \end{aligned} \quad (1)$$

Mood. To measure positive and negative moods, the 65-item *Profile of Mood State* (POMS) was used. POMS was rated on a 5-point Likert-scale from 0 (not at all) to 4 (extremely). POMS has different scales including Anger-Hostility, Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, Tension-Anxiety, and Vigor-Activity. Several studies used POMS. For example, Garland et al. [14] studied the effect of an 8-week Mindfulness-based Stress Reduction (MBSR) program on cancer patients. They found a correlation between an increase in mindfulness and decreased stress and negative moods. In another work, Tang et al. [44] studied intervention effects of a newly developed meditation method (integrative body-mind training). The POMS results showed that five days training can improve mood.

General Well-being. We measured well-being using the 22-item *Psychological General Well-being Index* (PGWBI) [11]. PGWBI was rated on a 6-point Likert-scale from 0 to 5. PGWBI is a well-known inventory which was used in an earlier work [8]. Chiesa et al. evaluated 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) [27] was used to measure happiness. SHS questionnaire was rated on a 7-point Likert-scale from 1 to 7. Other studies measured happiness [27] as an indication of emotional well-being.

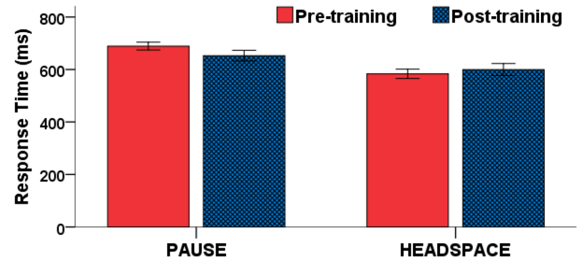

Figure 3. Response time. The figure shows a significant reduction in response time (±SE) after five days training with Pause.

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 training effects by comparing *Training* and *App* using repeated measures analysis of variance (ANOVA). Significance was set at $\alpha = 0.05$. SPSS was used to perform the analysis. Cronbach's-α was used to demonstrate the consistency of the scale items for each questionnaire. Cronbach's-α are 0.880, 0.933, and 0.808 for POMS, PGWBI, and SHS, respectively.

Attentional Network Test (ANT)

Results are shown in Figure 3. There is an interaction effect in *Training*×*App* ($F_{1,16} = 5.481$, $p < 0.05$, $\eta^2 = 0.255$) on *response time*. Simple main effects analysis showed a significant difference ($p < 0.05$) in the Pause group between pre-training ($M = 689.1$, $SD = 44.3$) and post-training ($M = 652.6$, $SD = 60.7$), 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 is also a main effect for *Training* ($F_{1,16} = 5.224$, $p < 0.05$, $\eta^2 = 0.246$) on *conflict effect*. There is a significant difference between pre-training ($M = 104.1$, $SD = 23.6$), and post-training ($M = 89.2$, $SD = 20.3$) in both groups. 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 training with MBMA, directed attention improved in both *App* groups. Additionally, Pause reduced response times while Headspace did not. The results indicate that consistent training with Pause leads to greater improvement in attentional skills.

Mood test (POMS)

Results are summarized in Figure 4. There are main effects in *Training* on *total mood* ($F_{1,16} = 13.972$, $p < 0.01$, $\eta^2 = 0.466$), *confusion-bewilderment* ($F_{1,16} = 5.441$, $p < 0.05$, $\eta^2 = 0.254$), *depression-dejection* ($F_{1,16} = 7.455$, $p < 0.05$, $\eta^2 = 0.318$), *fatigue-inertia* ($F_{1,16} = 14.676$, $p < 0.001$, $\eta^2 = 0.478$), and *tension-anxiety* ($F_{1,16} = 11.184$, $p < 0.01$,

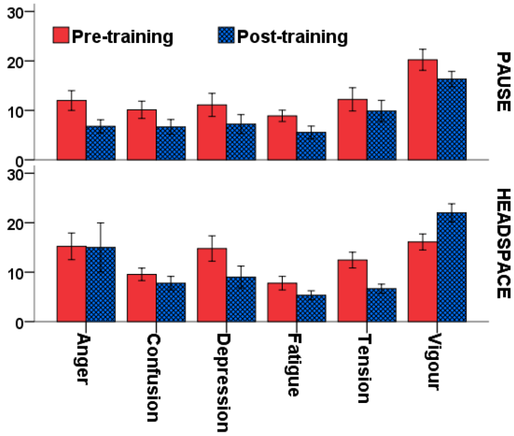

Figure 4. Intervention effect on mood ±SE. Using Pause helped participants reduce the confusion-bewilderment scale while Headspace reduced depression-dejection, fatigue-inertia, and tension-anxiety.

