FACTOR STRUCTURE AMONG POSSIBLE CORRELATES OF SKILL AT MINDFULNESS MEDITATION

by

Tucker Peck

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF PSYCHOLOGY

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

2015

THE UNIVERSITY OF ARIZONA

GRADUATE COLLEGE

As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Tucker Peck, titled Factor Structure among Possible Correlates of Skill at Mindfulness Meditation, and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

____ Date: 5/6/2014

Richard Bootzin

____ Date: 5/6/2014

Harold Arkowitz

____ Date: 5/6/2014

Alfred Kaszniak

____ Date: 5/6/2014

Matthias Mehl

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

____ Date: 5/6/2014

Dissertation Director: Richard Bootzin

STATEMENT BY AUTHOR

DEDICATION

This work is dedicated to my mother, who always told me there was no limit to how high I should set my goals in education.

Table of Contents

List of Tables

List of Figures

Abstract

Despite the growing interest in the general public and popular press about the scientific research into mindfulness meditation (e.g. Pickert, 2014), several critiques of this research have been published in the past few years outlining methodological flaws in many published studies on the topic (Goyal et al., 2014; Ospina et al., 2007). One potential way to improve methodology in this field would be to find better ways of measuring skill at meditation, giving researchers an ability to compare more advanced practitioners to those who are more novice.

A total of 69 participants were recruited. Pilot data were collected from 33 participants and analyzed using exploratory methods to assess whether any self-report measures of mindfulness practice might correlate with any physiological variables thought to possibly reflect a dimension of skill at meditation. Participants spent a night in the sleep lab, and prior to their sleep study spent six minutes in a baseline condition followed by six minutes in a meditation condition, and differences were recorded on a number of physiological measures. Correlational analyses revealed that, of the physiological and self-report measures, six were correlated with other measures, and principal component analysis found 2 factors, each with three components. 36 additional participants were then recruited in an attempt to determine whether these two factors would replicate, and this latter group participated only in the meditation protocol. Both factors were largely replicated independently in the second sample and remained stable collapsing the two groups together. Factor 1 combined an increase in both alpha and theta power centrally and occipitally between baseline and meditation with self-reported mindfulness practice, and Factor 2 combined the inverse of the Brief Symptom Inventory, the Mindful Attention and Awareness Scale, and the change in respiration between baseline and meditation.

Introduction

Meditation, a deliberate technique of directing attention that is often associated with relaxation (Cardoso, de Souza, Camano, & Leite, 2004), has become a popular practice in the United States during the past few decades. As of 2007, the Centers for Disease Control reported that over 20 million Americans practiced meditation, a 34% increase in the number of American meditators from only five years earlier (Barnes, Bloom, & Nahin, 2008). In tandem with this increase in popularity has been an increase in research on whether meditation is an efficacious therapy for numerous physical and psychological dysfunctions.

Mindfulness

Much of the recent psychological research into meditation has focused specifically on mindfulness meditation (Bishop et al., 2004). While definitions of mindfulness vary, Kabat-Zinn (2003) defines mindfulness 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). Refining this definition after a series of meetings to operationally define the term “mindfulness,” Bishop and colleagues (2004) define mindfulness using two components: self-regulation of attention focused on immediate experience, and an “orientation to one’s experiences … characterized by curiosity, openness, and acceptance” (p. 232). Bishop and colleagues define “mindfulness meditation” (MM) as the cultivation of mindfulness, where there is no attempt to alter present experience.

The word “mindfulness” is a translation of the word *sati* from Pali, a language similar to that spoken by the historical Buddha, and Bodhi (2011) states that *sati* is a form attention that includes an aspect of the realization of the impermanence of phenomena, and that the term "mindfulness" also connotes repetition such that this mode of attention can be repeatedly applied to viewing bodily, mental, and outer phenomena. Bodhi also states that classical Buddhist texts repeatedly use the phrase "clear comprehension" as part of the definition of *sati.*

While these definitions are hard to operationalize because researchers cannot tell, for example, whether a person's orientation to his experiences is truly characterized by curiosity or clarity, perhaps the most important point from these definitions is that mindfulness involves no attempt to alter the present experience (Bishop et al., 2004). MM is therefore distinct from such other forms of meditation as Transcendental Meditation (TM), where one internally recites a mantra (Maharishi, 1969; Maharishi, 2001), or lovingkindness meditation, in which one attempts to cultivate feelings of goodwill towards others (Salzberg, 2002).

A great deal of the recent research into mindfulness has been based on the protocol of Mindfulness-Based Stress Reduction (MBSR) (Kabat-Zinn, 1990) or the similar protocol of Mindfulness-Based Cognitive Therapy (MBCT) (Segal, Williams, & Teasdale, 2002). Both of these protocols involve an eight-week class where participants meet weekly with the instructor for several hours and are assigned mindfulness "homework" on the remaining days, with exercises consisting of such practices as slowly scanning the body for sensations, performing gentle Yoga poses, and engaging in silent, seated meditation. The main distinction between MBSR and MBCT is that the latter contains aspects of cognitive therapy (see Beck, 1995), with much of the format of these two protocols being similar. Despite the fact that the large body of research literature on these practices tends to focus on MBSR and MBCT as entire protocols, as Britton and colleagues point out (Britton, Haynes, Fridel, & Bootzin, 2010), it is important to note that these protocols consist of different component practices that may have equally heterogeneous effects.

Measurement of Mindfulness Meditation

The vast majority of the research literature on MM assesses the effects of this practice in one of three ways (see Ospina et al., 2007). The first approach is to compare those who practice meditation to those who do not (e.g. Holzel et al., 2007), but as this approach cannot control for pre-existing differences between the groups, it is impossible to conclusively attribute between-group differences to meditation practice, even if researchers control for as many pre-existing variables as possible. The second approach is to conduct an experiment, and in the best case (e.g. Teasdale et al., 2000), one group is randomly assigned to meditate while another is randomly assigned to a control group. While randomized control trials effectively control for pre-existing conditions, they tend to be quite costly in terms of time and resources, and they are by necessity short-term, as it is impractical to randomly assign certain participants to, for instance, 25 years of meditation while prohibiting another group from engaging in such practices. However, many meditators have been practicing for decades, so a methodology for studying such practitioners is necessary. The third extant method for studying meditation is comparing those who have practiced meditation more to those who have practiced less (e.g. Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007), a method that can examine long-term meditation practice and that to a degree controls for pre-existing factors because, for instance, all people who practiced 1000 hours of meditation used to be people who practiced 100 hours, and probably some people who have practiced 100 hours will become people who have practiced 1000, although there may be pre-existing differences between those who continue to practice and those who do not. The difficulty with this approach, however, is that practice may not necessarily be related to skill. It is entirely possible that factors such as talent and quality of coaching may make some 100-hour meditators more able to excel in their goals for their practice

– be it focused attention, mindful awareness, present-moment mindfulness, etc. – than 1000-hour meditators. Indeed, the meditation teachers who collaborated on this project said that it is possible to spend thousands of hours sitting still and receive relatively little benefit, particularly if the practitioner has little instruction or coaching in how to advance. Therefore, if it were possible to measure skill at MM, this may provide the best possible way to measure the effects of MM on any given variable of interest. If this were possible, then practitioners who are more skilled could be compared to practitioners who are less skilled on any variable of interest.

Likely the most commonly used technique for measuring mindfulness in the research literature is self-report questionnaires such as the Five-Factor Mindfulness Questionnaire (FFMQ) (Baer et al., 2008) or the Mindfulness Attention and Awareness Scale (MAAS) (Brown & Ryan, 2003). In a paper reviewing the relationships among five such scales, Baer and colleagues (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006) reported the encouraging finding that these scales were all significantly correlated with one another, and every scale significantly and inversely correlated with a number of measures of undesirable traits such as psychological symptoms, neuroticism, and absent-mindedness. Interestingly, though, only two of the five scales were significantly correlated with meditation experience, despite the hypothesized association between meditation practice and mindfulness. This may indicate that while these scales are all measuring the same construct, that construct is not mindfulness, since otherwise it should be associated with mindfulness practice, albeit imperfectly associated.

