Effects of a Mindfulness-Meditation App on Subjective Well-Being: An Active Randomized Controlled Trial and Experience Sampling Study

Abstract

Background: Mindfulness training (MT) includes a variety of contemplative practices aimed at promoting intentional awareness of experience, coupled with attitudes of non-judgment and curiosity. Following the success of 8-week, manualized, group interventions, MT has been implemented in a variety of modalities, including smartphone applications that seek to replicate the success of group interventions. However, while smartphone apps are scalable and accessible to a wider swath of population, their benefits remain largely untested.

Objective: The present study investigated a newly developed MT application called Wildflowers, which was co-developed with the lab for use in mindfulness research. It was hypothesized that MT through this application would improve subjective well-being, attentional control, and interoceptive integration, albeit with weaker effects than those published in the group intervention literature.

Methods: Undergraduate students completed 3-weeks of MT with Wildflowers (n = 45), or 3-weeks of mathematical problem-solving training with a game called 2048 (n = 41). State training effects were assessed through pre- and post-session ratings of current mood, stress level, and heart rate. Trait training effects were assessed through pre- and post-intervention questionnaires canvassing subjective well-being, and behavioural task measures of attentional control and interoceptive integration. State and trait training data were analyzed in a multilevel model, using emergent latent factors (acceptance, awareness, openness) to summarize the trait questionnaire battery.
**Results:** Analyses revealed both state and trait effects specific to MT; participants engaging in MT demonstrated improved mood ($r = 0.14$) and a reduction of stress ($r = -0.13$) immediately after each training session compared to before the training session, and decreased post-session stress over 3-weeks ($r = -0.08$). Additionally, MT relative to math training resulted in greater improvements in attentional control ($r = -0.24$). Interestingly, both groups demonstrated increased subjective ratings of awareness ($r = 0.28$) and acceptance ($r = 0.23$) from pre- to post-intervention, with greater changes in acceptance for the MT group trending ($r = 0.21$).

**Conclusions:** MT using a smartphone app may provide immediate effects on mood and stress while also providing long-term benefits for attentional control. Although further investigation is warranted, there is evidence that with continued usage, MT via a smartphone app may provide long-term benefits in changing how one relates to their inner and outer experiences.

**Trial Registration:** This study was not registered at ClinicalTrials.gov, but the study protocol matches that of the REB approval acquired prior to the study trial.

**Keywords:** Mindfulness Training; Well-Being; Attentional Control; Smartphone App; Active Control; Interoceptive Attention

**Introduction**

Mindfulness training (MT) is a collection of meditation, introspection, and yoga practices aimed at the cultivation of psychological resilience and the alleviation of mental health symptoms [1]. In its modern secular form, MT was originally developed as an instructor-facilitated, clinical group intervention for chronic pain and mood disorders [2,3], and much of its scientific efficacy stems from the study of these clinical interventions [4]. However, MT has recently been offered through a growing variety of novel and largely un-validated delivery vehicles, including a growing number of smartphone apps. To date, there are no actively-controlled, experience sampling studies investigating whether such apps can replicate the therapeutic efficacy associated with validated group interventions.

Mindfulness has been defined as “the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment” (p. 145) [5]. Accordingly, MT aims to cultivate this adaptive form of awareness, primarily through guided meditation practices, suggesting that mindful awareness is a regulatory skill that can be developed over time [6]. To promote mindful regulation, mindfulness meditation has been integrated into a variety of MT interventions, such as Mindfulness Based Cognitive Therapy (MBCT) and Mindfulness Based Stress Reduction (MBSR) [4]. Meta-analyses focusing on clinical populations have found moderate effects of mindfulness based interventions on reducing symptom burden in chronic pain, anxiety, and depression [4,5,7]. In non-clinical populations, mindfulness based interventions have been found to have strong effects on psychological well-being, including the reduction of stress, negative emotions, and anxiety [8]. Moreover, in both clinical and non-clinical populations, mindfulness based interventions have been found to increase self-reported mindfulness [9,10]. Mindfulness meditation both guided and self-guided, without the broader context of a MT intervention, has also been associated with improvements in well-being, including increases in self-reported mindfulness, improvements in attention, decreases in anxiety, decreases in stress, and reductions in negative personality traits [8,11].
Some of the proposed mechanisms for the effectiveness of MT include increases in meta-cognitive awareness, acceptance, and attentional control [12,13]. Meta-cognitive awareness involves being able to step back from one's internal experiences and observe them from a third person perspective [14]. Acceptance involves a willingness to allow difficult internal experiences to happen while taking a non-judgmental stance towards them; it has been suggested that greater acceptance reflects decreased experiential avoidance, which is attempting to change or control difficult internal experiences [15–17]. Attentional control may involve different subcomponents of attention, including the ability to direct attention towards stimuli (orienting), the ability to remain receptive to stimuli (alerting), and the ability to prioritize attention (conflict monitoring) [13]. These proposed mechanisms reflect key components of mindfulness, as defined by Bishop and colleagues, which includes self-regulation of attention and adopting an open and accepting attitude towards internal experiences [6].

Despite well-established benefits of mindfulness-based interventions, and some understanding of the mechanisms involved, MT dissemination can be difficult. For example, MBCT and MBSR require a commitment of weekly meetings and at-home practice of learned mindfulness skills for 8-weeks [3,18,19]. Moreover, these interventions are costly and not easily accessible due to the requirement of therapists to implement these interventions [20,21]. These limitations have prompted research on the minimum-dose required for efficacious MT; these investigations have found that brief mindfulness training as short as 3-days to 4-weeks had positive effects on anxiety, negative mood, mindfulness, perceived stress, and attention [22–24]. Moreover, a systematic review found no relationship between hours spent in MT sessions and changes in psychological distress [25], suggesting that formal meditation time is not the most important factor in efficacious MT. Indeed, a recent dismantling study of internet-based MT found no effect of formal meditation practice, although both formal and non-formal practice arms of the study outperformed a no-intervention control group [26].

Growing awareness of MT-related benefits, coupled with uncertainty around the necessary components leading to these benefits, has allowed for a rapid expansion of MT delivery modalities, including implementation through technological platforms. Computer delivered mindfulness-based interventions have proven to be successful in reducing anxiety, depression, and stress [20], and a variety of mindfulness based smartphone applications have been developed that seek to replicate the success of group interventions [27]. However, while smartphone apps are scalable and accessible to a wider swath of population, their benefits remain largely untested [28].