$\eta^2 = 0.411$). However, there is no effect on *anger-hostility*, and *vigor-activity*. Simple main effects analysis 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.

General Well-being test (PGWBI)
There is a main effect in *Training* on *General Well-being* ($F_{1,16} = 29.448$, $p < 0.001$, $\eta^2 = 0.648$). Participants reported higher post-training well-being ($M = 3.72$, $SD = 0.71$) than pre-training 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 at improving well-being. Our findings revealed that similar to traditional mindfulness practices [28, 30], training in mindfulness through MBMAs can increase the well-being of users.

Subjective Happiness Scale (SHS)
There is a main effect in *Training* on *Happiness* ($F_{1,16} = 4.448$, $p < 0.05$, $\eta^2 = 0.219$). Post-training happiness ($M = 4.67$, $SD = 0.82$) is higher than pre-training 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.

STUDY 2 - ENVIRONMENTAL EFFECTS
Study 2 aims to investigate how well our case study can perform compared to an existing MBMA in different environmental settings. Since our framework emphasizes attention-regulation, can Pause outperform Headspace in busy environments? And how does Pause perform in calm circumstances compared to Headspace?

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 MBMA in the Calm and Busy environments.

Participants
Another 11 individuals (3 females) aged 22-35 (M=28.2, SD=3.1) participated. 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.

Apparatus
Similar phones and headphones were used as in Study 1. 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.

Task and Procedure
Similar preparatory steps were conducted as in the previous study. 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 (see Figure 5). 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 minute breaks between them.

The experiment for the Calm environment 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 5a). However, the experiment in the Busy environment was conducted in the university cafeteria during the lunch time rush hour with a background noise range of 52.5 - 75.1 dB (see Figure 5b). The noise mainly included the conversation 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

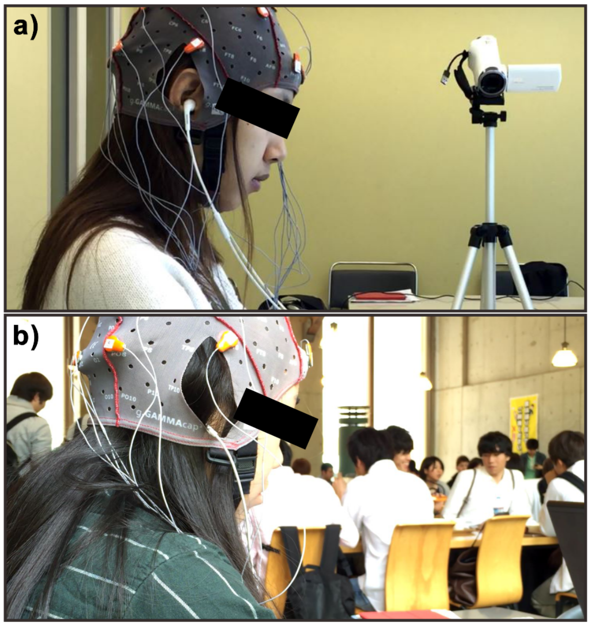

Figure 5. (a) A participant meditating in a room (calm environment), (b) university cafeteria (busy environment).

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 headphone in which the volume was set at 80%. During the rest time, the experimenter casually talked with the participant about different topics to restore her/him to the normal state. After the fourth day of training, a semi-structured interview was conducted. The whole experiment was video recorded.

Measures

Mindfulness practice can impact users' autonomic nervous system [43] 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 [43]. 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. Zeidan et al. [51] 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 the subtraction of minimum from maximum heart rate during practice. Decrease in mean heart rate and increase in delta heart rate correspond to better relaxation [51].

