Focusing on Now: Mindfulness in the 21st Century

Presented by Evan Alvarez-Keesee

In partial fulfillment of the requirements for completion of the
Polymathic Scholars Program in the College of Natural Sciences at
The University of Texas at Austin

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Introduction:

In the early stages of human brain evolution, anticipating future events and learning from memories of the past were both essential to survival. As the brains of our primate ancestors navigated complex environments and encountered various selection pressures, several brain regions evolved to improve upon these cognitive abilities (Allen & Fortin, 2013, Teffer & Semendeferi, 2012). One such region, the prefrontal cortex (PFC), is associated with planning complex behavior and making decisions (Yang & Raine, 2009). Interestingly, the complexity of the microstructure and neural organization in the human PFC has significantly surpassed that of our closest primate relatives (Teffer & Semendeferi, 2012). While this structural and computational advantage in the PFC is important for personality, critical thinking, and moral behavior (Anderdon et al., 1999), it is also linked to excessive rumination, or self-directed thoughts about the past and future (Whitmer, 2009, Cooney et al., 2010). Furthermore, the PFC is one of many regions implicated in the regulation of psychological stress (Dedovic et al., 2009). While this is only one area in which humans have increased complexity relative to other animals, it provides an example of the dual nature of evolutionary effects. That is, increased cognitive processing capabilities arise along with increased potential for malfunction of those capabilities. Accordingly, it has been suggested that neural reorganizations through evolution may have predisposed modern humans to various mental disorders (Teffer & Semendeferi, 2012). In short, we evolved the ability to think, but along with these changes to brain structure came the potential for rumination, worry, and stress. Although humans born more than a century ago knew nothing about brain structure, they have known for millennia that deliberately resting from preoccupation with the past and the future and focusing on the present moment has tangible benefits.

The intentional cessation of thought through focus on a single object is termed meditation. Mindfulness, a concept first described in ancient Buddhist texts, is the act of non-judgmentally attending to mental states and sensory perceptions in the present moment. Mindfulness meditation, one of many meditative practices, is the intentional practice of mindfulness in a meditative setting. For mindfulness meditation the object of focus is often the breath or the body. This meditation was used primarily in a spiritual context until it entered the scientific world in 1979 with Jon Kabat-Zinn's distillation of Buddhist methods into the Mindfulness-Based Stress Reduction (MSBR) program (Kabat-Zinn, 1982). This is a rigorous 8-week program which involves daily mindfulness meditation, yoga, homework, and a one-day meditative retreat. In the past thirty years MSBR and the analogous Mindfulness-Based Cognitive Therapy (MBCT) program have been applied clinically to manage symptoms of several disorders including depression, anxiety, chronic pain, insomnia, and cancer.

Neuroscientific literature on mindfulness shows that long term training has profound effects on brain structure. These include increased connectivity between hemispheres and increased cortical folding (i.e. greater processing capability) in specific areas important for self-awareness, emotional regulation, and attention (Lazar et al., 2015, Luders et al., 2012a). Also, while in a meditative state, the network of activated brain regions changes dramatically and reflects a decrease in rumination and an increase in attention to bodily states (Farb et al., 2007). More recent studies have shown positive effects of short-term practice (daily for a week) on attention, stress, and other cognitive measures (Zeidan et al., 2010, Tang et al., 2007).

While these studies illuminate important benefits of mindfulness practice, the meditation sessions are typically conducted in the laboratory with expert guidance. This type of study is advantageous as it controls for the meditative setting, but this form of practice is not widely applicable to most people. Similarly, most people will likely not have the required time and energy to devote to a program like MBSR. So how can people better incorporate mindfulness into their daily lives? One answer is through the use of technology. Currently around two thirds of adults in the U.S own and use smartphones (Smith, 2015). The rapid rise of smartphone technology has been accompanied by the creation of an abundance of smartphone applications for practicing mindfulness (Plaza et al., 2013). However, not many studies have evaluated these applications with the intent to replicate the benefits shown with short-term mindfulness practice. To address this gap in knowledge, we conducted a randomized, controlled study of young adult novice practitioners (n=30) to evaluate the cognitive benefits of using a smartphone application to practice mindfulness. We looked at effects on sustained attention, perceived stress, circadian rhythms, positive and negative affect, and trait mindfulness. The results from the study show that the mindfulness application studied can reduce stress and improve attention. The results are discussed in relation to how mobile-mindfulness can be incorporated into our society, as well as in relation to clinical applications of mobile-mindfulness.