Perhaps the fastest growing market for MT lies in smartphone apps for MT; the most popular current MT app, Headspace, boasted over 6 million users in 2016 [28]. Yet despite a booming user base, only two randomized controlled trials have investigated the efficacy of smartphone apps for MT, and only one of these trials used an active control group. Van Emmerik and colleagues investigated the beneficial effects of a mindfulness app called VGZ Mindfulness Coach. After 8-weeks of using this app, participants demonstrated increases in mindfulness, improvements in psychiatric symptoms, and improvements in quality of life, relative to a waitlist control condition [21]. Similar findings were observed with the Headspace Mindfulness meditation app in regards to psychiatric symptoms; after using the Headspace app for 10 days, participants demonstrated reduced depressive symptoms and increases in positive affect relative...
to an active control condition (participants had to make a list of what they did on that day the previous week). However, there were no changes in satisfaction with life or in negative affect. The authors reasoned that these findings may be a result of the short period that this app was used and that the changes in positive affect may have eventually led to changes in these other domains [29].

Although these studies found some benefits from using these MT applications, they both relied solely on subjective self-reports, which may be confounded with participant expectancy. For example, participants may believe that MT improves attention regulation [13], but such regulation can and should be assessed through behavioural performance rather than self-report alone. Moreover, these studies investigated the effects of MT while only comparing longitudinal ‘trait’ outcomes without evaluating the local or ‘state’ effects of meditation sessions. Exploring state effects may be useful in demonstrating the immediate benefits of MT by limiting retrospective bias [30].

**Goal and Hypotheses**

With few investigations of the effectiveness of MT applications on well-being, further research is warranted. The goal of this current study was to better evaluate the local and longitudinal effects of app-delivered MT relative to a randomized active-control group. For this purpose, we employed a newly developed MT app, which was designed to collect user’s ratings of current mood and stress level, as well as heart rate, before and after each guided meditation session. In the active control condition, a popular math game was adapted to allow for the same collection of mood, stress, and heart rate data.

As outcome variables, we attempted to provide several longitudinal and local MT targets. For longitudinal targets, we modelled three commonly-cited MT benefits: improved subjective well-being, attentional control [8–11,13], and interoceptive integration [31–34]. For local targets, we tested for improvements in mood, physiological arousal [24,35,36], and stress [11,22,26,37].

It was hypothesized that MT via a smartphone app would improve trait subjective well-being and behavioural indices of attention, albeit with weaker effects than those published in the group intervention MT literature. Additionally, it was expected that beneficial state MT effects would be observed on mood, heart rate, and perceived stress, suggesting the immediate benefits of brief mindfulness meditation.

**Methods**

**Recruitment and Design**

Undergraduate students were recruited from the University of Toronto Mississauga and randomly assigned to train with one of two smartphone applications: Wildflowers, a mindfulness training (MT) application, or 2048, a mathematical training application that was used as an active control condition. To be eligible to participate in the current study, participants were expected to: (a) have normal or corrected-to-normal vision and hearing, (b) be 18 years of age or older, (c) be fluent in English, and (d) own an iPhone, iPad, or iPod with access to internet.
Upon recruitment, each participant was asked to come in to the laboratory to complete self-report questionnaires of well-being through an online survey platform called Qualtrics, and complete behavioural measures of attentional and interoceptive integration on a computer in the laboratory. After completing the questionnaires and tasks, participants downloaded their assigned application and made sure it was working on their phone and they knew how to use it. Participants did not know their condition assignment until after completing the pre-training measures. Ratings of current mood, stress level, and heart rate were recorded within each app before and after each training session. After 3-weeks of training, using their assigned application for at least 10-minutes per day, each participant returned to the laboratory to re-take the self-report questionnaires and behavioural measures of attentional control and interoceptive integration. Before participating in the study, undergraduate students gave written informed consent. The research protocol was approved by the University of Toronto Social Sciences, Humanities, and Education Research Ethics Board. This study was not registered at ClinicalTrials.gov, but the study protocol matches that of the REB approval acquired prior to the study trial.

Training Conditions

**Mindfulness Training App**

Mindfulness training in the study was performed using a new app called Wildflowers (Mobio Inc., Toronto), that was developed in collaboration with our lab. This smartphone app incorporates features that have been deemed to be important to include in smartphone MT, as suggested by Mani and colleagues [27]. For example, Wildflowers includes guided meditations such as breathing, body scans, and open monitoring practices, and also provides didactic content in the form of lessons and information about the benefits of MT. Additionally, the app was designed to collect user’s ratings of current mood and stress level, as well as heart rate, before and after each guided meditation session. This feedback is aggregated and provided to the user, and may be useful in providing the user with helpful insights into the physiological and psychological benefits of MT.

Using the Wildflowers application (Multimedia Appendix 1), participants were able to choose and complete a variety of guided meditations. Participants could decide on a certain mindfulness meditation through different avenues. First, they could complete a lesson on a certain type of meditation (e.g., mindfulness of breath, mindfulness of body). Each lesson included: (a) a fact about the particular meditation, (b) teaching the user about ‘snapshots’ to record current mood, stress level, and heart rate, (c) a minute of flow where the participant was asked to connect with the present moment, (d) the meditation, (e) a fact on how to increase resilience, such as practicing being non-judgemental, and (f) ending with another snapshot. Instead of a lesson, participants could also choose from a library of guided meditations that are each unlocked after completing a certain number of meditations. Lastly, participants could also have a guided meditation suggested to them based on their current mood and stress level.

**Mathematical Training with 2048**

The training app for the control condition was based on open source code for a very popular mathematical game, called 2048 (Multimedia Appendix 2), where participants had to slide tiles around with numbers on them. If two tiles with the same value touched, they combined to create
a tile with a larger value. The object of the game is to combine tiles until a tile with the value of 2048 is created. The same ratings of mood, stress, and heart rate before and after each training session were also built into this redesigned app to provide parity in measurement of state effects between the two training conditions.

