Modern Psychological Studies

Volume 29 | Number 1 Article 1

2023

Mobile phone mindfulness: Effects of app-based meditation intervention on stress and HRV of undergraduate students

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Abstract

Since the COVID-19 pandemic, stress has increased exponentially in undergraduate populations. The current study sought to determine the efficacy of an eight-week relaxation intervention, using a free meditation app to reduce perceived stress and increase baseline heart rate variability (HRV) of undergraduate students, compared to using a traditional relaxation intervention across the same period. Participants (N=14) were randomized into either a meditation app group or self-directed diaphragmatic breathing group and were instructed to engage in their respective relaxation technique ten minutes daily for eight weeks. Pre- and post-intervention differences in perceived stress and HRV were examined, along with user satisfaction with the type of intervention. Perceived stress was significantly reduced in both groups. However, participants used the meditation app for a comparatively longer period of time and enjoyed the meditation app more than diaphragmatic breathing exercises. While there was no change in baseline HRV for either group, the percent change in HRV was significantly higher in the meditation app group. The results highlight the effectiveness of mobile phone meditation apps in reducing perceived stress in college students and suggest the app may be better at maintaining adherence amongst users when compared to traditional self-guided methods.

Keywords: meditation app, stress, HRV, mindfulness, diaphragmatic breathing

Mobile Phone Mindfulness: Effects of App-Based Meditation Intervention on Stress and HRV of Undergraduate Students

Distress, commonly referred to as stress, is the body's reaction to physical, mental, or emotional overwhelm causing physiological responses such as elevated blood pressure and heart rate (APA, 2018). Stress is usually an acute, short-term response, but it can have especially negative implications for those experiencing it chronically. Chronic stress occurs when the stress response is prolonged over a long period time, even when the stressor is no longer present (APA, 2019). As a result of its enduring nature, chronic stress is linked to diseases such as diabetes, cancer, autoimmune syndromes, cardiovascular dysfunctions, and depression (Mariotti, 2015).

Due to academic and personal pressures, undergraduate students are experiencing stress at a high frequency and severity. French researchers surveying undergraduate students discovered that 72.9% were suffering from psychological distress (Saleh et al., 2017). Additionally, Agolla and Ongori (2009) found that 77% of undergraduate students experience migraine headaches and 88% suffer from nervous or anxiety indigestion, two common symptoms of chronic stress. Stress levels are continuing to worsen as students have encountered more stressors due to the COVID-19 pandemic (Yang et al., 2021). A recent meta-analysis found that depression, anxiety, and psychological distress have increased since the pandemic (Lakhan, 2020).

Various attempts have been made to address the prevalence of chronic stress, including mindfulness meditation–based interventions in the form of extended retreats or courses. Previous research has shown these interventions may yield benefits such as lower perceived stress and anxiety, reduced severity of stress responses, and improve cognitive function in adult populations (Gál et al., 2021; Khoury et al., 2013; Singh et al., 2012). Participants who engaged in an in-

person 10-day mindfulness meditation course significantly reduced overall psychological distress from baseline to a three-month follow-up, indicating the possible lasting effects meditation practice can have on stress reduction (Ostafin et al., 2006).

Heart Rate Variability

Additional work examined the role of mindfulness meditation on psychophysiological responses including heart rate variability (HRV). HRV refers to the fluctuation in time between heart beats and is an indicator of psychological adaptiveness and self-regulation (HeartMath Institute, 2023). Léonard and colleagues (2019) showed that HRV was improved in participants during a mindfulness meditation session. Additional research examined if the positive effects of meditation on HRV were carried outside of session and if enhanced HRV was sustained. Preliminary research indicated that a 10-day meditation retreat improved HRV not only during active meditation, but also in resting baseline HRV measurements of participants one-week post-retreat (Krygier et al., 2013). Further research demonstrated that an in-person mindfulness meditation intervention lasting four weeks significantly increased resting baseline HRV (Shearer et al., 2016). Proper mindfulness meditation training can plausibly increase psychological adaptiveness as indicated by baseline HRV measurements.