Mindfulness Origins and Definitions:

Mindfulness is one of many types of meditation described in the texts of ancient cultures. The modern practice of mindfulness meditation that has been recently evaluated for cognitive/clinical purposes was developed specifically from Buddhist methodologies. The Satipatthana Sutta or The Discourse for Establishing Mindfulness is generally accepted as the canonical Buddhist text containing the instructions for the cultivation of mindfulness as an invaluable mental skill. In this text, the Buddha describes it as the ceaseless non-judgmental awareness of bodily sensations and mental states in the present moment (Sujato, 2012). This awareness has been dubbed 'bare attention' in which the underlying characteristic "is not wobbling; its function is not to forget. It is manifested as guarding or the state of being face to face with an object" (Bikkhu, 1976). While this is a slightly nebulous statement, it can be seen as a rough description of sustained attention, or the focusing of cognitive activity on a stimulus maintained over time.

In addition to present-centered attention, the text implies that mindfulness involves memory in addition to bare attention. The term mindfulness comes from the Pali word 'sati', which means 'to recollect'. This term became associated with mindfulness due to the deep concentrative state necessary to memorize long texts for later recollection. This evolved into a meditative practice by switching the object of attention from long texts to the body, feelings, consciousness, and other mental objects (Sujato, 2012). These four factors comprise the four foundations of mindfulness (satipathanna), and the contemplative methods for each foundation are described in detail in the Satipathanna Sutta. For example, when contemplating bodily posture, the text suggests that when a man is "walking, he knows 'I am walking'" (Analayo, 2003). For contemplating any of the four foundations, one must be aware of what is being contemplated. In other words, the mind must retain the object of focus in memory to gather a clear understanding of the experience for later practice. In this way, mindfulness is related to the concept of working memory, or the transient processing of new sensory information, in addition to sustained attention.

A specific method for achieving the goals outlined in the Satipatthana Sutta is described in the Anapanasatti Sutta or Breath-Mindfulness Discourse (Anālayo, 2003). Anapanasatti is the intentional focus on the breath in the present moment, and today is the most common technique used in western mindfulness programs. This discourse is divided into four progressive stages of practice, each corresponding to four foundations of mindfulness. This starts with discerning between short and long breaths, progresses to feeling the entire body during each inhalation and exhalation, and eventually to contemplation of feelings and emotions.

In both these texts, the benefits of mindfulness are explored. Unwanted rumination is considered the foundation of grief, sorrow, and lamentation. According to the Satipatthana Sutta, the practice of mindfulness disrupts this unwanted rumination; its purpose is "for the purification of beings, for the overcoming of sorrow and lamentation, for the extinguishing of suffering and grief, for walking on the path of truth, for the realization of nirvana" (Sujato, 2012). To Buddhist practitioners, the perceived benefits of this mindfulness were/are alleviation of grief, suffering, and acceptance of the no-self nature of consciousness (Gethin, 2001). Also, in the Anapanasati Sutta, Buddha states that the regular practice of breath-mindfulness is "of great fruit, [and] great benefit". These benefits are described as "the seven factors of enlightenment", namely joy, investigation, energy, mindfulness, relaxation, concentration and equanimity (Anālayo, 2003). Through this practice, according to the Buddha, one can contemplate the seven factors of enlightenment and use them in opposition to the five hindrances (sensory desire, ill-will, heaviness of body and dullness of mind, worry, and doubt), which impede progress in meditation. As most mental suffering today is comprised of one or more of these hindrances, mindfulness can be viewed as a tool to manage these symptoms of an overactive mind or one hijacked by propensity to ruminate.

Clinical applications of mindfulness training:

Although people have been practicing mindfulness for millennia, mindfulness research is a field less than forty years old. The birth of this field of research was mostly due to the invention of the Mindfulness-Based Stress Reduction program (MBSR) by John Kabat-Zinn in 1979 (Kabat-Zinn, 1982). This program is involves daily mindfulness meditation, yoga, and homework over an 8-week period culminated by a one-day meditative retreat. Kabat-Zinn was motivated to develop the program by the numerous potential clinical applications of mindfulness. The analogous 8-week program Mindfulness Based Cognitive Therapy (MBCT) was subsequently developed for psychiatric use with the intention to decrease recurrence of depression (Segal, 2002). The MBCT program focuses more on the suppression and reappraisal of negative rumination (Segal, 2002). The MBCT and MBSR programs have been shown effective in several randomized controlled trials. After its creation, MBSR was first tested with chronic pain patients, and showed a significant reduction in symptoms for more than 60% of patients (Kabat-Zinn, 1982). Kabat-Zinn hypothesized the reduction in pain was due to an enhanced attention toward proprioception that decreased pain severity. Other studies on MBSR or MBCT found decreases in depressive symptoms in breast cancer patients (Lengacher et al., 2009) and cancer in general (Ledesma & Kumano, 2009), decrease in anxiety and depressive symptoms in social anxiety disorder (Goldin & Gross, 2011), decreases in chronic pain in fibromyalgia (Grossman et al., 2007), decrease stress in patients with chronic inflammatory conditions (Rosenkranz et al., 2013), decreases in non-clinical stress (Chiesa & Serretti, 2009), improvements in insomnia symptoms (Ong et al., 2008, 2012), and even hypertension reduction (Hughes et al., 2013). MBCT was also found to significantly reduce the relapse rate of depression (Teasdale et al., 2010). Fjorback et al. (2011) found that 11 out of 21 MBSR/MBCT randomized controlled interventional studies showed significant positive results. This review concluded that MBSR/MBCT is effective at improving mental health in both clinical and non-clinical populations, but it remains unclear whether it affects physical health.