Measures of Subjective Well-Being

**Perceived Stress Scale (PSS)**
The PSS [38] is a 10-item scale that measures the global perception of stress. However, due to a missing question during data collection, results from the short 4-item version of the PSS was used in analyses. Internal consistency has been reported as $\alpha = 0.82$ and convergent validity for the 4-item version has been reported as $r = 0.58$ to $r = 0.70$ [39]. Test retest evidence for the 4-item version is lacking; however, test retest reliability has been reported for the 10-item version as $r > 0.70$ [40].

**Big Five Inventory (BFI)**
The BFI [41,42] is a 44-item scale that measures the five dimensions of personality. This scale contains five subscales that reflect the five dimensions of personality: extraversion, agreeableness, conscientiousness, neuroticism, and openness. Extraversion includes sociability, assertiveness, and positive emotionality. Agreeableness includes altruism, tender-mindedness, trust, and modesty. Conscientiousness includes thinking before acting, delaying gratification, following norms and rules, and organizational tendencies. Neuroticism includes anxiousness, nervousness, sadness, and tenseness. Lastly, openness contrasts openness to experience with close mindedness. Internal consistency has been reported as $\alpha = 0.75$ to $\alpha = 0.90$, test retest reliability has been reported as $r = 0.80$ to $r = 0.90$, and convergent validity has been reported as $r = 0.71$ to $r = 0.97$ [42,43].

**Psychological Well-Being Scale (PWBS)**
The PWBS [44] is an 84-item questionnaire that measures psychological well-being. This measure includes six subscales. The autonomy subscale contrasts self-determination and independence with concerns about the evaluation of others. The self-acceptance subscale contrasts a positive attitude towards the self, accepting both good and bad qualities, with being dissatisfied with the self and certain qualities. The positive relations with others subscale contrasts having warm, trusting, and satisfying relationships versus having few close and trusting relationships. The environmental mastery subscale contrasts having a sense of competence versus difficulties managing every day affairs. The purpose in life subscale contrasts a sense of direction with a sense of a lack of meaning in life. Finally, the personal growth subscale contrasts having a consistent feeling of continued development with a sense of personal stagnation. For the PWBS, internal consistency has been reported as $\alpha = 0.33$ to $\alpha = 0.56$ [44] and convergent validity has been reported as $r = 0.25$ to $r = 0.73$. During the development of the PWBS, which included 20-items per subscale, test retest reliability was reported as $r = 0.81$ to $r = 0.85$ [45].

**Acceptance and Action Questionnaire – II (AAQ-II)**
The AAQ-II [17] is a 7-item scale that measures psychological inflexibility and experiential avoidance. The AAQ-II has demonstrated satisfactory evidence of internal consistency ($\alpha =$
Philadelphia Mindfulness Scale (PHLMS)
The PHLMS [46] is a 20-item scale that measures two components of mindfulness. This scale consists of two subscales: the awareness subscale, which reflects a continuous monitoring of current internal and/or external experience, and the acceptance subscale, which reflects a non-judgemental attitude towards internal and/or external experiences. The PHLMS has demonstrated sufficient evidence of internal consistency (α = 0.81 to α = 0.85) and convergent validity (r = 0.25 to r = 0.97) [17]. However, test retest reliability has not been reported [47].

Multidimensional Assessment of Interoceptive Awareness (MAIA)
The MAIA [48] is a 32-item scale that measures the multidimensional construct of interoceptive body awareness. This scale is made up of eight subscales: noticing, not-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body listening, and trusting. Noticing reflects the awareness of body sensations. Not-distracting reflects not avoiding sensations of pain or discomfort. Not-worrying reflects the tendency to not worry about psychological or physical discomfort. Attention regulation reflects the ability to sustain and control attention. Emotional awareness reflects awareness of the connection between physical sensations and psychological states. Self-regulation reflects the ability to regulate distress by attending to body sensations. Body listening reflects the ability to listen to the body. Lastly, trusting reflects the feeling that one’s body is safe and able to be trusted. This scale has demonstrated sufficient evidence of convergent validity with other measures of body/mindful awareness, and internal consistency has been reported as α = 0.66 to α = 0.82 [48]. Evidence of test retest reliability is lacking for the English version of the MAIA, however, has been reported for a German version of this test as r = 0.66 to r = 0.79 [31].

Spiritual Experience Index Revised (SEI-R)
The SEI-R [49] is a 23-item scale that measures a person’s faith and spiritual journey. This scale consists of two subscales: the spiritual support subscale refers to the reliance on faith for support, and the spiritual openness subscale refers to being open to new spiritual experiences. The SEI-R has demonstrated sufficient evidence of convergent validity, and internal consistency has been reported as α = 0.79 and α = 0.95 [49]. However, evidence of test retest reliability has not been reported.

Meaning in Life Questionnaire (MLQ)
The MLQ [50] is a 10-item scale that measures two dimensions of the meaning in life, and as such includes two subscales: presence of meaning, and search for meaning. Presence of meaning reflects the degree that a respondent feels that their life has meaning. Search for meaning reflects the degree that a respondent strives to find understanding in their life. Internal consistency has been reported as α = 0.82 to α = 0.88, test retest reliability has been reported as r = 0.70 and r = 0.73, and convergent validity has been reported as r = 0.28 to r = 0.74 [50].

Mood Board Circumplex
The mood board is a visual representation of negative and positive emotions on a spectrum, ranging from intense emotions to mild emotions. This mood board provides a maximum of 32
emotions that a participant can select, and yields four scores: degree of intense negative emotions, degree of intense positive emotions, degree of mild negative emotions, and degree of mild positive emotions. This measure was administered and scored in a similar manner as the positive and negative affect schedule [51].

**Measure of Attentional Control**

*Centre for Research on Safe Driving Attention Network Test (CRSD-ANT)*

The CRSD-ANT is a 10-minute version of the Attention Network Test that measures three different functions of attention: alerting, orienting, and conflict monitoring [52]. Alerting involves achieving and maintaining attention to incoming stimuli, orienting involves directing attention to sensory input, and conflict monitoring involves resolving conflict among responses [53]. This behavioural task requires participants to determine whether a directional object (car) is pointing left or right, and the network scores (alerting effect, orienting effect, conflict effect) are calculated as the difference between median response times [52,53].