Previous research has shown that conventional mindfulness meditation interventions were effective at reducing stress and improving HRV. However, expensive retreats and courses prove to be significant barriers to entry, illustrated by the association of income to meditation practice (Macinko & Upchurch, 2019). The costliness of traditional meditation training is contributing to socioeconomic inequalities in mental health because income level and age largely determine access to mindfulness meditation training (Petrovic et al., 2018). One option to address financial barriers is diaphragmatic breathing, a low-cost relaxation technique that doesn’t

require specialty training or classes. Diaphragmatic breathing is the process of focusing on using the diaphragm and stomach to complete the breath cycle, and it is effective in stress reduction (Ma et al., 2017).

However, consistency and duration of practice are crucial, which are variables that are hard to maintain as a beginner without proper instruction, perhaps reducing the effectiveness of the unstructured, self-guided practice of diaphragmatic breathing (Zhang et al., 2021). Moreover, low adherence and noncompliance limits the learning of mindfulness (Lymeus et al., 2019). A recent meta-analysis discovered a significant association between time-practiced meditating and intervention outcome, affirming the importance of regular practice and high adherence (Parsons et al., 2017). Further, conventional meditation retreats are too large of a commitment for some beginners (Lymeus et al., 2019). Traditional meditation therapies and stress-reduction techniques have shown to be effective. However, they tend to be relatively expensive and time intensive, therefore making them inaccessible to undergraduate students with significant time and financial constraints (Jacobs et al., 2013; Lindberg, 2023).

Meditation Applications

The demand from undergraduate students and beyond for cheaper stress-reduction training has led to the rise in popularity of meditation phone applications. There has been debate regarding if these alternative meditation methods are as successful as traditional ones. Similar to outcomes of conventional meditation training modalities, a study using the popular meditation app, Calm, for an eight-week intervention found significant differences in perceived stress between experimental and control groups (Huberty et al., 2019). Additional studies have highlighted the efficacy of meditation apps in reducing the stress and depressive symptoms of their users (Lahtinen et al., 2021). Online mindfulness meditation has been shown to enhance

HRV during session (Kirk & Axelson, 2020). However, the sustained effects of app-based mindfulness meditation on resting baseline HRV are less clear. For example, Chang and others (2020) conducted a meditation intervention with a group of 45 participants using both face-to-face and video lessons over the course of one month. It was found that both the face-to-face and video lessons significantly improved participants' heart rate and HRV. On the other hand, a study recruiting 33 pre-med undergraduate students to use a low-cost meditation website for eight weeks did not find significant differences in pre- and post-intervention resting baseline HRV measurements (Burgstahler & Stenson, 2020). Previous research lacks clarity and can be contradictory, highlighting the literature's general lack of data regarding the effects of meditation apps on baseline HRV.

Meditation apps, aside from HRV impact, have similar effectiveness to traditional meditation therapies at a significantly lower cost. A Calm membership costs approximately $70 annually, which may still be inaccessible to some (Huberty et al., 2019). Thus, it is important to consider the effectiveness of completely free meditation platforms, such as Insight Timer. Insight Timer is a free application available for iPhone and Android that features a collection of guided mindfulness meditation recordings (Insight Timer, 2023). Focusing on meditation duration and adherence is necessary to contribute to a growing body of literature in this field of research. As previously mentioned, time spent meditating is a significant predictor of intervention outcome (Parsons et al., 2017). Adherence of users on mental health apps is overall low; only 41.6% of accounts continued to use a PTSD treatment application one month after installation (Owen et al., 2015). A past study revealed that 42% of users of online mental health intervention programs engage in moderate use (Fleming et al., 2018). However, adherence of meditation app interventions has not yet been compared to that of self-guided interventions. The current study

aims to address the following question: does the structure of meditation apps increase intervention adherence of beginners who otherwise would be practicing stress-reduction techniques on their own (e.g., diaphragmatic breathing)?

The Current Study

Considering the growing popularity of meditation apps among undergraduates, it is imperative that we better understand their efficacy and the habits and preferences of their users. Previous studies have failed to comprehensively examine the effects of free-to-use meditation apps on stress and baseline HRV, specifically with a self-guided comparison group. Thus, the present study sought to understand the effects of an eight-week intervention using a free meditation app, Insight Timer, on perceived stress and HRV using a self-guided diaphragmatic breathing comparison group. Also examined were the differences in adherence and users' perception of intervention efficacy in the meditation app group and the breathing comparison group, respectively. Consistent with previous literature, we predicted that perceived stress would be significantly reduced in both groups (e.g., Huberty et al., 2019; Ma et al., 2017). We hypothesized that the meditation app group would have higher adherence and more positive user perception than the comparison group. Due to lack of previous research, no prediction was made on the effects of the interventions on baseline HRV.