Since the creation of these programs, people have speculated on the potential mechanisms underlying the effects of mindfulness training on mental health and well-being. Ludwig and Kabat-Zinn (2008) proposed that through these programs mindfulness could affect recovery from disease by modulating pain severity and perception, decreasing anxiety and depression, increasing motivation for positive lifestyle changes, decreasing usage of psychiatric drugs, increasing awareness of and devotion to medical treatments, improving social connectedness, and/or causing biological changes such as changes in the autonomic nervous system, as well as in the neuroendocrine and immune systems. While many of these ideas were born out of evidence that MBSR/MBCT is effective for certain disorders, few of these potential mechanisms have been fully evaluated. However, recently other mechanistic clues have found. In a review designed to determine the mechanisms behind MBSR/MBCT effects on well-being Gua et al. (2015) found strong evidence for cognitive reactivity, or the propensity to reactivate negative thinking, and trait-mindfulness, or moment-to-moment mindfulness, as mediators between MBSR/MBCT mindfulness interventions and positive health outcomes. This result is consistent with a finding from Raesa et al., (2009) showing a strong negative correlation between cognitive reactivity and trait-mindfulness. These results imply that increased awareness of bodily sensations and mental states generally accompanies a decrease in negative rumination. More in-depth mechanistic findings are explored below.

While mindfulness-based interventions are effective, Teasdale et al., (2003) cautions that they should be used with careful consideration and deliberate intention. First, MBSR/MBCT should not be treated as generic solutions to all clinical problems. Instead, the type of intervention should be carefully tailored to suit the needs of a given disorder. For example, the authors found that MBCT can be unhelpful when taught to people with only two depressive relapses and helpful for those with three or more. This suggests there are distinct reasons for depressive relapse, and MBCT may not apply to all of them. Also, the effectiveness of these interventions seems to be highly dependent on the way the content is taught to patients. The authors argue that the more the patient understands which aspects of mindfulness (relaxation, awareness, acceptance, emotional regulation) apply to their disorder, the more efficacious the treatment will be. Finally, while they value the secular context in which the practice is taught, they suggest that presenting mindfulness as a small part of a larger intervention motivated by the cessation of needless emotional suffering (the path to enlightenment in Buddhism) will increase efficacy of treatment (Teasdale et al., 2003). This means meditation should not just be viewed as a mechanical practice akin to brushing teeth or taking an antidepressant, but as a tool that can be used to shift to a new way of thinking. These considerations complicate the implementation of these programs as trained professionals aware of these caveats are needed for effective treatment.

Neural Correlates of Mindfulness:

To fully understand the mechanisms by which MBSR/MBCT affect changes to cognition and well being, it is essential to examine the neural effects of such interventions. In recent years several EEG and fMRI studies have been done to determine brain regions implicated in the practice as well as any structural changes that may result. In a functional imaging study designed to illuminate neural correlates of mindfulness, Farb et al. (2007) showed that mindfulness is associated the ability to dissociate from the narrative circuit (temporally dependent conception of the self, also known as the default mode netrork) centered around the medial prefrontal cortex (mPFC) and engage in momentary awareness circuits (temporally independent conception of the self) which are centered around lateral PFC regions, the insula, and somatosensory cortex. Participants that completed MSBR training were better at switching from the narrative to the momentary circuits compared to novice participants (Farb et al., 2007). This dissociation is consistent with EEG findings showing that mindfulness meditators of any level exhibit lower frontal gamma activity associated with the narrative circuit while meditating (Berovich-Ohana et al., 2012). The increased ability to switch between networks/conceptions of the self is hypothesized to explain many of the benefits seen in the aforementioned studies involving MBSR/MBCT.

The study of expert practitioners has shown that not only is mindfulness meditation a dissociative tool, but it also has considerable effects on brain structure. Luders et al. (2012b) showed that long-term practitioners have “increased connectivity between auditory cortex and areas associated with attentional and self-referential processes” and these changes are indicative of a heightened attentional focus, sensory processing, and awareness of sensations. One important region affected by this increase in connectivity is the anterior insula, which appears to be responsible for interoception, or the generation of an internal representation of the body (Critchley et al., 2004). Luders et al. (2012a) found that long term practitioners have increased cortical gyrification, or degree of folding in cortex, particularly in the right anterior insula. This is consistent with reports of increased insular thickness in long-term meditators (Lazar et al., 2015), and a positive correlation between insular gray matter volume and trait mindfulness (Murakami et al., 2009). Interestingly, dysfunction in the right anterior insula manifests as heightened prediction signals for future aversive body states, and leads to the unnecessary rumination and “non-goal directed cognitive activity” characteristic of most anxiety disorders (Paulus & Stein, 2006). This is consistent with the anxiolytic application of mindfulness training. Increased complexity of the insula seems to be associated with an increase in emotional regulation and a decrease in rumination and worry. Luders et al. (2012a) suggests this structural change could be due to “integration of autonomic, affective, and cognitive processes”.