**Measure of Interoceptive Integration**

*Respiration Integration Task (RIT)*

The RIT is a newly developed behavioural task created to assess interoceptive attention. In the RIT, participants view a circle on a computer screen that expands and contracts rhythmically. In each trial, participants will view two cycles of expansion/contraction, the reference and the target. The reference circle always expands and contracts at a fixed rate, whereas the target varies in its frequency. Participants are to report on whether the target is faster or slower than the reference. The change in the frequency of cycling begins with a large change (about 2000 ms), and employs a psychophysics staircase to determine the ‘just noticeable difference’ of change detection. The staircase uses a ‘3 up / 1 down’ algorithm, in which three consecutive correct responses reduce the frequency change in the subsequent trial, making it more difficult, while one incorrect response increases the frequency difference, making it easier.

The RIT has three phases, a vision only baseline, a respiration entraining practice period, and the respiration integration period. During the baseline, participants use vision alone to detect changes in circle frequency. Once this threshold is established, participants spend 60 seconds entraining their breath, i.e., practicing matching respiration to the movement of the circle as it pulses at the reference frequency. Then, in the integration period, participants repeat the task while matching their breathing to the expansion/contraction of the sphere. The visual and breath scores are calculated by taking the mean frequency across the final 6 from each of these conditions.

**Statistical Analysis**

*Power*

An a priori power analysis for the group-specific training effects were modelled as the interaction of the within-subjects factor of time (pre vs. post) and the between-subjects factor of group (MT vs. Control). The power analysis was conducted using the G*Power software application to determine how much power would be needed to find weak to moderate interaction
effects in the present study. A moderate effect, eta-squared of .06, or Cohen’s F of .25, was assumed. It was also assumed that repeated measures scores had a moderate to strong correlation of 0.5. The analysis suggested a total N = 34 for 80% power. A weaker effect of Cohen’s F = .15 would require 90 participants, and so the study was powered conservatively for this effect, i.e., we attempted to recruit approximately 45 participants in each group.

Following data analysis, a post hoc power analysis simulation, with 10,000 simulations, was conducted using the statistical platform R 3.4.3 [54] to more accurately simulate the post-hoc power of the study. Scores were assumed to start at 0 and have a standard deviation of 1 to detect a 0.5 (half deviation) change in the MT group and no true change in the control group, with an effect size $d = .5$, which is considered moderate according to Cohen [55]. The simulation revealed the current study ($n = 45$ per group) had 65% power to detect the desired interaction effect. Using the simulation approach, the study would have needed a sample size of $n = 90$ per group to achieve 80% power. The discrepancy between the G*Power and simulation approaches suggests a need for further research on power calculation methodology.

**Data Exclusion**
A participant was excluded from analysis if they did not adhere to the study protocol. Minimal adherence was defined as 10 minutes of practice per day, missing no more than 4 of the 21 days, and completing both the pre- and post-training assessment measures.

**Data Reduction**
An exploratory factor analysis (EFA) was conducted upon the scale measures listed above in the R statistical computing environment [54]. The number of factors required was first estimated using the paran library for performing Horn’s parallel analysis of Principal Components/Factors [56].

**Group Comparisons**
All statistical analyses were conducted using the statistical platform R 3.4.3 [54] with an alpha level of .05 for all tests. Demographics between groups were compared using a $t$ test and a chi-squared test. Prior to group comparisons, the questionnaire data was reduced using EFA to increase ease of interpretability and minimize type I error. Multilevel models were used to compare both state and trait measures of well-being between groups over time. Lastly, the relationship between the state and trait measures of well-being were investigated through correlations.

**Results**

**Participants**
As shown in the participant flow diagram for the study (Figure 1), the final sample included 41 participants in the math training group (mean age = 19.78, $SD = 2.43$, 88% female), and 45 participants in the MT group (mean age = 20.24, $SD = 2.63$, 80% female). A $t$ test revealed that the groups did not significantly differ in terms of age ($t(82.86) = -0.85, 95\% \text{ CI}[-1.56, 0.62], P = 0.40$), and a chi-squared test revealed that the groups did not significantly differ in terms of gender ($X^2(2) = 5.49, p = 0.064$).
Figure 1. Participant Flow Diagram

Statistical Analysis Assumptions
The data was inspected to make sure that assumptions that could affect the interpretation of the results were satisfied. Inspection of the normality of residuals, influential cases, autocorrelation of residuals, and homogeneity of variances revealed no major violation of assumptions (see Multimedia Appendix 3).

Data Reduction
Before conducting the EFA, the factorability of the 31 questionnaire subscales in the present study was examined. It was determined that all of the subscales were suitable to include in the EFA (see Multimedia Appendix 3). Horn’s parallel analysis of Principal Components [56] suggested that four factors should be retained in the EFA (Multimedia Appendix 4); however, since the fourth factor was well below the random eigen values generated during the analysis test, a three factor solution was chosen to be more suitable. The EFA was conducted using Ordinary Least Squares to find the minimum residual solution using the psych package [57] in R, and an oblique rotation method, promax, was used to allow for correlations between factors.

Table 1. Factor loadings of well-being questionnaires entered into the exploratory factor analysis with bolded values representing the strongest loadings for each latent factor.

<table>
<thead>
<tr>
<th>Scale / Subscale</th>
<th>Acceptance Factor Loadings</th>
<th>Awareness Factor Loadings</th>
<th>Openness Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSS - short version</td>
<td>-0.67</td>
<td>0.06</td>
<td>-0.13</td>
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<tr>
<td>BFI / Extraversion</td>
<td>0.38</td>
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<td>Correlation</td>
<td>p-value</td>
<td>interpretation</td>
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<td>BFI / Neuroticism</td>
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<td>MLQ / Search for Meaning</td>
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<tr>
<td>Mood Board / Mild Positive Emotions</td>
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</tbody>
</table>

The three-factor solution (Table 1) explained 42.5% of the shared variance. It was determined that factor 1 (Eigen value = 6.45) was best labelled as acceptance since this factor included subscales measuring acceptance and not avoiding or worrying about psychological discomfort. Factor 2 (Eigen value = 4.34) was best labelled as awareness due to the inclusion of subscales measuring psychological and physical awareness, and attention regulation. Lastly, factor 3
(Eigen value = 2.38) was best labelled as openness and included subscales measures openness, personal growth, and the reporting of both negative and positive emotions. For the reliability analysis, a subscale was considered to be a part of a factor if its loading was greatest for that factor relative to the other factors (bolded values in Table 1). Each of the factors demonstrated good evidence of internal reliability; the acceptance factor had an internal reliability of $\alpha = 0.89$, the awareness factor had an internal reliability of $\alpha = 0.86$, and the openness factor had an internal reliability of $\alpha = 0.70$. Additionally, acceptance and awareness ($r = 0.32$), acceptance and openness ($r = 0.21$), and awareness and openness ($r = 0.35$) each demonstrated a positive relationship with each other.