Methods

Participants

Enrollment in the study occurred in two parts. First, potential participants were solicited via an online human subjects pool to complete an online survey to determine eligibility, obtain informed consent, and establish baseline perceived stress measurements. Participants were compensated by receiving mandatory course credit in psychology courses. In total, 121

individuals completed the eligibility survey. Participants were eligible if they were full-time undergraduate students at the university and (1) at least 18 years of age, (2) scored at least 14 points on the Perceived Stress Scale (PSS), (3) owned a smartphone, (4) were willing to download the Insight Timer app, (5) had not consistently meditated or practiced diaphragmatic breathing prior to participation in the study, and (6) were willing to be randomized. Scores above 14 on the PSS indicate elevated stress levels. Potential eligible participants were then contacted via email to determine interest in participating in the study and incentivized with a $25 gift card. If participants chose to continue with the study, they were permitted to withdraw at any time with no penalty.

Enrolled participants from a small liberal arts university (N=14) were all female and predominantly white (86%). Gender was not part of the inclusion criteria; however, students at the university taking psychology classes were mostly female, so a single-gender sample was recruited by chance. Gender homogeneity in the sample ensured gender differences in stress response were not an influence (Verma et al., 2011). Eighteen participants initially enrolled; however, three participants did not complete post-intervention HRV measurements, and one participant was excluded due to practice of additional outside relaxation techniques unrelated to the present study. Seven participants from the meditation group and seven from the breathing group completed all post-intervention measures.

Materials

Eligibility Survey

The eligibility survey was used to determine if potential participants met the inclusion criteria. The eligibility survey included a brief demographic questionnaire, other questions evaluating inclusion criteria, and the PSS adopted from Cohen and colleagues (1983). Higher

scores on the PSS indicate higher levels of perceived stress. More information about the eligibility survey can be found in Appendix C.

EmWave Pro Finger Sensor and Software

HRV measurements were obtained using EmWave Pro software and a finger sensor. EmWave Pro software provides an accumulated coherence score, a unit-less measure to indicate synchronization between sympathetic and parasympathetic branches of the autonomic nervous system (HeartMath Institute, 2023). Higher coherence scores represent more parasympathetic activity.

Insight Timer

Insight Timer is a free mindfulness meditation app available on iOS and Android smartphones. It features a collection of pre-recorded guided meditation sessions that users can play through their phone speakers or headphones.

Online Log Sheet

Participants were instructed to log their time daily meditating or completing breathing exercises on an online Microsoft Excel sheet.

Exit Survey

Participants completed an online exit survey following the conclusion of their eight weeks of meditation or breathing exercises. The exit survey consisted of a second administration of the PSS and questions to gauge participants' enjoyment and perceived efficacy of their respective stress reduction technique. This included questions such as "Did you enjoy the stress-reduction technique?" and "Was the stress-reduction technique helpful in reducing your stress?", among others. The exit survey for the intervention group included questions about Insight Timer,

and it contained questions about diaphragmatic breathing for the comparison group. Information regarding the exit survey can be found in Appendix D and Appendix E.

Procedure

Determining Eligibility and Randomization

The research protocol was approved by the university's institutional review board. As previously mentioned, participants were first screened by an eligibility survey administered online using Microsoft Forms. Using a randomizer website, selected participants were then placed into either the meditation app intervention group or the diaphragmatic breathing comparison group. Self-guided diaphragmatic breathing was used to compare efficacy, user perception, and adherence to the meditation intervention group.

Intervention and Comparison Groups

Participants in the meditation app intervention group were instructed to download Insight Timer on their smartphones and use it to complete guided mindfulness meditation sessions for at least 10 minutes daily for eight weeks, recording when they meditated on an online log sheet. Participants were instructed to complete a seven-day "Learn to Meditate" program on Insight Timer. After this, participants were free to complete any guided meditation sessions they pleased. Those in the diaphragmatic breathing group were briefly trained on how to successfully perform the exercise, and then instructed to complete breathing exercises 10 minutes daily for eight weeks. To examine differences in adherence, participants in the comparison group did not use an app to guide them, instead completing the exercises on their own. Diaphragmatic breathing exercises were also recorded by participants on the online log sheet. The ideal (assigned) duration of either meditation app usage or breathing exercise practice was 70 minutes/week or 560 minutes total.