Because many studies have reported physiological and neurological changes associated with meditation, and because self-report can be prone to such challenges as participants interpreting questions differently, erroneous responses, and deliberate misrepresentation, it seems that an ideal measurement of mindfulness skill might combine self-report questionnaires with physiological measures. Several such physiological measures have been proposed.

First, Lazar and colleagues (2005) conducted one of the few studies using a physiological marker of meditation skill as an independent variable (note that this study, as well several of the following studies, looked at meditation skill but not specifically MM skill). These researchers observed that skill in meditation – as measured by teacher-report from a group of practitioners with the same teacher – correlated with the rate at which one's breath became slow and shallow between baseline and meditation. Second, it has been reported that MM is associated with a decrease in heart rate (Barnes, Davis, Murzynowski, & Treiber, 2004) and that different meditation practices affect heart rate differently (Peng et al., 2004), such that heart rate correlated with MM skill. Finally, Cahn and Polich (2006) reported that meditation practice appeared in several studies to correlate with the power of alpha and theta EEG frequencies produced during meditation relative to baseline relaxation, although there were no reports specific to mindfulness. While there have also been brain imaging studies finding differences that appear to be associated with meditation experience (e.g. Lazar et al., 2005), the high cost of conducting such analyses would often make it impractical to use brain imaging as a marker of mindfulness.

Meditation and EEG

A number of studies over the past fifty years have investigated the electroencephalographic correlates of different styles of meditation, but these studies have been plagued by a number of problems. Many studies, particularly the earlier studies, suffer from major methodological flaws, and recent research has reported that the analyses of these data would likely be considered weak by current standards (Chiesa & Serretti, 2010; Ivanovski & Melhi, 2007). Studies have also focused on a wide variety of meditation practices, making the results hard to interpret across studies. Finally the vast majority of studies involved only a small number of subjects, leading to weak statistical power. In fact, of the more than sixty studies reviewed by Cahn and Polich (2006), only 17 reported data on greater than 30 subjects.

While the literature on meditative EEG contains a number of contradictory findings, perhaps the most repeated finding is an increase in alpha and/or theta power, either across the scalp or in specific regions, as a state effect of meditation. Increases in theta power have been found as a state effect of meditation in those practicing TM (Hebert & Lehmann, 1977), a form of concentration meditation called Sudarshan Kriya Shamatha (Baijal & Srinivasan, 2010), listening to a tape that included a body scan, breath awareness, and mental focusing (Jacobs & Friedman, 2004), and a Zen technique called Zazen (Murata et al., 1994), which can be considered a mindfulness practice (Chiesa & Serretti, 2010). Similar findings have also been reported for an increase in alpha power in TM (Williams & West, 1975), Yogic meditations (Khare & Nigam, 2000), and other contemplative techniques. However, the most common finding across many styles of meditation has been an increase in the power of both alpha and theta together at various places on the scalp. This has been reported for Ananda Marga Yoga (Ghista, Nandagopal, Ramamurthi, Das, Mukherji, & Srinivasan, 1976), Sahaja Yoga (Aftanas & Golocheikine, 2001), Zen meditation (Takahashi et al., 2005), and Nondirective meditation (Lagopoulos et al., 2009). In addition to the observation that alpha and theta power tend to increase during meditation in a number of styles, several researchers have made the observation that these increases may be related to practice, skill, or proficiency in meditation practice, such that more experienced practitioners may exhibit greater increases in alpha and theta power than novices. Alpha-theta power has been equated with “skill” in Zen meditators (Kasamatsu and Hirai, 1966) and “proficiency” in Tibetan Yogic meditation (Corby, Roth, Zarcone, & Kopell, 1978), and it has also been reported that theta power alone seemed to be indicative of “expertise” in Zazen meditation (Murata et al., 1994).

Despite the fact that the vast majority of modern research on meditation seems to focus specifically on mindfulness meditation, there has been a paucity of research into the EEG correlates of mindfulness meditation (Ivanovski & Malhi, 2007). The present study, therefore, aims to be among the first adequately-powered studies to assess whether EEG may be a possible correlate of practice or skill in MM.

Methods

Participants

This study analyzed data from 69 mindfulness meditators from the Tucson Community Meditation Center, Dharma Treasure Sangha, the Arizona Meditation Research Interest Group, the Zen Desert Sangha, and other mindfulness-based meditation groups in the Tucson area; 33 completed the first phase of the study and 36 completed the second. While it could be argued that recruiting from different meditation groups might lead to a group with heterogeneous practices, data on meditators in the Tucson community (Peck, 2010) show that even within one meditation group there is such a variety of both present and past meditative practices that heterogeneity cannot be avoided. It may also be argued that a population with a heterogeneous practice history may be ideal, since this is representative of the population of meditators, at least in Tucson and possibly in the United States.

Participants were excluded who reported, at the time of the interview, suffering from any form of psychopathology that may be associated with altered EEG, including depression, anxiety disorders, bipolar disorder, and psychotic disorders. A history of psychopathology was not sufficient to exclude a participant from the study, as long as that participant answered “no” to the questions “Do you still suffer from this disorder?” and “Do you take any medicine for the disorder?” Participants were also excluded if they reported the use of any recreational drugs in the past thirty days or the intention to use such drugs between the time they were interviewed and their in-lab assessment. Participants were also excluded for fibromyagia or diagnosed chronic pain, as these conditions are known to affect sleeping EEG, a relevant variable for the first phase of the study, and participants currently using prescription hypnotics or unwilling/unable to abstain from over-the-counter hypnotics were excluded as well. Participants were required to be fluent and literate in English, though perhaps because all advertising was in English, no one was excluded for this reason.

No data were kept on those participants who were excluded. The main reasons participants would be excluded from the study were for medical and psychological disorders as well as legal and illicit drug use, and because of the small size of the Tucson meditation community, the sensitivity of this kind of information, the fact that the PI and several others involved in the study are part of this community, it was important that this information be kept entirely confidential. Despite the best efforts to ensure confidentiality, it is virtually impossible to keep data secret from the PI, so data on why participants were excluded, and which participants were excluded, were immediately shredded. Although this could potentially be construed as limiting this study’s generalizabilty, protecting the privacy of the participants was given more importance.

Procedure

This study was conducted in two phases. Phase 1 of the study was an exploratory phase, where possible measures of meditation skill were recorded in advance of an overnight polysomnographic sleep study. In Phase 2, participants only completed the brief meditation protocol, following which their participation in the study terminated.

Participants who contacted the primary investigator to express interest in the study were screened by telephone by the study coordinator, Sarah Taraborelli, in Phase 2, and were screened in-person by a technician in Phase 1. Participants who were found to be eligible were emailed a meditation diary, a copy of the consent form so they would be familiar with the study protocol before arriving, and directions to the lab; participants in Phase 1 also received a sleep diary by email. On arrival, participants were met by a sleep technician, oriented to the lab, and then given several questionnaires: the FFMQ (Phase 2 only), MAAS, Brief Symptom Inventory, Hyperarousal Scale, Beck Anxiety Inventory, Beck Depression Inventory (Phase 2 only) (Beck & Beck, 1972), Meditation Hours Log (See Appendix A), and the Meditation Styles Questionnaire (Britton, unpublished) (Appendix B). Some participants in Phase 2 also received a questionnaire related to dream content as part of an investigation being conducted by an undergraduate honors student. All participants were asked to come to the lab 2-3 hours before their normal bedtime to control for possible circadian effects on EEG (Cacot, Tesolin, & Sebban, 1995).