While these dramatic changes to brain morphology and connectivity are only seen in expert meditators typically with 20 years of experience, these studies help to match brain regions to established markers of mindfulness such as attentional control and awareness.

Mindfulness and Attention:

Fundamentally, mindfulness is a way to train attention. Attention is a complex process that can be broken down into three subsystems: orienting, alerting, and cognitive control (Petersen & Posner, 2012). In the context of mindfulness meditation, orienting is the selective focus on the object of meditation (typically the breath), alerting is sustaining attention on the object, and cognitive control refers to the awareness and acceptance of mental states during meditation. There is evidence to suggest mindfulness training has positive effects on all of these systems (Jha, Krompinger, & Baime, 2007, Teper & Inzlicht, 2013). Also, Teper, Segal, & Inzlicht (2013) found that increased cognitive control in meditators consequently led to increased emotional control, or decreased propensity to ruminate and worry. Thus, it seems the quality of attentional control, which can be modulated by mindfulness training, is directly related to other metrics of well-being.

One important process intimately related to attention is sleep. Intuitively, these two processes are related since decreased attentional control would lead to an increased propensity to ruminate before falling asleep, thereby increasing pre-sleep arousal and time taken to fall asleep. Consistent with this intuition, a comorbidity has been noted between children with ADHD and sleep disorders (Corkum, Tannock, & Moldofsky, 1998). While a few studies have shown mindfulness training to be less than effective in improving sleep quality, Ong et al. (2012) showed that combining mindfulness meditation with cognitive behavioral therapy significantly decreased pre-sleep arousal and sleep-related distress in insomnia patients. While this study did not investigate the mechanism behind these improvements, it is likely related to modulation of attentional control. Another important finding came from Howell et al. (2007) in which trait-mindfulness was positively correlated with well-being and the relationship was mediated by sleep quality. Taken together, these findings suggest that while improving sleep may not be the primary target for mindfulness interventions, further research investigating the relationship between sleep, mindfulness, and attention is warranted.

Effects of short-term mobile-based mindfulness training on various cognitive measures in young-adult novice practitioners:

While the benefits of the MSBR program are well established and far-reaching, this program presents a steep commitment of time and energy to the average person. Mindfulness training less intense than MSBR is being evaluated for general effects on cognition. It has been shown that brief mindfulness training (5 days/20 minutes per day) can significantly improve working memory, executive functioning, and sustained attention (Zeidan et al., 2010, Tang et al., 2007). Although this type of training is typically done in the lab with an experienced instructor, the present availability mindfulness-based mobile applications (MBMAs) allows for a more realistic examination of how mindfulness can benefit the average person without removing him/her from his/her normal lifestyle on a regular basis. The large body of MBMAs have been catalogued and analyzed, but only a few have been evaluated for the cognitive effects associated with mindfulness training (Plaza et al., 2013). Howells, Ivtzan, & Eiro-Orosa (2014) conducted a study similar to the present one, and found that 10 days of mobile mindfulness training significantly decreased negative affect, increased positive affect, increased ‘flourishing’ (a measure of happiness) and decreased CES-D scores (a measure of depressive symptoms). The purpose of this study was to replicate findings shown with brief mindfulness training such as improved sustained attention and working memory, as well as monitor any changes in circadian rhythms that may arise in response to the training. We hypothesized that with seven days of MBMA-based training, participants would show significant improvements in sustained attention, perceived stress, sleep quality and the stability of circadian rhythms.

Methods:

For this study, 30 undergraduate UT students ages 20.17 ±1.73 came in for two sessions, separated by 10 days of mindfulness meditation practice or audiobook listening. For the initial session, participants filled out the Positive and Negative Affect Schedule (PANAS; Watson, et al., 1988), the Perceived Stress Scale (PSS; Cohen et al., 1983), the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989; Buysse et al., 1991), and the Freiburg Mindfulness Inventory (FMI; Walach et al., 2006). The participants then completed a 10-minute psychomotor vigilance task (PVT) to measure sustained attention. Participants in the experimental group then downloaded the free application Mindfulness by Mental Workout, while those in the control group downloaded Audiobooks, a free audiobook application. Participants were then fitted with actigraphs (wristwatch devices that measure temperature and movement) to be worn for the duration of the experiment and returned at the final session.