EEG. Spectral analysis of the EEG signal using Fast Fourier Transform (FFT) is correlated with the mindfulness state [4]. The power of the signal ($\mu Volts^2$) 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 [35]. Increase in theta band activity is associated with meditative concentration, while the increase in alpha band activity indicates relaxation. Previous work [41] also studied low alpha (8-10 Hz) and high alpha (11-13 Hz) band activity. Takahashi et al. [41] reported an increase in theta and low alpha band activities during Zen meditation. Cahn and Polish [4] reviewed over 60 papers discussing EEG profiles in the state of meditation with Yoga, Zen, Qigong, and Yogic meditation. 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 practice 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 [17]. 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 [42].

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 analyzed.

Interviews. Semi-structured interviews were used asking questions about the mindfulness experience when using Pause or Headspace in the Calm and Busy environments (hereafter referred to as "Calm" and "Busy"). We used a simple open

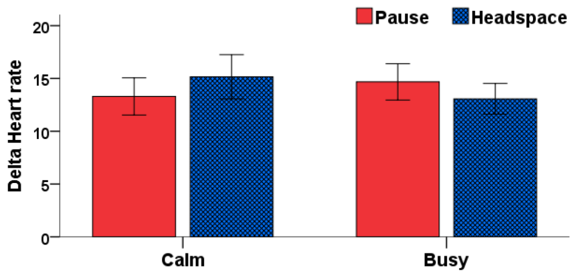

Figure 6. Heart rate ±SE (Delta).

coding process where we created labels based on meaning to analyze the interviews.

Results and Discussion

Analysis methods for heart rate were the same as in Study 1. We analyzed the relaxation effect by comparing *App* and *Environment*. However, EEG data did not pass the parametric evaluation test. Thus, Wilcoxon Signed-Rank tests were used for nonparametric analysis.

Heart Rate

There is an interaction effect in *App* × *Environment* ($F_{1,43} = 5.870$, $p < 0.05$, $\eta^2 = 0.120$) on *Delta* (see Figure 6). 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 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.

EEG

Figure 7a 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 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 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 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 a deeper meditation state when using Pause compared with Headspace in the Busy.

Figure 7b 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 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 practitioners 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, attention-regulation framework 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 [29, 50] 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.

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*

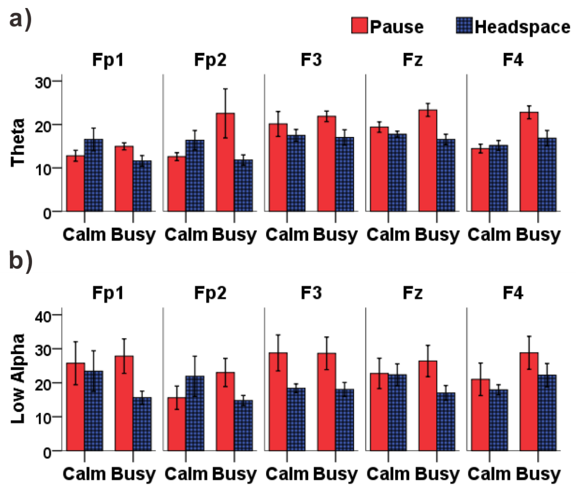

Figure 7. a) Theta band ±SE (4-7 Hz) , b) Low alpha band ±SE (8-10 Hz) for Pause and Headspace in the calm and busy environments. Each column represents Fp1, Fp2, F3, Fz, and F4 EEG electrodes.

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 state."*

Four participants talked about the effect of continuous feedback. [P7]: *"Continuous audio-visual feedback from Pause helped me ignore distractions in the public place (busy). This is in contrast to Headspace which sometimes suddenly stopped after long talking."* 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 for Pause over guided meditation, i.e., given its interactivity, Pause is preferred by users (8/11) who are more easily distracted, or less motivated to meditate. By contrast, participants with higher motivation (3/11) prefer to use Headspace regardless of the environment because they have adequate motivation and knowledge to follow instructions. For example, a participant [P3] said: *"Headspace helps me to meditate similar to what I did before without a phone. I think Headspace is good enough. Cafeteria (busy) noise cannot disturb my meditation."*

GENERAL DISCUSSION

Our work and contribution proposed a theory-grounded framework for attention-regulation. Particularly, our framework informs (1) how technologies can support detection without the need of dedicated accessories, and (2) what kinds of feedback technology should provide. Indeed, our framework attempts to answer the high-level question "to what extent can technology support mindfulness without interrupting the natural progressive meditative state of the user? [33]" To further validate the framework, we have demonstrated the usefulness of the framework using Pause. Our validation confirmed that the framework can lead to improved intervention effects, particularly on attention. Furthermore, our validation 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.