Longitudinal Training Effects

Subjective Well-Being

To test the hypothesis that trait well-being would improve over-time as a result of MT, each of the three factors (acceptance, awareness, openness) were analyzed in a multilevel model using the nlme package [58] in R.

Table 2. Multilevel models of trait well-being measures with bolded values representing significant findings, and italicized values representing marginal findings.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Estimate (SE)</th>
<th>t-value (df)</th>
<th>P value</th>
<th>Pearson r</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance</td>
<td>Time</td>
<td>0.19 (0.09)</td>
<td>2.12 (84)</td>
<td>0.04</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>0.28 (0.20)</td>
<td>1.40 (84)</td>
<td>0.17</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Group</td>
<td>0.24 (0.12)</td>
<td>1.93 (84)</td>
<td>0.06</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td>Time</td>
<td>0.30 (0.11)</td>
<td>2.65 (84)</td>
<td>0.01</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>0.26 (0.20)</td>
<td>1.28 (84)</td>
<td>0.20</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Group</td>
<td>0.13 (0.15)</td>
<td>0.83 (84)</td>
<td>0.41</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Openness</td>
<td>Time</td>
<td>0.04 (0.10)</td>
<td>0.43 (84)</td>
<td>0.67</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>0.47 (0.19)</td>
<td>2.49 (84)</td>
<td>0.01</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Group</td>
<td>-0.07 (0.14)</td>
<td>-0.50 (84)</td>
<td>0.62</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td>Alerting Effect</td>
<td>Time</td>
<td>-0.03 (0.19)</td>
<td>-0.14 (84)</td>
<td>0.89</td>
<td>-0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>-0.09 (0.22)</td>
<td>-0.43 (84)</td>
<td>0.67</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Group</td>
<td>0.37 (0.26)</td>
<td>1.43 (84)</td>
<td>0.16</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Orienting Effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Each of the three factors from the EFA were modelled as a function of Time (pre- versus post-training) and Group (MT versus math training). Additionally, pairwise follow-up comparisons, Tukey HSD corrected for multiple comparisons, using least-squares means were conducted using the lsmeans function from the lsmeans package [59] in R.

Analysis of subjective well-being data revealed a significant main effect of time for the acceptance factor (Table 2; Figure 2), as well as a trend towards an interaction between time and group. Follow-up comparisons suggested that this marginal interaction was driven by a significant increase in acceptance (lsmean difference = -0.42, SE = 0.08, t(84) = -5.02, p < 0.0001) from pre- to post-training for participants in the MT condition. Additionally, a trend was observed where participants at post-math training had lower levels of acceptance than participants at post-MT (lsmean difference = -0.52, SE = 0.20, t(84) = -2.56, p = 0.058).

Figure 2. Changes in Acceptance Before and After MT and Math Training.

Figure 3. Changes in Awareness Before and After MT and Math Training.
A significant main effect of time was observed for the awareness factor (Table 2; Figure 3). Follow-up comparisons revealed that from pre- to post-MT, participants demonstrated increased levels of awareness (\( \text{lsmean difference} = -0.43, \ SE = 0.11, \ t(84) = -3.98, \ P = 0.0008 \)). Additionally, from pre- to post-math training, participants demonstrated increased levels of awareness (\( \text{lsmean difference} = -0.30, \ SE = 0.11, \ t(84) = -2.65, \ P = 0.046 \)).

Figure 4. Changes in Openness Before and After MT and Math Training.

There was no main effect of time or interaction between time and group observed for the openness factor (Table 2; Figure 4). A main effect of group was observed, suggesting that randomization failed to equate openness. However, the effects for the acceptance and awareness factors were maintained after controlling for openness in the earlier analyses.

Attentional Control
To test the hypothesis that attentional control would improve as a result of MT, each of the three network scores from the CRSD-ANT (orienting effect, alerting effect, conflict effect) were
analyzed in a multilevel model. Each of the network scores were modelled as a function of time (pre- versus post-training) and group (MT versus math training). Additionally, pairwise follow-up comparisons were conducted.

Figure 5. Changes in Alerting Effect Before and After MT and Math Training.

Analysis of the CRSD-ANT revealed no main effects or interactions for the alerting effect (Table 2; Figure 5).

Figure 6. Changes in Orienting Effect Before and After MT and Math Training.

No main effects or interactions were observed for the orienting effect (Table 2; Figure 6).

Figure 7. Changes in Conflict Effect Before and After MT and Math Training.
A significant interaction between time and group was observed for the conflict effect (Table 2; Figure 7). Follow-up comparisons revealed that this interaction was driven by significant improvements in the conflict effect from pre- to post-training for participants in the MT group (\textit{lsmean difference} = 0.37, \textit{SE} = 0.14, \textit{t}(84) = 2.63, \textit{P} = 0.049), but no evidence of change in the control group.

\textbf{Interoceptive Integration}

To test the hypothesis that behavioural interoceptive attention would improve as a result of MT, participants scores from the RIT were analyzed in a multilevel model, modelled as a function of group (MT versus math training), time (pre- versus post-training), and condition (visual baseline versus breath integration). Additionally, pairwise follow-up comparisons were conducted.

Table 3. Multilevel model of respiration integration task performance with bolded values representing significant findings

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Estimate (SE\textsuperscript{a})</th>
<th>t-value (df\textsuperscript{b})</th>
<th>\textit{P} value</th>
<th>Pearson r</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>-0.06 (0.13)</td>
<td>-0.50 (213)</td>
<td>0.62</td>
<td>-0.03</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>0.09 (0.15)</td>
<td>0.57 (83)</td>
<td>0.57</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>0.26 (0.12)</td>
<td>2.16 (213)</td>
<td>\textbf{0.03}</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Time * Group</td>
<td>0.02 (0.17)</td>
<td>0.12 (213)</td>
<td>0.91</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Time * Condition</td>
<td>-0.16 (0.18)</td>
<td>-0.94 (213)</td>
<td>0.35</td>
<td>-0.06</td>
<td></td>
</tr>
<tr>
<td>Group * Condition</td>
<td>0.10 (0.17)</td>
<td>0.60 (213)</td>
<td>0.55</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Time * Group * Condition</td>
<td>-0.10 (0.24)</td>
<td>-0.41 (213)</td>
<td>0.68</td>
<td>-0.03</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} SE = standard error, \textsuperscript{b} df = degrees of freedom

Figure 8. Changes in Respiratory Integration Task Performance by Task Condition, Group, and Time
Analysis revealed a main effect of condition for the RIT, with the breath condition associated with better detection thresholds than the visual baseline condition (Table 3; Figure 8). However, the results showed no indication of MT effects over time.