After filling out questionnaires, participants spent forty-five minutes to an hour being connected to the PSG. Scalp electrodes for EEG were placed at C3, C4, O1, O2, F3, and F4, (see Jasper, 1958) with EEG reference electrodes at Cz, Fpz, M1 and M2 (called A1 and A2 under previous nomenclature). Eye movements were measured with E1 and E2 electrodes (previously called LOC and ROC), heartbeat with two contralateral EKG electrodes under the right collarbone on the left side-body, and a thermistor to measure breathing. Participants in Phase 1 also had 3 electrodes applied to the chin to measure EMG, and they wore a nasal cannula in addition to the thermistor, while Phase 2 participants did not wear these.

Following electrode attachment and assuring that impedances were less than five ohms on head electrodes and less than or equal to ten ohms in other electrodes, participants took part in a meditation protocol similar to that used by Lazar and colleagues (2005). Participants were asked to assume their meditation posture, including closing their eyes, but not to meditate. Following six minutes of this baseline procedure, a bell was rung and participants were asked to begin their meditation. In the first phase of the study the meditation period lasted six minutes, and in the second phase it lasted twelve minutes, with the extra six minutes being kept as ancillary data for future analysis. Because participants were not informed of the duration of the baseline or meditation periods prior to the procedure, any effects on the first six minutes of practice caused by lengthening the meditation period would be exceedingly unlikely. At the end of the meditation period, a bell was rung again, and the protocol ended. Participants in the second phase of the study received $20 compensation; participants in the first phase received $50 because their participation involved a significantly larger time commitment.

Data Analysis

Spectral Analysis EEG data from all channels were exported from Twin PSG (Grass Technologies, Warwick, RI) clinical software and imported into MATLAB. All channel data were referenced to the appropriate contra-lateral mastoid. An average was taken between homologous frontal, central and occipital channels (e.g. an average of C3 and C4, called "central"), as this allowed analysis of participants' data in the case that readings from one or the other electrode were corrupted.

Data were high-pass FIR filtered at .3 Hz using the Grass software and exported to MATLAB (The MathWorks, Inc., Natick, MA) for the remainder of EEG data processing. Filtered time-series EEG data from each channel were divided into 4-second epochs with 75% overlap, providing a frequency resolution of .25 Hz and allowing for evenly weighted spectral power estimates using fast fourier transform (FFT) with a Hamming window. For each subject and each channel, epoched EEG data were passed through an automatic artifact detection algorithm following recommendations provided by Foti and colleagues (2009), removing epochs containing a point-to-point voltage change of 100 uV or greater (for "spikes"), a start-to-end voltage change of 250 uV or greater (for "drifts"), and/or a start-to-end voltage change of 0.5 uV or less (for "flat signals"). Next, spectral estimates were calculated via FFT. For each channel, a single spectral power value for each frequency band of interest was derived by averaging FFT power estimates of all .25Hz frequency bins within the given band, yielding spectral estimates in nine bands: delta (0.5-4 Hz), theta (4-8.0 Hz), alpha (8-12 Hz), sigma (12-16 Hz), beta (16-30 Hz), and gamma (30-40 Hz). Data were then further cleaned with a semi-automatic procedure that displayed delta and gamma power values (separately) across each recording block (baseline or meditation) for each channel, along with a threshold line corresponding to the 99.5th percentile of that channel's power for each block. User input was allowed to adjust this threshold when necessary. Epochs with power values exceeding the threshold were then removed with the aim of eliminating any 4-sec epochs with substantially higher power than all other epochs in that recording block that were not already detected by the automatic algorithm described above.

Meditation Hours Log and the Definition of "Mindfulness" and "Meditation" The present study aimed to investigate only mindfulness meditation, because the category of "meditation" is sufficiently broad as to include a large number of practices that might be quite different from one another. Unfortunately, the definition of mindfulness found in the literature is wholly insufficient to distinguish which participants practice mindfulness and which practice another form of meditation. The PI consulted with two prominent meditation teachers (Upasaka Culadasa, Ph.D., and Shinzen Young) on this topic, and both agreed that there was no way to tell whether a person was practicing mindfulness, because it is not possible to see a person's subjective experience, and because there is no clear, agreed-upon definition of "mindfulness." Based on what a person calls her practice, however, it can be assumed that certain practices are probably mindfulness, and others are probably not. In consultation with the two teachers, the following words were determined likely to refer to mindfulness practices: mindfulness, Vipassana, Zazen, breath meditation (also called Anapana or Anapanasatti), open awareness, and any of the practices Shinzen has named (such as "focus in"; there are a number of these practices). The most difficult practice to classify was Metta, also called lovingkindness meditation, because this practice, which involves the cultivation of a particular emotion and therefore does meet the criteria for mindfulness, is often performed in conjunction with mindfulness and in very small amounts relative to mindfulness practice. In one common format, for instance, meditators practice mindfulness all day for nearly ten days, and then Metta briefly at the very end (Goenka, 2000). Thus, when participants said that they practiced "Vipassana/Metta" or when Metta was listed in between two practices that were determined likely to be mindfulness practices, Metta was itself counted as mindfulness, unless the participant was sufficiently clear about the distinction between how much time was devoted to one and how much to the other.

Additionally, a number of participants listed practices on the MHL that are likely not to meet the definition of meditation, practices such as Reiki (a practice of healing touch) and some forms of Yoga, which can be more comparable to calisthenics than to attentional practices. Therefore, practices listed on the MHL were divided into three categories: mindfulness, non-mindfulness meditation (e.g. TM), and non-meditation (e.g. Yoga, unless another descriptor was included to indicate a meditative component to the Yoga). Meditation was totaled in three different ways: Mindfulness; Total Meditation, a group excluding those practices unlikely to meet the definition of "meditation" but collapsing mindfulness and non-mindfulness meditation into one group; and Total Practice, including everything listed on the MHL.

The MHL had the significant benefit that it gave participants the freedom to list their meditation practice in whatever way made the most sense to them, likely giving the most accurate estimate of lifetime practice. However, this made it challenging to calculate the total meditation for each participant. Calculations were performed independently by three different scorers and averaged, except in the instance where one value was an outlier with respect to the other two, in which case only the other two were averaged. For several participants for whom there was no clear agreement among the three scorers, two additional scorers made independent calculations.

In Phase 2 of the study, the meditation period was extended from 6 minutes to 12 minutes, but data were only used from the first six minutes of the meditation protocol to keep

Phase 2 consistent with Phase 1. No significant differences were found between the 6-minute and 12-minute periods, likely because both periods are relatively short.

RESULTS

Thirty-five participants completed Phase 1, and 36 participants completed Phase 2; no participants were included in both phases. One participant who completed Phase 1 was excluded from data analysis for failure to comply with the directions during the study, and data on one participant were lost, so $n = 33$ for Phase 1 analyses. Demographic information on participants, as well as average meditation practice, can be found in Table 1.

Table 1: Characteristics of Participants

	Phase 1	Phase 2	Combined
Total participants	33	36	69
Total male	18	18	36
Age range	18 - 82	21 - 82	18 – 82
Mean age (sd)	43.2 (16.3)	47.0 (16.0)	45.1 (16.6)
% Caucasian	79%	77.8%	78%
% Hispanic	6%	19.4%	13%
Mean hours of mindfulness (sd)	3599 (5609)	969 (1359)	2244 (4206)
Mean total hours of practice (sd)	6425 (8764)	1612 (1957)	3904 (6616)
% mindfulness practice	56%	60%	57%

Participants in Phase 2 were demographically similar to those in Phase 1, with no significant difference between the groups in age or gender. However, there was a significant difference between the groups in their meditation practice, where practitioners in Phase 1 had practiced 3.7 times more mindfulness and 4.0 times more overall meditation. This may have reflected a demand characteristic of the study, where the more advanced meditators were more strongly affiliated with meditation groups and consequently were recruited more quickly and easily. While Phase 2 may have consisted of some participants who did not live in Tucson during the time in which Phase 1 was conducted, likely the majority of Phase 2 participants did not know about Phase 1, or were uninterested in participating when Phase 1 was conducted, and consequently Phase 2 may have attracted those who were newer at meditation and less affiliated with local groups, listservs, and other arenas through which they would have been recruited.