In between laboratory sessions the control group listened to a randomly chosen 15-minute audiobook excerpt in the application Audiobooks once per day. For the experimental group, after the first session participants waited to complete mindfulness sessions for three days. The following day they began doing 15-minute guided mindfulness sessions in the Mindfulness application once per day for 7 days. The purpose of this delay was to establish a baseline for sleep quality and circadian rhythms for the experimental group. All participants completed a nightly sleep diary, and answered brief sleep surveys each morning. For the experimental group, this survey asked questions about the previous day's meditation session to ensure completion. For the final session, they completed the PANAS, PSS, PSQI, FMI, and PVT for a second time.

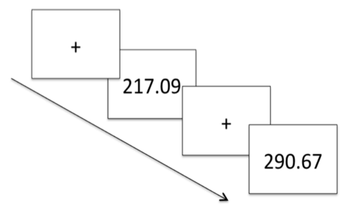
We measured the effects of brief mindfulness training by using health and mood surveys, a sustained attention task, and actigraphic assessment. The surveys will included the PANAS, PSS, PSQI, and FMI. The PANAS measures positive and negative affect over time using two ten item scales. For the PSS, PSQI, and PVT, which measure perceived stress, sleep quality, and sustained attention, we anticipated seeing improvements based on previous research (Zeidan et al., 2010, Tang et al., 2007). Also, the FMI is a survey that quantifies the trait-mindfulness (attention to the present moment) of the participant.

Through actigraphic assessment we characterized the participant's circadian rhythms. By fitting the participants with the actigraph and having them fill out sleep diaries each night, recorded total sleep time, time taken to fall asleep, and how many minutes participants were awake during the night. The sleep diary complements the actigraph, which provides the objective measures of sleep. We ensured sleep times are accurate by comparing the sleep diary to the actigraphic data. From these actigraphic data, we can gain an understanding of circadian rhythm variables such as interdaily stability, intradaily variability, and amplitude. Interdaily stability is a measure of the amount of change in sleep/wake cycles between days, and reflects whether the participant is going to bed and waking up at approximately the same time or if they have highly varied sleep and wake times. This variable is high if the person has stable sleep patterns across days. Intradaily variability is a measure of the number of transitions between rest and activity within a single day. This measure compares the levels of activity during the day (whether they are napping or moving around) with how still the participant is at night. Since this value is based on variability, a smaller value means there is less change within the day and is an indication of a healthy circadian cycle. Finally, amplitude is the ratio between the amount of movement during the 10 most active hours of the day with the amount of movement during sleep. High amplitude suggests the participant is most active during the day and least active at night. These measures provide quantitative values involved with circadian rhythms. We used this and the PSQI to compare circadian rhythms and sleep quality between the experimental and control groups. We expected to see greater stability and quality of sleep in the experimental group based on previous mindfulness-based treatment of insomnia (Ong et al., 2012).

Results:

Sustained attention improved in experimental group:

The psychomotor vigilance task (PVT) is a task in which a clock counting forward by milliseconds replaces a fixation cross at random intervals over ten minutes. The participant watches the fixation cross and presses the space bar as soon as he/she detects the appearance of the clock, and the reaction time for each trial is recorded (see schematic below).



Schematic for PVT

From these data both the mean reaction time over all trials and the mean of the top 10% of reaction times are valuable measures of sustained attention. Before calculating these means, the reaction times under 100 ms and over 500 ms were discarded, as they signify false starts and attentional lapses, respectively. As the participants completed the PVT during both lab sessions, we compared the change in these measures from the first lab session to the second and then between control and experimental groups. For mean reaction time over all trials, the difference between groups was not significant (Table 1). However, the mean of the top 10% of reaction times decreased significantly more in the experimental group than in the control group (Figure 1, p=0.06).

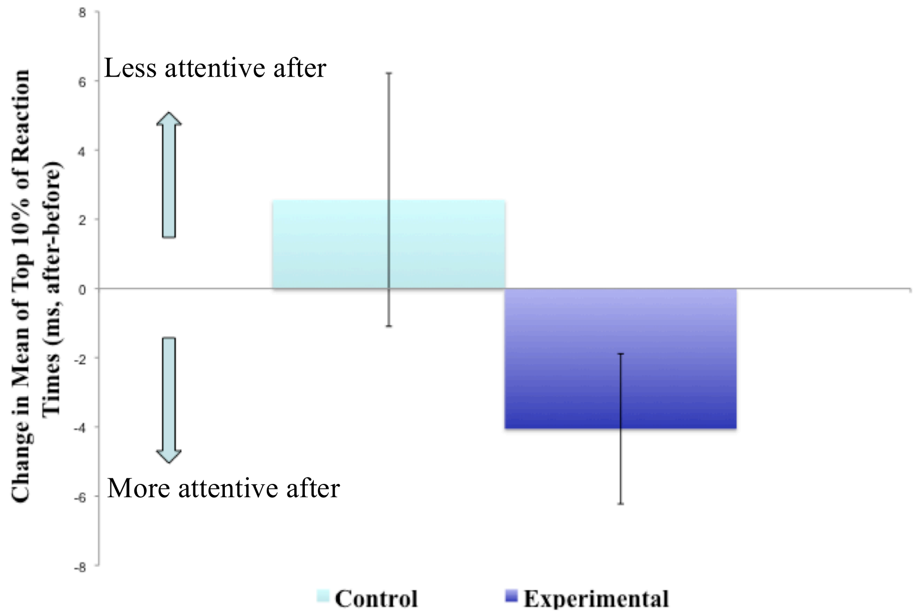


Figure 1: Change in mean of top 10% of reaction times calculated by subtracting the mean from the first lab session from the mean from the second lab session (p=0.06)