**State Training Effects**

**Subjective Well-Being**

To test the hypothesis that participants in the MT group would demonstrate immediate effects on well-being, each of the in-app measures (mood, stress, heart rate) were analyzed in a multilevel model. Each of these measures were modelled as a function of group (MT versus math training), time (multiple training sessions per participant) and session (before versus after each training session), with subject, time, and session as random intercepts.

Table 4. Multilevel models of state measures of well-Being with bolded values representing significant findings

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Estimate (SE)</th>
<th>t-value (df)</th>
<th>P value</th>
<th>Pearson r</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mood</td>
<td>Time (days)</td>
<td>-0.01 (0.01)</td>
<td>-1.65 (1117)</td>
<td>0.10</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>-0.01 (0.15)</td>
<td>-0.07 (76)</td>
<td>0.95</td>
<td>-0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Session (pre vs. post)</td>
<td>0.02 (0.07)</td>
<td>0.31 (1190)</td>
<td>0.75</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Group</td>
<td>0.01 (0.01)</td>
<td>0.85 (1117)</td>
<td>0.40</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Session</td>
<td>0.004 (0.01)</td>
<td>0.63 (1190)</td>
<td>0.53</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group * Session</td>
<td>0.47 (0.09)</td>
<td>4.99 (1190)</td>
<td>&lt; 0.00</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time * Group * Session</td>
<td>-0.002 (0.01)</td>
<td>-0.21 (1190)</td>
<td>0.84</td>
<td>-0.01</td>
<td></td>
</tr>
</tbody>
</table>

**Stress**
### Time (days)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Coefficient (SE)</th>
<th>t-value (df)</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>-0.55 (0.16)</td>
<td>0.001</td>
<td>0.001</td>
<td>-0.37</td>
</tr>
<tr>
<td>Session (pre vs. post)</td>
<td>-0.01 (0.05)</td>
<td>0.89</td>
<td>0.89</td>
<td>-0.004</td>
</tr>
<tr>
<td>Time * Group</td>
<td>0.01 (0.01)</td>
<td>0.15</td>
<td>0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>Time * Session</td>
<td>0.01 (0.004)</td>
<td>0.26</td>
<td>0.26</td>
<td>0.03</td>
</tr>
<tr>
<td>Group * Session</td>
<td>-0.31 (0.07)</td>
<td>&lt; 0.00</td>
<td>&lt; 0.00</td>
<td>-0.13</td>
</tr>
<tr>
<td>Time * Group * Session</td>
<td>-0.02 (0.01)</td>
<td>0.005</td>
<td>0.005</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

### Heart Rate

<table>
<thead>
<tr>
<th>Effect</th>
<th>Coefficient (SE)</th>
<th>t-value (df)</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>-0.08 (0.14)</td>
<td>0.59</td>
<td>0.59</td>
<td>-0.06</td>
</tr>
<tr>
<td>Session (pre vs. post)</td>
<td>-0.01 (0.09)</td>
<td>0.92</td>
<td>0.92</td>
<td>-0.003</td>
</tr>
<tr>
<td>Time * Group</td>
<td>0.01 (0.01)</td>
<td>0.53</td>
<td>0.53</td>
<td>0.02</td>
</tr>
<tr>
<td>Time * Session</td>
<td>0.01 (0.01)</td>
<td>0.31</td>
<td>0.31</td>
<td>0.03</td>
</tr>
<tr>
<td>Group * Session</td>
<td>0.13 (0.13)</td>
<td>0.09</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>Time * Group * Session</td>
<td>-0.03 (0.01)</td>
<td>0.03</td>
<td>0.03</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

*a SE = standard error, b df = degrees of freedom

**Figure 9.** Changes in Mood Before and After Each Training Session Over the Course of Training.

Analysis revealed a significant interaction between group and session on mood (Table 4; Figure 9). Follow-up comparisons revealed that participants in the MT group demonstrated a significant improvement in mood after each training session (*lsmean difference* = -0.51, *SE* = 0.03, *t*(1190) = -15.15, *P* < 0.0001), whereas participants in the math training group did not.
A significant main effect of group, an interaction between group and session, and three-way interaction between time, group, and session were demonstrated for ratings of stress level (Table 4; Figure 10). Being part of the MT group was generally associated with lower stress, even before practice sessions: follow-up comparisons revealed that participants in the MT group relative to the math training group demonstrated significantly lower levels of subjective stress both pre-training (lsmean difference = 0.44, SE = 0.14, t(76) = 3.11, P < 0.01) and post-training sessions (lsmean difference = 0.91, SE = 0.14, t(76) = 6.42, P < 0.0001). For the group by session interaction, follow-up comparisons revealed that participants in the MT group demonstrated a significant decrease in stress levels after each training session (lsmean difference = 0.43, SE = 0.02, t(1190) = 17.96, P < 0.0001), whereas participants in the math training group did not. For the three-way interaction, significant reductions of stress over time were uniquely observed for participants in the MT group post-training session (b = -0.01, SE = 0.004, t(616) = -2.65, P < 0.01, r = -0.11), but such time effects were not observed pre-training in the MT group, nor at pre- or post-training for the math training group. Together, these results indicate participants in the MT training group began daily training sessions with less overall stress, that MT sessions uniquely produced a further reduction in stress, and that the impact of training sessions in the MT group uniquely increased over the 3-week training period.
A significant three-way interaction between time, group, and session was observed for heart rate (Table 4; Figure 11). Follow-up comparisons revealed that this interaction was driven by participants in the math training group, for whom post-training heart rate increased over the course of the training period \((b = -0.02, SE = 0.01, t(1011) = -2.03, P < 0.04, r = -0.06)\), while pre-training heart rate in the math training group, and both pre- and post-training heart rate in the MT group did not change with time. These results suggest that the math training became increasingly arousing in terms of heart rate over the study period, but no such effects were associated with MT.