The mean number of hours of mindfulness practice in Phase 1 was skewed by two outliers, who reported lifetime histories of 17,265 and 27,911 hours of mindfulness. The third-highest report of mindfulness practice in the study (including both phases) was 7,693 hours. If these highest two participants are excluded, the mean hours of mindfulness for participants in Phase 1 drops to 2333 hours. However, this is still significantly different ($p = .01$) from participants in Phase 2, who on average had practiced 969 hours of mindfulness. Of the other variables of interest, the only one on which participants significantly differed by Phase was on MAAS score, in which participants in Phase 1 scored on average 0.34 points higher. There was also a nonsignificant trend towards higher theta change in Phase 1, $p = .09$.

Data in Phase 1 were collected with no a priori hypotheses but were explored for correlations. The following variables were explored using correlational analysis:

1. Self-reported hours of mindfulness practice, total meditation, and total practice (see p. 15 for definitions of these three categories)
2. Increase in EEG in each frequency band (delta, theta, alpha, sigma, beta, and gamma) at each averaged region (e.g. C3 & C4 electrodes averaged to "central")
3. Scores on several highly correlated self-report measures of psychopathology (BSI, BAI, BDI, & HAS; see p. 11).
4. MAAS
5. Respiration change

6. Change in heart rate, as measured both by beats per minute and inter-beat interval
7. Meditation practice in the week leading up to the study

Relevant findings from the correlational analysis of the central channels are below. Measures not listed below failed to correlate with any other possible measures of mindfulness skill. It is particularly interesting to note that when controlling for the contribution of mindfulness practice, total practice and non-mindfulness meditation were not significantly associated with any variables.

Table 2: Phase 1 Correlations Using EEG from the Averaged Central Channels (C3 & C4)

	Hours of mindful-ness practice	Theta Difference	Alpha Difference	Delta Difference	MAAS	BSI	Respiratory Change
Mindful	x	r = .695 p < .001	r = .337 p = .063	r = -.306 p = .094	ns	ns	r = .312 p = .093
Theta		x	r = .727 p < .001	r = -.433 p = .013	ns	ns	ns
Alpha			x	r = 0.642 p < .001	ns	ns	ns
Delta				X	ns	ns	ns
MAAS					x	r = -.332 p = .059	ns
BSI						x	r = -.419 p = .09
Resp.							x

N = 33
ns = not significant

Table 2 uses EEG recordings from the central channel. Data from the occipital channels showed an identical pattern, although change in delta power, which was inversely correlated with mindfulness practice, was positively associated with MAAS scores. Using EEG from the frontal channel, delta change was not associated with mindfulness hours, and the relationship between alpha difference and mindfulness hours was not significant (r = .252, p = .165). Theta difference was significantly correlated with mindfulness hours in the frontal channels.

While respiration did, on average, decrease during meditation relative to baseline by an average of 3.6 breaths per minute in Phase 1, interestingly, greater decreases were associated with higher scores of self-reported psychological distress as measured by the global severity index of the Brief Symptom Inventory (BSI), contrary to the expectation that greater decreases in breathing would be associated with greater skill at meditation (Lazar et al., 2005) and consequently *lower* scores on the BSI (Cohen-Katz, Wiley, Capuano, Baker, & Shapiro, 2005; Jain et al., 2007).

Principal component analysis (PCA) with varimax rotation was used to assess for underlying factors in the correlational pattern. Varimax rotation was used because the correlation table indicated an orthogonality between two possible factors: slow EEG frequency increases and self-reported mindfulness hours in one possible factor, and the BSI, MAAS, and respiration change in the other. (Results were comparable using promax rotation, which does not assume orthoganlity between the two factors). Two factors were found with Eigenvalue > 1 (Eigenvalue = 2.8 for Factor 1 and 1.6 for Factor 2). The results of the PCA, using the central channel EEG, are below in Table 3. The factor that includes EEG was not present in frontal channels but was comparable in occipital channels.

Table 3: Factor Loadings of Phase 1 Principal Component Analysis (Central EEG)

	Factor 1	Factor 2
Mindfulness practice	.728	-.053
Delta Difference	-.746	.038
Theta Difference	.837	-.192
Alpha Difference	.820	-.014
Respiratory Difference	.461	.684
BSI	.150	-.883
MAAS	-.236	.602

N = 33

Phase 2

The hypothesis of Phase 2 was that the factors in Phase 1 would be replicable in a new sample. While it would have been statistically ideal for the sample in Phase 2 to be independent, constraints on recruitment for the study led to both phases being too small to accurately detect stability of correlations (see Schönbrodt & Perugini, 2013). In addition to budgetary and time constraints, the size of the study population may have made larger sample sizes impossible; the number of mindfulness meditators living in Tucson who are eligible and willing to have participated in this study is probably not be much larger than the sample collected.

It was the case in Phase 2 that using $\alpha = .05$, no possible measures of mindfulness skill were significantly correlated with other measures. However, this may not be relevant, as using $\alpha = .05$ on two underpowered samples would be likely to result in a Type 2 error. The factor structure among the variables in Phase 1, however, did largely replicate in the Phase 2 data.

Using occipital EEG, the only difference between the rotated factor structure in Phase 1 and Phase 2 is a moderate relationship of alpha increase to Factor 2. Using central EEG, theta increase was not related to Factor 1, but otherwise the factors replicated.

Table 4: Phase 2 Correlations Using EEG from the Averaged Central Channels (C3 & C4)

	Hours of mindful-ness practice	Theta Difference	Alpha Difference	Delta Difference	MAAS	BSI	Respiratory Change
Mindful	x	r = .022 p = .900	r = .193 p = .274	r = -.018 p = .921	Ns	ns	r = -.065 p = .744
Theta		x	r = .126 p = .464	r = .180 p = .293	Ns	ns	ns
Alpha			x	r = 0.082 p = .635	Ns	ns	ns
Delta				X	Ns	ns	ns
MAAS					X	r = -.746 p < .001	ns
BSI						x	r = -.253 p = .178
Resp.							x

N = 36

Table 5: Factor Loadings of Phase 2 Principal Component Analysis (Central EEG)

	Factor 1	Factor 2
Mindfulness practice	.694	-.181
Alpha Difference	.834	.047
Respiratory Difference	.006	.473
BSI	.173	-.878
MAAS	-.079	.868

N = 36

Table 6: Factor Loadings of Phase 2 Principal Component Analysis (Occipital EEG)

	Factor 1	Factor 2
Mindfulness practice	.652	-.275
Theta Difference	.741	-.081
Alpha Difference	.771	.408
Respiratory Difference	-.031	.405
BSI	.067	-.882
MAAS	.002	.885

N = 36

The same correlation matrix used in Phase 1 is shown below for data from the combined sample. All reported correlations remain significant when using a partial correlation to control for the effects of age. Age itself is significantly correlated with lifetime hours of mindfulness practice and with the increase in theta power. Also, all difference scores remain significant when controlling for baseline measures.