HRV Testing

After randomization, participants individually entered the biofeedback lab at the university so baseline HRV measurements could be obtained using EmWave Pro software and a finger sensor. Participants were seated, the sensor was attached to their non-dominant middle finger, and a four-minute acclimation period followed. Prior to the start of the measurement, participants were instructed to sit upright with their eyes closed while breathing normally, abstain from phone usage, and avoid moving around to prevent interference. HRV was then measured for five minutes, followed by a short debrief on what HRV is and what was being measured. After the eight weeks were up, this procedure was repeated a second time for both the intervention and comparison groups. Post-intervention HRV measurements were recorded near the same time of day as pre-intervention HRV measurements (within a four-hour window). At this time, participants also completed the exit survey.

Results

A paired samples t-test showed that the meditation app intervention significantly reduced PSS scores from pre-intervention (M = 21.86, SD = 4.95) to post-intervention (M = 14.71, SD = 3.73), t (6) = 3.44, p = .014. Similarly, there was a significant difference between pre-intervention (M = 21.29, SD = 5.25) and post-intervention (M = 13.71, SD = 8.69) PSS scores for the diaphragmatic breathing group, t (6) = 3.88, p = .008. This difference can be seen in Figure 1. Further, participants in the meditation app group (M = 78.97, SD = 27.05) used their respective stress-reduction technique for more minutes per week than those in the diaphragmatic breathing group (M = 45.06, SD = 20.38), t (12) = 2.65, p = .021. Responses from the exit survey revealed 100% enjoyed using the meditation app, 100% believed the meditation app reduced their stress, 75% are planning to continue to use the app, and 100% are likely to recommend the

app to a peer. Furthermore, 75% enjoyed the breathing exercises, 75% believed diaphragmatic breathing exercises reduced their stress, 75% are planning to continue practicing the exercises, and 88% are likely to recommend breathing exercises to a peer.

There was no significant difference in pre-intervention (M = 1.23, SD = .45) and post-intervention (M = 1.47, SD = .45) baseline coherence scores for participants in the meditation app group, t (6) = -1.36, p = .222. Similarly, there was no significant effect on baseline coherence scores of those in the comparison group from pre-intervention (M = 1.10, SD = .31) to post-intervention (M = 1.01, SD = .20), t (6) = .737, p = .489. Differences in coherence scores between the two groups are depicted in Figure 2. However, the percent change in baseline coherence scores from pre- to post-intervention was significantly higher for the meditation app group (M = .47, SD = .45) in comparison to the diaphragmatic breathing group (M = .01, SD = .20), t (12) = 2.45, p = .031. In addition, five out of the seven participants in the meditation app group improved their coherence scores compared to two out of the seven in the diaphragmatic breathing group.

Discussion

The goal of the current study was to compare the effects of a free-to-use mindfulness meditation app on perceived stress and HRV to those of a self-guided diaphragmatic breathing intervention, which was a novelty in the literature. Also examined were differences in user preference and adherence between the two groups. Results showed that perceived stress was reduced in both groups, adherence was higher in the meditation app group, and change in HRV was greater for the meditation app group despite there not being any significant difference between pre- and post-intervention coherence scores for both groups.

Consistent with previous literature (Huberty et al., 2019; Ma et al., 2017) and our prediction, PSS scores were significantly reduced by both the meditation app intervention and diaphragmatic breathing intervention. These findings contribute to a growing body of research that meditation apps are as effective as conventional meditation interventions in reducing stress, specifically in undergraduate populations. Our findings highlight the utility of free-to-use meditation apps, especially in a market dominated by apps that charge an annual membership fee.

Additionally, findings supported our hypothesis that adherence would be higher in the meditation group than in the self-guided comparison group. First, participants in the meditation app group used the app for nearly twice as much time per week than those in the comparison group practiced breathing exercises. Also, participants were more likely to recommend the meditation app to a peer and were more likely to believe the meditation app reduced their stress compared to breathing exercises. These results should be considered when determining what stress-reduction techniques are preferred by undergraduate students, and how to maintain high adherence within student populations, an important indicator of intervention outcome (Parsons et al., 2017).