**Association between Trait and State Measures of Well-Being**

An exploratory analysis of the associations between change scores for the trait measures (pre- and post-training), and change scores for the state measures (pre- and post-practice session) were conducted via correlation analysis. Results (Table 5) revealed significant relationships between state and trait measures of well-being: changes in acceptance with changes in mood, changes in acceptance with changes in stress, and changes in orienting effect with changes in heart rate. Additionally, there were significant relationships within trait measures, such as changes in conflict effect with changes in acceptance, and changes in orienting effect with changes in acceptance.

**Table 5. Correlations between state (pre- and post-session) and trait (pre- and post-intervention) measures of well-being change**

<table>
<thead>
<tr>
<th>State Well-Being</th>
<th>Trait Well-Being</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate</td>
<td>Acceptance</td>
</tr>
<tr>
<td>Stress</td>
<td>Awareness</td>
</tr>
<tr>
<td>Mood</td>
<td>Openness</td>
</tr>
<tr>
<td></td>
<td>Alerting</td>
</tr>
<tr>
<td></td>
<td>Orienting</td>
</tr>
<tr>
<td></td>
<td>Conflict</td>
</tr>
</tbody>
</table>

| Stress | -0.19 |


<table>
<thead>
<tr>
<th>Measure</th>
<th>p-value 1</th>
<th>p-value 2</th>
<th>p-value 3</th>
<th>p-value 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mood</td>
<td>-0.17</td>
<td>-0.34b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptance</td>
<td>-0.18</td>
<td>-0.34a 0.42b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awareness</td>
<td>0.01</td>
<td>-0.17 0.20</td>
<td>0.25a</td>
<td></td>
</tr>
<tr>
<td>Openness</td>
<td>0.18</td>
<td>-0.08 0.19</td>
<td>0.14 0.40c</td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>-0.47a</td>
<td>0.11 -0.07</td>
<td>-0.06 -0.12</td>
<td>-0.09</td>
</tr>
<tr>
<td>Orienting</td>
<td>0.06 -0.22</td>
<td>0.25 0.22a</td>
<td>0.02 -0.01</td>
<td>0.22a</td>
</tr>
<tr>
<td>Conflict</td>
<td>0.03 0.11 0.29b</td>
<td>-0.04 -0.01</td>
<td>0.14 0.13</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>-0.33 -0.61c 0.57c</td>
<td>0.21 0.09</td>
<td>-0.05 0.15</td>
<td>0.15 -0.24a</td>
</tr>
</tbody>
</table>

a P Value < 0.05, b P Value < 0.01, c P Value < 0.001

Discussion

Principal Findings
This was the first actively-controlled study to investigate whether MT apps can promote the therapeutic effects associated with validated group MT interventions, namely subjective well-being, attentional control, and interoceptive integration.

Subjective well-being was assessed both in terms of trait (pre- and post-training) and state (pre- and post-practice session) self-reports. A trend towards MT-specific changes in acceptance from pre- to post-training was observed, and closer inspection of the data suggested that the MT group may have driven a general increase in acceptance over time. This result was complemented by MT effects at the state level: relative to the math training group, participants in the MT group demonstrated improved mood and reduced stress following each training session. Importantly, changes in acceptance across the intervention were correlated with session-specific changes in stress and mood. While the overall effect of training on acceptance was weak, this is one of the first documented reports of state-effects of meditation contributing to interventional level effects on dispositional mindfulness.

These findings are consistent with a broader literature in which dispositional acceptance has been associated with reduced experiential avoidance [15–17], decreased negative affect, and reduced stress reactivity [60,61]. At the state level, brief mindfulness interventions have been linked to beneficial effects on stress and mood [24,35]. However, few studies have described how changes at the dispositional or trait level relate to individual training session effects. Here, we provide some of the first evidence that it is precisely these session-level effects on mood and stress appraisals that manifest as trait like changes in distress tolerance. Specifically, it seems that app-guided MT may have immediate effects on mood and stress, and that these effects help to explain broader changes in the self-appraised capacity to cope with negative experiences. Such a finding is in keeping with the principles of mindfulness training, in which practitioners are taught to engage rather than avoid negative emotions and reduce their impact on more general mood and stress appraisals. Encouragingly, the beneficial impact of MT on subjective stress in the MT group increased overtime; significant reductions in stress were observed over time in the post-training stress levels of the MT group, but not in the math training group. Therefore, over a
longer time course, accumulating state effects of MT practice may support greater changes in acceptance; however, further research is warranted to support this hypothesis.

Contrary to the study hypotheses, participants in the MT and math training groups reported significant increases in both acceptance and awareness over the study period. One explanation for this finding may be the fact that participants in both groups recorded their mood and stress levels before and after each training session. Research has shown that recording mood and stress in and of itself may contribute to improvements in negative symptomatology by increasing emotional self-awareness [62], and could promote acceptance of negative emotion by exposing participants to the natural variation in daily affective experience. Both groups performed daily ratings on mood and stress before and after each training session, a reflective practice which could itself foster awareness and insight around emotional experience. Furthermore, the general increase in acceptance and awareness may help to explain why MT-specific increases in acceptance were so modest: change acceptance and awareness were moderately correlated, and the active control group may have benefitted from the increased awareness inherent to a daily reflection study design. This result both suggests a benefit to even minimal daily reflection on emotional experience, but also supports the importance of including an active control group in contemplative research. Without such a control group, the increase in awareness in the MT group may have suggested that this change was related to the mindfulness component in the MT smartphone app. However, with the math training group in the study, it was possible to further ascertain benefits unique to MT above and beyond general effects of the daily reflection paradigm.

There were no training effects for either group observed for the openness factor. This result is not entirely surprising in the context of research that has shown that those who choose to practice mindfulness demonstrate greater openness [63], and openness was not predicted a priori to emerge as a factor for analysis. In the present study, participants in the MT group demonstrated overall greater openness than participants in the math training group. However, openness did not appear to be impacted by training in either group, and controlling for individual differences in openness did not alter the other study findings. As participants were unaware of randomization condition at baseline assessment, it is unlikely that the group difference was caused by experimental condition, and more likely reflects the difficulty in equating all study variables through random assignment.