Self-reported focus during mindfulness sessions improved over the week of training:

Participants who underwent mindfulness training answered a question in the daily sleep surveys asking them to describe their performance during the mindfulness session of the previous day. Out of 16 participants who completed the training, 14 of them reported improvement in their ability to maintain focus on their breath during the guided meditation. These participants found it difficult to maintain focus on their breath during the first few mindfulness sessions. For example, for the third mindfulness session one participant reported it "was relaxing, but [his] mind kept wandering." The same participant reported that during subsequent sessions it was "easier to focus". This was a common trend for all but two participants.

Trait mindfulness is positively correlated with sustained attention:

Trait mindfulness is the measure of how mindful an individual is in his/her daily life. Individuals with high trait mindfulness have increased moment-to-moment awareness of experience and increased ability to regulate emotions (Ruocco & Direkoglu, 2012). The Friedburg Mindfulness Inventory (FMI) is one of many surveys used to quantify this trait. This 10-item inventory asks individuals to rate themselves on measures including openness to present experience, ability to deal with negative occurrences, and awareness of bodily sensations while eating, cooking, cleaning, or talking. Higher scores on this inventory reflect higher levels of trait mindfulness. We expected to see an increase in FMI scores in the experimental group relative to the control group. However, scores from the experimental group actually decreased more than the control group from the first to the second lab session (p=0.29, Figure 2).

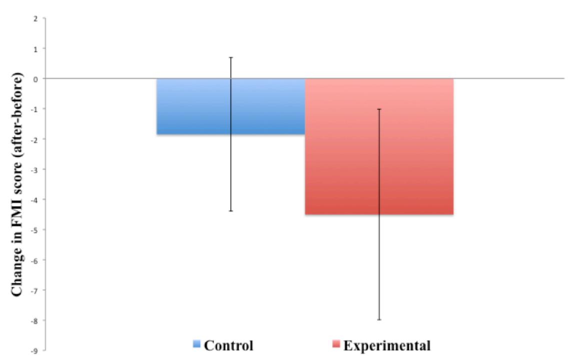


Figure 2: Change in mean of FMI scores for both groups calculated by subtracting the mean from the first laboratory session from the mean of the second laboratory session (p=0.29).

As Ruocco and Direkoglu, 2012 found a positive correlation between sustained attention and trait-mindfulness, we looked for a correlation between reaction times from the PVT and scores from the FMI indicating levels of trait-mindfulness. We expected to find a negative correlation between reaction times and FMI scores, reflecting a positive correlation between sustained attention and trait-mindfulness. Including all PVT and FMI scores from both groups and from both lab sessions (60 data points), we found a negative correlation between the mean of the top 10% of reaction times and FMI scores (r= -0.49, Figure 3A). The same analysis of the mean of all reaction times did not show a significant correlation. In order to see if mindfulness training affected this correlation, we looked for the same correlation using scores from the second session only. For the experimental group, the correlation was more negative (r= -0.69, Figure 3B) than the overall correlation shown in Figure 3A, and also more negative than the analogous comparison for the control group during the second session (r= -0.49). Thus, participants who underwent mindfulness training had more of the variability in sustained attention explained by trait-mindfulness than those who did not.

(A) **(B)**

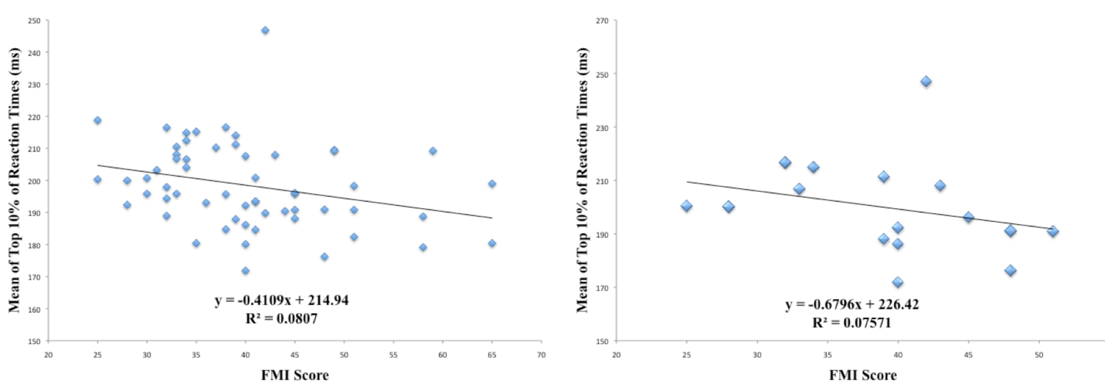


Figure 3: **(A)** Mean of top 10% of reaction times vs. FMI score for all participants across both laboratory sessions (r= -0.41). **(B)** Mean of top 10% of reaction times vs. FMI score for experimental group during second laboratory session only (r= -0.67).