Revisiting the Framework

It is worth revisiting our framework and asking why each component (Detection and Feedback) is important for interactive meditation. First, 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. Being able to detect attention opens up a new creative space for designing digital experiences with feedback regarding human focused attention. Our case study is only the first example, and this is an open invitation for designers and researchers to together explore this new space.

The Breathe app[10] 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). Our framework contributes by grounding the detection mechanism with RR which enables detection on mobile devices without the need for dedicated accessories. Our framework can also inform other kinds of detection mechanisms. For example, although our case study uses slow finger movement across the screen, slow arm movements detected by the gyroscope or accelerometer of any mobile devices (e.g., watch, phone) can also be exploited to support the detection process (e.g., technology-mediated Tai Chi practice).

Second, Feedback is the other essential component that is important to support self-regulation. 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. Our framework contributes by using ART as a principle to guide the design of feedback. Particularly, ART informs that feedback should stimulate the users' meta-awareness while avoiding any unnecessary effort, i.e., avoiding the users to make any judgment on the feedback itself (effortless reflection). In other

[10]https://itunes.apple.com/us/app/breathe

words, non-judgmental awareness of the present moment leads users to enter into deeper mindfulness states. For example, emWave2 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. We think our framework can be extended to other kinds of feedback mechanisms. For example, using ART, immersive virtual reality feedback [10] can be designed while users move their body in a slow, repetitive manner.

The Challenge of Non-Judgmental Awareness

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. It takes time to practice and achieve non-judgemental awareness and be able to bring the mind back to focus again without critical self-judgements. To address these challenges, Pause uses the feedback mechanism to stimulate meta-awareness. As soon as the mind is distracted, feedback is provided. Because of the simple interaction design, everyone can easily resume slow, continuous finger movements. So, even though self-judgement may arise, the finger interaction helps users to quickly disengage from mental self-judgements. Thus Pause can help develop a new healthy relationship with the judgemental mind, and contribute to the development of non-judgemental awareness.

Pause vs. Past Biofeedback Work

Our findings revealed that our case study is effective in promoting attention-regulation and these results are consistent with earlier biofeedback studies. For example, MeditAid [36] and RelaWorld [24] which used neurofeedback, effectively promote attention-regulation and enhance concentration. However, those studies 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 for biofeedback devices is Sonic Cradle [45] 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. Our work also showed an overall improvement in mood.

We did not use biofeedback because our work primarily focused on merging the prevalence of smartphones together with the concept of the attention-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 a case study to address this challenge. This is consistent with traditions of meditation practice where meditation masters provide various approaches (e.g., breathing, walking) to support different types of users and environments, but with the one goal of training mindfulness. Designers and innovators should tailor their MBMA designs to suit the wide variety of people according to their cultures, tastes, abilities, and lifestyles.

Pause vs. Traditional Meditation

Pause draws upon Kabat-Zinn's definition of mindfulness [20], i.e., paying attention, on purpose, in the present moment, non-judgmentally. To lead users to pay attention in the present moment, Pause uses slow, continuous finger movement which requires sustained voluntary attention. However, Pause only focuses on mindfulness but not on other aspects of meditation such as compassion and loving kindness.

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 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 for 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 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 Pause, they become better at controlling their own attention and ultimately they will not need Pause anymore. So this becomes a training exercise which develops voluntary attention.

CONCLUSION

Our motivation is to use mindfulness practice as a tool to enhance human well-being. Previous MBMAs are mostly guided meditations and may not always be effective or convenient. Aside from guided meditation MBMAs, biofeedback through a self-regulation process is an emerging tool for mindfulness practice. However, this practice has not been widely adopted due to the need for dedicated accessories. We propose a new framework following the same self-regulative mindfulness principles but using a simpler approach through slow, repetitive, continuous movements. We developed a case study and showed that it can achieve positive results and can be comfortably used in non-standard environments like busy public places. Due to ease of access and lower cost compared apps that use biofeedback devices, our work creates the opportunity for MBMAs to be more widely adopted and more useful, and this may lead to greater well-being in society.

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