Attentional control was assessed on a trait level using the CRSD-ANT, which yielded alerting, orienting, and conflict effect scores. Analyses revealed training effects specific to MT; relative to the math training group, 3-weeks of MT led to greater improvements in conflict monitoring. However, training effects were not observed for alerting effect or orienting effect. These results are in line with Tang and colleagues [36] who measured attentional control using the 20 minute version of the attention network test (ANT) and found that after 5-days of integrated body-mind training (IBMT), which included several body-mind techniques including MT, participants in the IBMT condition demonstrated improvements in executive functioning relative to the relaxation group. Additionally, no differences in orienting effect or alerting effect were found. Similarly, Zeidan and colleagues [23] found improvements in executive functioning after 4-days of MT relative to an active control group, and Ainsworth and colleagues [64] found improvements in executive function after focused attention and open monitoring MT relative to a control group.
The present results are also reflected in studies comparing naïve meditators with experienced meditators, which have found that experienced meditators demonstrate greater cognitive flexibility [65–67]. Taken together, the results of the present study suggest that using a MT app may provide similar benefits as other MT interventions for increasing attentional control/cognitive flexibility.

Conflict monitoring, also known as executive attention or switching [68], is a form of attention regulation that includes self-regulation (cognitive, emotion, behaviour) [68,69]. In the present study, improvements in conflict monitoring observed in the MT group may reflect improved self-regulation skills, and indeed changes in conflict monitoring scores were moderately correlated with changes in acceptance. Improved self-regulation skills have been associated with improvements in trait mindfulness [70], which in the present study may be evidenced by the significant positive correlation observed between conflict monitoring and acceptance. Moreover, previous research has found that greater emotional acceptance may mediate the effects of MT on executive control [71]. Although here both the MT and math training groups demonstrated an equivalent increase in acceptance, with a larger sample or dose of MT training, it is possible that MT-specific enhancement in conflict monitoring may promote later, MT-specific increases in acceptance.

Interoceptive attention was assessed with the respiration integration task. In terms of interoceptive attention, there were no training effects. However, participants in both groups demonstrated greater accuracy when using their breath to judge the circle rather than just using their visual abilities. These results suggest that interoceptive attention may facilitate accuracy on discrimination tasks, but that such attention was not particularly impacted by the training paradigm.

Only one unique effect of math training was observed: Participants in the math training group demonstrated an increase in heart rate over time post-practice session, but not for the pre-practice session, or pre- and post-practice in the MT group. This result may suggest that with an increased focus on negative symptoms during mood monitoring, participants in the math training group may have experienced increased negative reactivity [72]. However, the math training group did not demonstrate concurrent changes in mood or stress. Therefore, the present results may also suggest that as participants continued to play the math game, they may have become increasingly engaged with beating past performance and gaining a sense of achievement. It is not possible to conclude why post-practice heart rate was increasingly elevated for participants in the math training group, but these results suggest that not all forms of physiological arousal are diagnostic of changes to mood or stress reactivity.

Limitations
While the present study provides evidence for the beneficial effects of MT using a smartphone application, there are several limitations that should be noted. First, although practice was monitored, participants were only reminded to practice if they missed three consecutive days. Therefore, participants did not necessarily practice with their assigned app (Wildflowers or 2048) every day, which might affect the extent of the significant findings observed. On the other hand, this limitation adds more ecological validity to the present study as people in the real world would not be monitored closely to ensure they are practicing every day. Second, state
mindfulness was not measured during daily training sessions, so it is hard to know if the benefits to mood and stress observed were a result of transiently increased state mindfulness, or a result of another factor that was not considered in the present study. However, a study design which promotes daily reflection on state mindfulness may have introduced further unintended training effects to the control group. Lastly, although the results strongly support benefits of MT on state measures of subjective well-being, the marginal pre- to post-intervention results around the acceptance factor make it inappropriate to draw strong conclusions about the relative efficacy of MT relative to active control. These marginal results may be due to the power of the present study. While the a priori power analysis suggested adequate power, a post-hoc simulation-based power analysis suggested that the study was underpowered for addressing these group by time interactions. Therefore, a future study with better power should attempt to replicate and extend our understanding of the relationship between the state and trait well-being factors.

**Future Directions**
The present work provides preliminary evidence on the benefits of using a MT smartphone application. These findings suggest that future work should continue to investigate the benefits of MT apps in clinical populations. Additionally, future studies should investigate the longitudinal effects of using MT applications. Lastly, the present results on improvements in attention regulation warrant studies exploring neural changes as a result of MT using a smartphone application. For example, Tang and colleagues observed that two weeks of brief mindfulness training altered the resting state functional connectivity of large scale brain networks [73]. Therefore, it may be fruitful for future studies to explore both the self-reported, behavioural, and neural benefits of MT using a smartphone application.

**Conclusion**
The results of the present study suggest that MT with a smartphone app may provide immediate effects on mood and stress while also providing long-term benefits for attentional control. Although further investigation is warranted, there is evidence that with continued usage, MT via a smartphone app may provide long-term benefits in changing how one relates to their inner and outer experiences.

**Conflicts of Interest**
Bechara J. Saab served as a technical liaison with Mobio Interactive Inc., but did not contribute to data collection or analysis.

**Abbreviations**
ANT: Attention Network Test
CRSD-ANT: Centre for Research on Safe Driving Attention Network Test
df: degrees of freedom
EFA: exploratory factor analysis
IBMT: integrated body-mind training
MT: mindfulness training
MBCT: mindfulness based cognitive therapy
MBSR: mindfulness based stress reduction
RIT: respiration integration task
SE: standard error
Multimedia Appendix 1
Screenshots of Wildflowers Mindfulness Training Condition.

Multimedia Appendix 2
Screenshots of 2048 Math Training Control Condition.

Multimedia Appendix 3
Additional Details for Statistical Analyses.

Multimedia Appendix 4
Scree Plot of Horn’s Parallel Analysis of Principal Components Used to Determine the Appropriate Factor Solution for the Exploratory Factor Analysis.

Multimedia Appendix 5
CONSORT-EHEALTH checklist (V 1.6.1).

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