In alignment with previous research (Burgstahler & Stenson, 2020), it was found that neither the meditation app intervention nor breathing exercises significantly improved HRV as measured by coherence score. However, the percent change of HRV was significantly higher for the meditation app group than the diaphragmatic breathing group. The majority of participants in the meditation app group improved their coherence scores while only two out of seven in the comparison group improved theirs. The difference in improvements of HRV between the groups

was most likely caused by higher adherence in the meditation app group. Still, the results add to our understanding of the effects of meditation app interventions on HRV.

Limitations and Future Directions

The current study has several limitations to be addressed. First, data was collected from a relatively small sample, and lacked gender and racial diversity. The sample was predominantly White females, thus, reducing generalizability of results. This lack of diversity in the sample accounted for possible gender differences in intervention efficacy. Stecher and colleagues (2021) have identified that most users on meditation app platforms are White females. Future research needs to examine the reasoning for this occurrence and if meditation app intervention efficacy is dependent on gender or race using larger and more diverse samples.

In addition, social desirability bias may have played a role in the outcome of the study. Participants self-reported time meditating or breathing into their log sheets, and their sessions were not supervised or validated. Because of this, participants may have inflated their times or otherwise falsely reported sessions. Participants self-reported their times for both the meditation app and breathing groups, so social desirability bias was not a confound. Even so, stricter supervision of participants and validation of sessions during the interventions may be helpful in future research designs seeking to understand a dose-response relationship. That is, being certain of the accuracy of time meditated is important in determining how many minutes per week is necessary to reduce stress and improve HRV. The ideal *dosage* of meditation practice to significantly improve stress and HRV is not yet known, which future research should explore. Additionally, the act of tracking meditation or breathing activity on a log may have increased frequency and duration of stress-reduction technique practice. Self-monitoring is associated with

adherence and goal completion in weight-loss interventions (Gibson & Sainsbury, 2017), so the use of a log sheet should be noted.

Conclusion

The results of the present study demonstrate the effectiveness of free-to-use meditation apps in reducing stress, in maintaining high adherence and positive user perception in comparison to self-guided methods, and possibly in improving HRV in female populations. These findings have implications for students, mental health clinicians, and future research that should focus on the effects of app interventions on HRV using large, diverse populations. Stress is only worsening for college students, and research that helps to understand how to alleviate the burden of mental health issues is invaluable.

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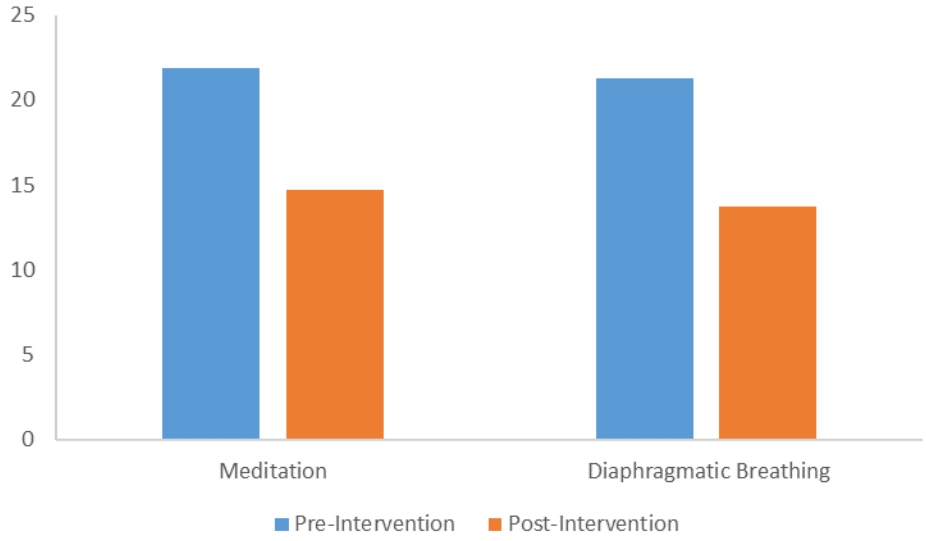
Appendix A