Perceived stress decreased in experimental group:

Participants completed the perceived stress scale (PSS) in both laboratory sessions. This inventory asks participants to rate stress levels in various aspects of their lives over the past month. We hypothesized scores on the PSS would decrease in the experimental group relative to control. Figure 4 shows this was the case (p=0.07).

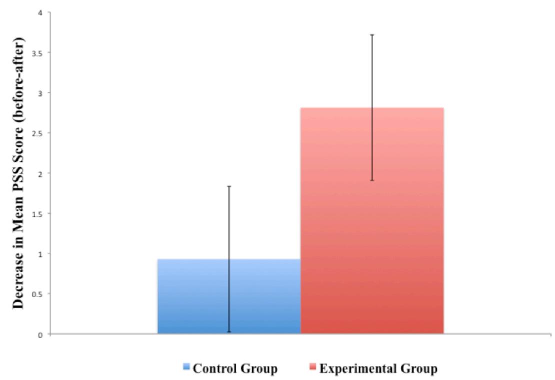


Figure 4: Decrease in mean PSS scores for both groups calculated by subtracting the mean of PSS scores from the second laboratory session from those from the first laboratory session (p=0.07).

Positive and negative affect did not change significantly:

Scores from the PANAS did not change significantly over the interim period in the experimental group. That is, neither positive nor negative affect were affected by the mindfulness training.

Sleep measures did not show much significant change:

We collected sleep measures for all participants from sleep surveys, the PSQI, and actigraphic measurements of circadian rhythms. From the sleep surveys we gathered sleep latency and sleep duration. However, none of these measures showed significant differences between groups. Similarly, sleep quality measured from the PSQI scores also did not show any significant change between groups.

Circadian rhythm measurements measured through actigraphy included interdaily stability, intradaily variability, and relative amplitude, as explained above. The first analysis shown in Figure 4A compares these measurements between control and experimental groups. For this comparison, neither interdaily stability nor intradaily variability differed significantly between groups. However, relative amplitude was significantly lower in the experimental group (p=0.03, Figure 4A). The second analysis done is a comparison within the experimental group between the first three days of the interim period during which the participants did not meditate and the last three days (Figure 4B). None of these measures differed significantly between these time periods, with intradaily stability being the closest to significance (p=0.12, Figure 4B).

(A) **(B)**

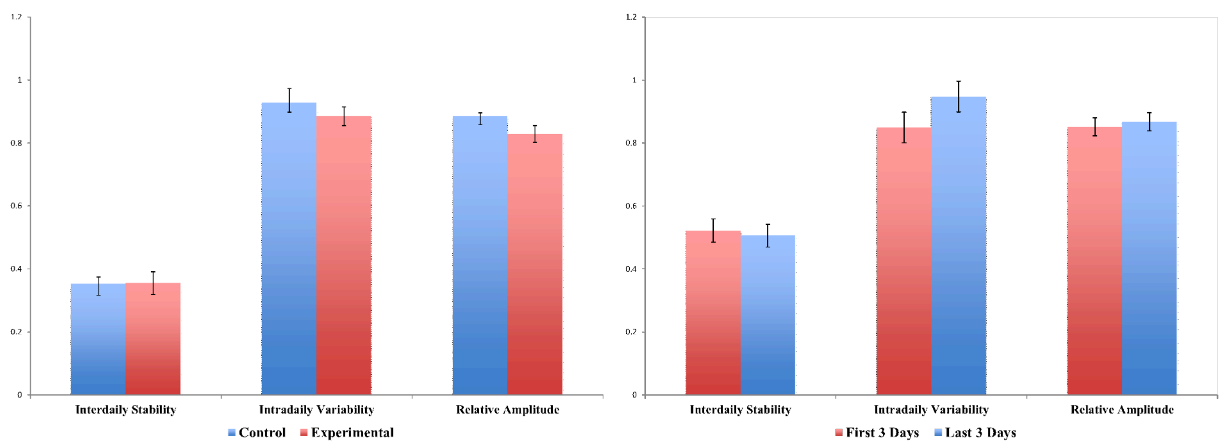


Figure 4: **(A)** Circadian rhythm measurements for all both groups over ten day interim period. Interdaily stability and intradaily variability show no significant difference between groups (p=0.47, p=0.24). Relative amplitude is significantly lower in experimental group (p=0.03). **(B)** Circadian rhythm measurements for experimental group from first 3 days and the last 3 days of the interim period. There are no significant differences in interdaily stability (p=0.39), intradaily variability (p=0.12), or relative amplitude (p=0.35).