Table 7: Correlations Using Central EEG, Phases 1 & 2 Combined

	Hours of mindful-ness practice	Theta Difference	Alpha Difference	Delta Difference	MAAS	BSI	Respiratory Change
Mindful	x	r = .446 p < .001	r = .324 p = .008	ns	Ns	ns	ns
Theta		x	r = .392 p = .001	ns	Ns	ns	ns
Alpha			x	r = -.237 p = .052	Ns	ns	ns
Delta				X	Ns	r = -.208 p = .089 (ns)	ns
MAAS					X	r = -.591 p < .001	ns
BSI						x	r = -.289 p = .024
Resp.							x

N = 69

In the combined sample, correlational findings were comparable in the frontal channels to those in the central channels, reported above. In the occipital channels, findings were comparable except that delta change was significantly inversely correlated with hours of mindfulness, r = -

.263, p = .041.   Because of this difference, principal component analysis tables are shown separately for central and for occipital EEG.

Table 8: Factor Loadings of Combined Phases, Principal Component Analysis (Central)

	Factor 1	Factor 2
Mindfulness practice	.759	.025
Theta Difference	.811	-.048
Alpha Difference	.730	-.019
Respiratory Difference	.256	.526
BSI	.185	-.881
MAAS	-.091	.780

N = 69

Table 9: Factor Loadings of Combined Phases, Principal Component Analysis (Occipital)

	Factor 1	Factor 2
Mindfulness practice	.755	.043
Delta Difference	-.415	.185
Theta Difference	.698	-.122
Alpha Difference	.793	.160
Respiratory Difference	.276	.549
BSI	.166	-.883
MAAS	-.179	.744

N = 69

All two-way relationships within the factors were analyzed graphically to look for the possibility of nonlinear associations, as some systems of meditation posit curvilinear relationships between meditation practice and perceived benefits (e.g. Sayadaw, 1992). All 2-way relationships among the components of each factor, however, failed to show any apparent nonlinear patterns.

Because the ultimate aim of this study is to work towards developing multicomponent measures of MM skill that could result in participants being assigned factor scores indicative of their skill at various aspects of meditation, all possible measures were included in factor analysis. However, in validation of these measures, it may also be useful to examine the relationship between more well-established measures such as practice and MAAS scores with those that are less traditional.

In the combined sample, alpha and theta change between baseline and meditation can be collapsed into a single variable, and the correlation between this variable and mindfulness practice is $r = .452$, $p = .0002$, $r^2 = .204$. This relationship is shown graphically below in Figure 1. Two participants who had practiced more than 15,000 hours of mindfulness are excluded from Figure 1, even though they are included in the analyses, because the inclusion of these outliers would require tripling the size of the x axis, making the graph difficult to read. However, these outliers fall near the regression line and there is consequently minimal effect on the overall pattern caused by their exclusion from the graph.

While the BSI and the MAAS are strongly associated with one another ($r = -.591$, $p < .001$), respiration difference predicts only the BSI ($r = -.289$, $p = .024$) and not the MAAS ($r = .051$). Because of this, and because the scales correlate inversely, collapsing the MAAS and BSI into a single variable would likely be confusing. The relationship between respiratory difference and BSI is graphed below in Figure 2.

Figure 1: Mindfulness Hours and Alpha-Theta Change

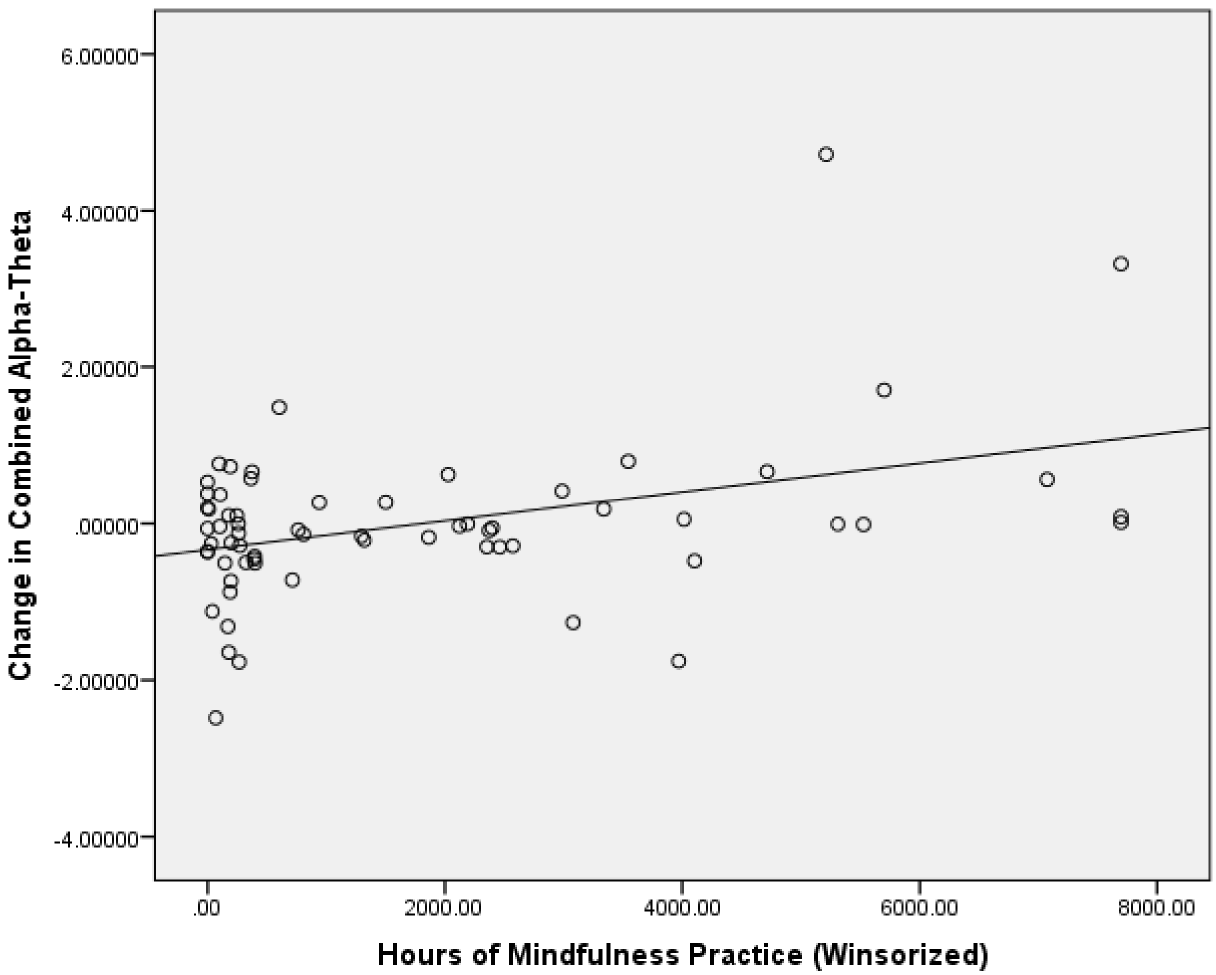
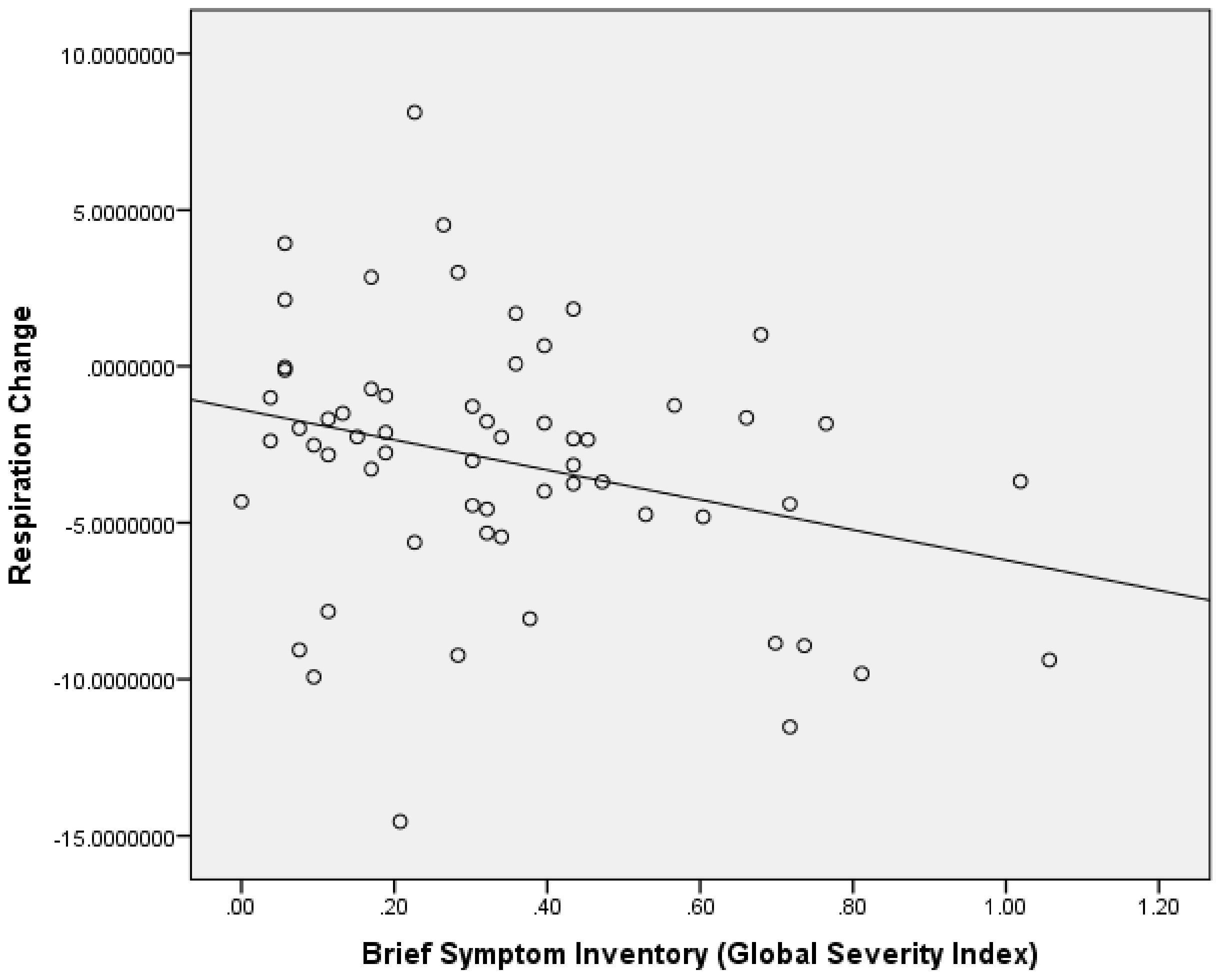