Figure 1

Mean perceived stress scores of participants by intervention group

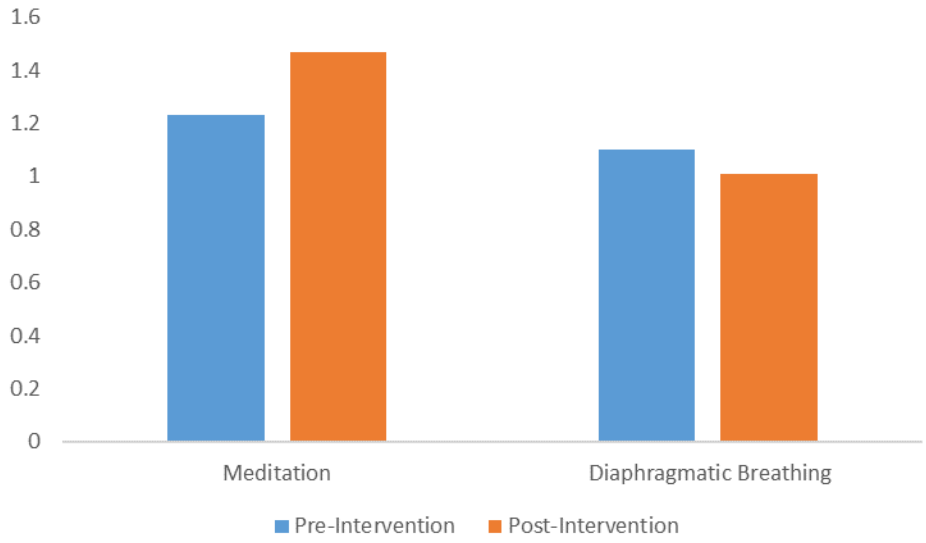


Note. Mean perceived stress scores were significantly lower post-meditation for both the meditation and diaphragmatic breathing groups.

Appendix B

Figure 2

Mean coherence scores by intervention group



Note. There were no differences between pre-intervention and post-intervention mean coherence scores for either group.

Appendix C

Eligibility Survey

Demographic Questionnaire

Are you a student at (removed for blind)?

Yes/No

Which gender do you most identify with?

Male/Female/Non-binary/Prefer not to answer

Which best describes you?

Freshman/Sophomore/Junior/Senior

Please indicate your ethnicity

White/Black or African American/American Indian or Alaska Native/Asian/Native Hawaiian or Pacific Islander/Other

What is your age in years?

Do you have a smartphone with reliable internet access?

Yes/No

Do you consistently meditate, do diaphragmatic breathing exercises, or consistently use a meditation app?

Yes/No

Are you completing this survey from Sona Systems for research requirement participation credit?

Yes/No

Perceived Stress Scale

In the last month, how often have you been upset because of something that happened unexpectedly?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that you were unable to control the important things in your life?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt nervous and stressed?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt confident about your ability to handle your person problems?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that things were going your way?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you found that you could not cope with all the things that you had to do?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you been able to control irritations in your life?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that you were on top of things?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you been angered because of things that happened that were outside of your control?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?

Never/Almost Never/Sometimes/Fairly Often/Very Often

Appendix D

Exit Survey (Meditation App Group)

Perceived Stress Scale

In the last month, how often have you been upset because of something that happened unexpectedly?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that you were unable to control the important things in your life?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt nervous and stressed?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt confident about your ability to handle your person problems?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that things were going your way?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you found that you could not cope with all the things that you had to do?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you been able to control irritations in your life?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that you were on top of things?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you been angered because of things that happened that were outside of your control?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?

Never/Almost Never/Sometimes/Fairly Often/Very Often

Satisfaction Questionnaire

Did you enjoy using Insight Timer?

Yes/No

Was meditation helpful in reducing your stress?

Yes/No

Will you continue to use Insight Timer or other meditation apps beyond your participation in this study?

Yes/No

Would you recommend Insight Timer to a fellow college student?

Yes/No

Appendix E

Exit Survey (Diaphragmatic Breathing Group)

Perceived Stress Scale

In the last month, how often have you been upset because of something that happened unexpectedly?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that you were unable to control the important things in your life?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt nervous and stressed?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt confident about your ability to handle your person problems?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that things were going your way?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you found that you could not cope with all the things that you had to do?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you been able to control irritations in your life?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt that you were on top of things?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you been angered because of things that happened that were outside of your control?

Never/Almost Never/Sometimes/Fairly Often/Very Often

In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?

Never/Almost Never/Sometimes/Fairly Often/Very Often

Satisfaction Questionnaire

Did you enjoy doing breathing exercises?

Yes/No

Were breathing exercises helpful in reducing your stress?

Yes/No

Will you continue to practice diaphragmatic breathing beyond your participation in this study?

Yes/No

Would you recommend diaphragmatic breathing to a fellow college student?

Yes/No