Discussion:

The results from this study, while not particularly robust, provide evidence for benefits of mobile-based mindfulness meditation. For sustained attention, it is interesting to note that the only improvement seen was in the mean of the 10% of reaction times, and not in the mean of all reaction times. This suggests mindfulness training did not necessarily improve the participants' ability to focus during the entire ten-minute PVT, rather it might have improved their ability to focus during a small portion of the task. This could reflect an improvement in allocating attentional resources when the participants were focusing most effectively. While this does not imply that mindfulness training is the direct cause for this improvement, the fact that most participants reported an increased ability to focus during mindfulness sessions is consistent with this possibility.

For trait mindfulness, the result was not consistent with the hypothesis that it would increase in those that underwent mindfulness training. In fact, those in the experimental group reported decreased mindfulness after relative to the control group after meditating for week. While the result is not significant, it could suggest that mindfulness training increased participants' awareness and criticality of their own mindfulness, and thus rated themselves lower on the FMI during the second laboratory session. It is unclear why the control group also decreased in trait mindfulness, though it could be a typical effect of filling out the same form twice.

The finding that trait mindfulness was positively correlated with sustained attention across all subjects is consistent with a previous finding from Ruocco and Direkoglu, 2012. This correlation was stronger for those in the experimental group during the second laboratory session. This suggests mindfulness training strengthened the relationship between trait mindfulness and sustained attention.

Perceived stress decreased in the experimental group relative to the control group, as hypothesized. This result is consistent with previous findings. Baer et al., 2012 found that MBSR decreased perceived stress significantly after four weeks of training, and Xueming et al., 2015 found a negative correlation between trait mindfulness and perceived stress. As the current result was observed after only one week of training, it is possible other factors are responsible. Although participants were not explicitly told about the hypotheses of the study, one possible factor is a placebic effect. That is, the participants may have formed biases based on expected improvement in perceived stress and these biases may have affected the PSS scores. While the mechanistic underpinnings of this result are unclear, it is likely related to decreased rumination in the experimental group. This is certainly the case during the mindfulness sessions, as evidenced by the subjective performance reports mentioned earlier. It is also possible these participants experienced decreased stressful rumination outside of the mindfulness sessions, leading to a decreased perception of stress during the second laboratory session.

Both the subjective sleep measures and objective circadian rhythm measurements were likely not significant due to the structure of the study. As it takes a minimum of ten days to obtain circadian rhythm measurements, a longer study would likely yield more robust results. The one significant result relating to sleep was the decrease in relative amplitude observed in the experimental group relative to control. As this is a ratio of the most active period to the least active period during the day, this could mean that those who underwent mindfulness training adopted a more relaxed lifestyle throughout the week. This effect is not due to the decreased activity during meditation sessions themselves, as those were removed from the actigraph data during analysis. Clearly, however, there is not enough evidence to fully interpret this result. With the comparison between the circadian rhythm measurements of the experimental group during the first three days to those of the last three days, significant changes were likely not seen for the same reason mentioned above.

Conclusion:

The results from the study suggest the mindfulness application studied may be effective for improving attention and decreasing stress. As the study was limited by small sample size and duration of practice, no strong conclusions can be made regarding the connection between mindfulness practice and sleep. As a pilot study, this work will hopefully provide a framework for evaluating more mindfulness applications in the future. This is important as these applications have a variety of features (e.g. mindful pauses throughout the day) that could be optimized and standardized based on results of more randomized controlled studies. Also, these applications should be tested for efficacy in clinical applications. Patients with symptoms of depression, anxiety, or stress from other diseases could use mindfulness applications to compliment standard treatment. More clinical research in this area could also lead to specialization of these applications for specific disorders.

Whether considering medically afflicted populations or not, it is clear that our society is more distracted than ever before. This distraction is not incompatible with necessity or productivity. We must use the evolutionary gift of complex thought to lead fruitful lives, to plan, to love, to do science, and the like. The problem is that we are too often unknowingly lost in thought. Most of us are never too far from our phones, and we are constantly reminded of our obligations, desires, and past actions. Through social media we are more connected than ever before, yet we also worry about how we are perceived by others more than ever before. Jon Kabat-Zinn argued in his book *Coming to Our Senses* that this new 'era of 24/7 connectivity' leaves no time for introspection, observation, and awareness. While this is a fair claim, we can also see it is possible to fight fire with fire in this case. That is, technology can improve our awareness as much as it restrains it. In light of this, mindfulness applications should be viewed as useful tools for reminding us that we perpetually reside within the present moment, and that the past and future are merely thoughts emerging in the present. This realization has much to offer.

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