Figure 2: Respiration Change and Brief Symptom Inventory Score



Several of the variables of interest in this study were difference scores, rather than the scores either at baseline or during the meditation protocol. Analyses showing the respective associations between absolute scores for EEG and respiration are shown below in Tables 10 and 11.

Table 10: Combined-Sample Correlations of Baseline & Meditation EEG

	Theta baseline	Theta Meditation	Alpha Baseline	Alpha Meditation
Mindfulness Hours	r = .245 p = .055	r = .367 p = .003	r = .102 p = .429	r = .220 p = .085

N = 69

Table 11: Combined-Sample Correlations of BSI and Respiration

	Baseline Respiration	Meditation Respiration
Brief Symptom Inventory	r = .056 p - .661	r = -.184 p = .148

N = 69

DISCUSSION

The goal of this study was to investigate whether self-report and physiological markers of meditation might cluster together and indicate possible measures of skill at MM. While this study is one of only a small number in this field of research and therefore cannot make definitive conclusions about skill or how it may be measured, it is likely that skill at meditation would need to be measured multidimensionally, because numerous skills associated with meditation have been described. For instance, focusing one's attention is one skill of mindfulness meditation, whereas open monitoring is likely a separate skill (Lutz, Slagter., Dunne, & Davidson, 2008). Other skills, such as relaxation (Jacobs & Friedman, 2004), self-transcendence (Travis & Shear, 2010), insight (Mehrmann & Karmacharya, 2013) and the ill-defined notion of "enlightenment" (Davis & Vago, 2013) have also been proposed. While replication and further research are necessary before conclusions can be drawn about how to interpret the two factors found in this study, it is possible that these two factors may be associated with two distinct skills developed during practice.

State Alpha-Theta Increase during Meditation Predicts Hours of Mindfulness Practice

This study replicates previous findings that meditation practice is associated with a state increase in both alpha and theta power across the scalp during meditation, and these findings go beyond previous research in that this study contains one of the largest subject pools researched. Perhaps more importantly, this study showed that an increase in alpha and theta power is associated specifically with mindfulness meditation; it was unrelated to the practice non-mindfulness forms of meditation in this sample. While a discussion of what, if any, meditative skill this factor may be associated with is purely speculative, there are several reasons to suspect that this factor may measure a lower-order skill of meditation, such as relaxation.

First, as discussed earlier, increases in alpha and/or theta power across the scalp have been found across a wide variety of meditation techniques. Different meditation techniques focus on different skills, but likely relaxation is a state common to all meditative techniques. Second, the fact that the meditation period in this study was only six minutes long may not have allowed participants enough time enter sufficiently deeply into the meditative state such that markers associated with higher-order skills at meditation to become apparent. For instance, this study found no relationship between gamma power and other putative markers of meditation, even though this association has been reported in a fairly similar group of meditators engaged in a fairly similar protocol, where recordings were made from minutes 21 through 27 of a mindfulness meditation session (Cahn, Delmorme, & Polich, 2010). It is possible that gamma may be associated with a higher-order skill or process in mindfulness meditation that exhibits itself following more time devoted to cultivating the meditative state, and consequently this change in high-frequency EEG was not observed in this sample but the change in low-frequency EEG was observed.

The research literature on the effects of deliberately inducing alpha/theta frequencies across the scalp using biofeedback demonstrates that these frequencies are generally associated with positive outcomes, but this body of research is small and tends to suffer from low numbers of participants in studies. In an uncontrolled study of people suffering from alcoholism, Saxton and Peniston (1995) found that inducing alpha/theta frequencies led to a decrease in scores on the Beck Depression Inventory, as well as improvement on a number of scales on a personality inventory; similar results were also found in a small randomized-control trial of American veterans of the Vietnam war suffering from PTSD (Peniston & Kulkosky, 1991). Moore (2000) found these rhythms to be associated with decreased anxiety disorder symptoms. It has also been reported that induced alpha-theta rhythms are associated with participants reporting feeling energetic, agreeable, and confident (Raymond, Varney, Parkinson, & Gruzelier, 2005), as well as with increases in subjective wellbeing and enhanced performance on a test of flexibility in thinking (Boynton, 2001). It is difficult to determine from this literature what particular mental states or skills may be associated with alpha-theta frequencies across much of the scalp, although relaxation would be a candidate for a mental process leading to improvements across such a wide range of variables.

Another possibility is that alpha-theta change represents one's ability to turn attention towards internal processes and away from external stimuli. While alpha power throughout most of the cortex has been associated with "cortical idling" (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003), it has been reported that induced frontal alpha frequencies are associated with internally directed attention (Cooper, Burgess, Croft, & Gruzelier, 2006; Cooper et al., 2003; Ward, 2003). Travis and Shear (2010) report that the same has been found for theta power, although the evidence they cite in support of this claim involves hippocampal recordings from rabbits, making it unclear whether this relates to the present findings. Alpha-theta may therefore also be indicative of one's attention turning inwards, and the ability to turn the attention inwards would be indicative of a skill developed in a number of different techniques of meditation.

Delta power is a hallmark of deep sleep (e.g. Iber, Ancoli-Israel, Cheeson, & Quan, 2007) and has been reported to be associated with drowsiness during mindfulness meditation (Cahn, Delorme, & Polich, 2010). The fact that increases in alpha and theta are in some regions associated with decreases in delta likely also provides support for the notion that alpha and theta are measuring some dimension of meditation proficiency, as Cahn and colleagues reported that those with more daily hours of current meditation practice were less likely to experience drowsiness during meditation, and a decrease in drowsiness, both historically and in the research literature, has been considered a benefit of meditation (Britton, Lindahl, Cahn, Davis, & Goldman, 2014).

Respiratory Change in Meditation Predicts BSI

As hypothesized, respiration rate did decrease during meditation. However, the finding that greater decrease in respiration rate was associated with higher BSI scores, and higher BSI scores are associated with lower MAAS scores, is the opposite of what was expected. However, the hypothesis that greater decrease in breathing would be associated with markers of increased meditation proficiency came from Lazar (2005), who found that the change in respiration rate was strongly associated with self-reported hours of practice, not with self-report inventories. Lazar wrote in a personal communication to this study's author that the difference in findings may be due to the fact that the MM practitioners in her sample were advanced and homogeneous in their practice, whereas both practice amount and type of meditation practiced were far more diverse in the current sample.

Overall BSI scores (as measured by the Global Severity Index of the BSI, which is the average score per item) were likely lower in this sample than in the general population, as was expected in a population of meditators (Jain et al., 2007). The mean score in this sample was 0.345, while a community sample of British participants scored an average of 0.44 and a British outpatient clinical sample scored a mean of 1.65 (Ryan, 2007). A mean of .30 was found in an American community sample (Derogatis & Melisaratos, 1983), but as this study is more than a generation old, the British sample may be more reflective of current norms. In addition to findings that MM practice is associated with decreased scores on the BSI, it has been reported numerous times that meditation is associated with a decrease in psychological distress (Goyal et al., 2014; Ospina et al., 2007), and this finding can therefore be interpreted as evidence supporting the relationship between respiratory change and meditation. However, it should be cautioned that a very large number of variables have been reported to be associated with decreased psychological distress, so it cannot be assumed that this is specific to meditation. The association with the MAAS also suggests that Factor 2 may be measuring meditation, but as it is not clear that the MAAS truly measures mindfulness rather than some other construct related to wellbeing (Grossman, 2014), this conclusion remains tenuous. Because this factor is not directly related to meditation practice but rather to a number of constructs that themselves are only probably related to meditation, it is particularly important to view this factor cautiously. Because of the unclear nature of this factor, it is likely premature to speculate on with which particular skill in meditation this factor may possibly correlate; this question will be best addressed by future research using this factor as a predictor.

Future Directions

While this study does provide correlational and factor analytical data among a number of possible correlates of meditation skill, it is important to note that these data are purely correlational; it has not yet been investigated whether these factors may predict some other measure of skill. Likely the historical "gold standard" of meditation skill is a teacher's report on his/her students' practice, since a number of different systems of meditation have a trajectory through which practitioners pass as their skill improves, and one of the teacher's main roles is to guide students along these trajectories (for examples, see Culadasa, Immergut, & Graves, in press; Sayadaw, 1998; Thrangu, 2002). The author therefore is planning a follow-up study in which a group of meditators who all have the same teacher will come into the lab for assessment, and Factors 1 and 2 will be independently used to sort participants into two different rank-ordered lists. The meditation teacher will also rank the students on as many dimensions of meditation skill as he thinks appropriate. It will then be seen whether Factors 1 and 2 can be used to predict any of the meditation teacher's lists, as well as which lists it predicts.

Additionally, it will be important to assess whether using Factors 1 and 2 can predict similar outcomes to other ways of measuring meditation. It was found in the data from Phase 1 of this study (Peck, Lester, Lasky, & Bootzin, 2011), as well as elsewhere (Britton, Haynes, Fridel, & Bootzin, 2010), that meditation practice was associated with improved sleep when measured by self-report, but when sleep was objectively measured using polysomnography, meditation was associated with sleep patterns that appeared more aroused and are often associated with subjective reports that sleep was unsatisfactory or non-restorative. Therefore the author also plans to assess whether using Factors 1 or 2, a similar pattern can be found between meditation and sleep.

Appendix A

Meditation Hours Log

Attached is a four-column form that will be used to approximate how many hours of meditation you have done over the course of your lifetime. In the left column, labeled "period of time," you may use any periods you think best. For instance, you could start with 1996 – 1999, followed by January – April 2000, followed by May 1 – 8, 2000, followed by May 9, 2000 – 2007. In the second column, write the type of meditation you practiced in that period. You may use either English names (e.g. mindfulness) or Eastern names (e.g. Shamatha). In the third column, please write how many hours of meditation you practiced, measured either in days or weeks, and circle "h" or "m" to designate whether you are measuring time in hours or minutes. In the fourth column, please specify whether you are measuring your meditation for each time period in days or in weeks. Below is a sample chart:

Period of time	Meditation style practiced		Per
1996 – 1999	Mindfulness	45 h/m	Day / Week
Jan – Apr 2000	Mindfulness	25 h/m	Day / Week
May 1 – 8, 2000	Transcendental Med.	12 h/m	Day / Week
May 9, 2000 – 2007	Shamatha	30 h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week

Period of time	Meditation style practiced	Hours	Per
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week
		h/m	Day / Week

Appendix B

Meditation Practice Styles

Since__________ _______ ___________

Instructions: Please take a moment to indicate your typical meditation practice in the last 12 months. Your complete and honest answers are very important to us, so take your time!

Meditation Type	**Approximate frequency** (# of times per day, week or month)	**Approximate duration of each session** (minutes)	**Do you use a tape?**(Yes, no, sometimes)	**Comments**
Focused Awareness: Awareness of breath only (or other object)				
Open monitoring/presence "choiceless awareness" (awareness of whatever arises…breath, body, thought, sounds etc without selection)				
Body Scan				
Walking Meditation				
Yoga/Mindful Movement				
Working with thoughts ("image vs talk")				
Working with Emotions ("touch vs feel")				
Forgiveness Loving Kindness (Metta)				

Compassion (Karuna) Tonglen				
"Mountain", "Lake" or other visualization practice				

3. Have you been practicing any other kind of meditation that was not listed above? If yes, please describe and indicate frequency, duration and tape use:

4. Which teachers/traditions have you practiced or studied? Circle all that apply.

MBSR/MBCT: Jon Kabat-Zinn, Saki Santorelli

American Insight/Vipassana: Joseph Goldstein, Sharon Salzburg, Jack Kornfield, Eric Kolvig, Anna Douglass (IMS/Spirit Rock)

Eclectic/Other: Shinzen Young

Tibetan Buddhism: Anne Klein; Alan Wallace; Greg Bender/Lama Palden; Pema Chodron; His Holines the Dalai Lama

Asian Vipassana/Insight: S.N. Goenka; Thich Nhat Hanh; Upasaka Culadasa

Zen: Joan Halifax

OTHER, Please describe:

5. **Retreats:** teacher/ tradition (if known) location and duration in last 5 years

Appendix C: Meditation Instructions

1.) As much as possible, please enter your normal meditation pose. You may use the chair, or you may also sit on the pillows on the floor, if you prefer. Please close your eyes.

2.) For the next few minutes, please keep your meditation posture but try **not** to meditate. Allow your attention to wander without any special focus on an object. <6 minutes>

3.) Now for the next few minutes, please meditate as you normally do. We will ring the bell to signal the beginning of meditation, and we'll ring it again to signal the end of meditation. <RING BELL>.

4.) <Bell rung after 12 minutes>

References

Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: High-resolution EEG investigation of meditation. *Neuroscience Letters, 310*, 57–60.

Baer, R.A., Smith, G.T., Hopkins, J., Krietemeyer, J., & Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. *Assessment, 13*(1), 27 – 45.

Baer, R.A., Smith, G.T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S. … Williams, J.M.G. (2008). Construct validity of the five facet mindfulness questionnaire in meditating and nonmeditating samples. *Assessment, 15*(3), 329-342.

Baijal, S., & Srinivasan, N. (2010). Theta activity and meditative states: spectral changes during concentrative meditation. *Cognitive Processing, 11*(1), 31-38.

Barnes, P.M., Bloom, B., & Nahin, R. (2008). Complementary and alternative medicine use among adults and children: United States, 2007. *CDC National Health Statistics Report #12*.

Barnes, V.A., Davis, H.C., Murzynowski, J.B., & Treiber, F.A. (2004). Impact of meditation on resting and ambulatory blood pressure and heart rate in youth. *Psychosomatic Medicine, 66,* 909-914.

Beck, A. T., & Beck, R. W. (1972). Screening depressed patients in family practice: A rapid technic. *Postgraduate Medicine, 52*(6), 81-85.

Beck, A.T., Epstein, N., Brown, G., Steer, R.A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology, 56*(6), 893-897.

Beck, J. (1995). *Cognitive therapy: Basics and beyond*. New York & London: The Guilford Press.

Bishop, S.R., Lau, M., Shapiro, S., Carlson, L., Anderson, N.D., Carmody, J., et al. (2004). Mindfulness: A proposed operational definition. *Clinical Psychology: Science and Practice, 11*, 230-241.

Bodhi, Bhikku. (2011). What does mindfulness really mean? A canonical perspective. *Contemporary Buddhism, 12*(1), 19-39.

Boulet, J., & Boss, M.W. (1991). Reliability and validity of the brief symptom inventory. *Psychological Assessment: A Journal of Consulting and Clinical Psychology, 3*(3), 433-437.

Boynton, T. (2001). Applied research using alpha/theta training for enhancing creativity and well-being. *Journal of Neurotherapy, 5*(1-2), 5-18.

Brefczynski-Lewis, J. A., Lutz, A., Schaefer, H. S., Levinson, D. B., & Davidson, R. J. (2007). Neural correlates of attentional expertise in long-term meditation practitioners. *Proceedings of the national Academy of Sciences, 104*, 11483-11488.

Britton, W. B., Haynes, P. L., Fridel, K. W., & Bootzin, R. R. (2010). Polysomnographic and subjective profiles of sleep continuity before and after mindfulness-based cognitive therapy in partially remitted depression. *Psychosomatic Medicine, 72*(6), 539-548.

Britton, W. B., Lindahl, J. R., Cahn, B. R., Davis, J. H., & Goldman, R. E. (2014). Awakening is not a metaphor: the effects of Buddhist meditation practices on basic wakefulness. *Annals of the New York Academy of Sciences, 1307*(1), 64-81. Psychosomatic Medicine, 72(6), 539-548.

Brown, K.W, & Ryan, R.M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology, 84*(4), 822-848.

Cacot, P., Tesolin, B., & Sebban, C. (1995). Diurnal variations of EEG power in healthy adults. *Electroencephalography and Clinical Neurophysiology, 94*(5), 305-312.

Cahn, B. R., Delorme, A., & Polich, J. (2010). Occipital gamma activation during Vipassana meditation. *Cognitive Processing, 11*(1), 39-56.

Cahn, B. R., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin, 132*(2), 180.

Cardoso, R., de Souza, E., Camano, L., & Leite, J.R. (2004). Meditation in health: An operational definition. *Brain Research Protocols, 14*(1), 58-60.

Chan, A.S., Han, Y.M.V, & Cheung, M. (2008). Electroencephalographic (EEG) measurements of mindfulness-based triarchic body-pathway relaxation technique: A pilot study. *Applied Psychophysiology and Biofeedback, 33,* 39-47.

Chiesa, A., & Serretti, A. (2010). A systematic review of neurobiological and clinical features of mindfulness meditations. *Psychological Medicine, 40*(8), 1239-1252.

Cohen-Katz, J., Wiley, S. D., Capuano, T., Baker, D. M., & Shapiro, S. (2005). The effects of mindfulness-based stress reduction on nurse stress and burnout, Part II: A quantitative and qualitative study. *Holistic Nursing Practice, 19*(1), 26-35.

Cooper, N. R., Burgess, A. P., Croft, R. J., & Gruzelier, J. H. (2006). Investigating evoked and induced electroencephalogram activity in task-related alpha power increases during an internally directed attention task. *Neuroreport*, 17(2), 205-208.

Cooper, N. R., Croft, R. J., Dominey, S. J., Burgess, A. P., & Gruzelier, J. H. (2003). Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *International Journal of Psychophysiology, 47*(1), 65-74.

Corby, J. C., Roth, W. T., Zarcone, V. P., Jr., & Kopell, B. S. (1978). Psychophysiological correlates of the practice of tantric yoga meditation. *Archives of General Psychiatry, 35*, 571–577.

Culadasa, U., Immergut, M., & Graves, J. (In press). *Mastering meditation.* Tucson, AZ: Dharma Treasure Press.

Davis, J. H., & Vago, D. R. (2013). Can enlightenment be traced to specific neural correlates, cognition, or behavior? No, and (a qualified) Yes. *Frontiers in Psychology*, 4.

Derogatis, L. R., & Melisaratos, N. (1983). The Brief Symptom Inventory: An introductory report. *Psychological medicine, 3,* 595-605.

Egner, T., Strawson, E., & Gruzelier, J. H. (2002). EEG signature and phenomenology of alpha/theta neurofeedback training versus mock feedback. *Applied Psychophysiology and Biofeedback*, 27(4), 261-270.

Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: Evidence from temporal-spatial PCA. *Psychophysiology, 46*(3), 521-530.

Ghista, D. N., Nandagopal, D., Ramamurthi, B., Das, A., Mukherji, A., & Srinivasan, T. M. (1976). Physiological characterisation of the 'meditative state'during intuitional practice (the Ananda Marga system of mediation) and its therapeutic value. *Medical and Biological Engineering, 14*(2), 209-214.

Goenka, S.N. (2000). *The discourse summaries: Talks from a ten-day course in vipassana meditation*. Pariyatti Publishing.

Goyal, M., Singh, S., Sibinga, E. M., Gould, N. F., Rowland-Seymour, A., Sharma, R., ... & Haythornthwaite, J. A. (2014). Meditation programs for psychological stress and well-being: A systematic review and meta-analysis. *JAMA Internal Medicine*.

Grossman, P. (2014, Apr. 4). *Ethics, obstacles and commodification in mindfulness practice, training and science.* Presented at the Center for Mindfulness 12th Annual Scientific Conference, Dedham, MA.

Hebert, R., & Lehmann, D. (1977). Theta bursts: An EEG pattern in normal subjects practising the transcendental meditation technique. *Electroencephalography and Clinical Neurophysiology, 42*(3), 397-405.

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience letters, 421*(1), 16-21.

Iber, C., Ancoli-Israel, S., Cheeson, & Quan, S.F. (2007). *The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications, 1st ed*. Westchester, Illinois: American Academy of Sleep Medicine.

Ivanovski, B., & Malhi, G. S. (2007). The psychological and neurophysiological concomitants of mindfulness forms of meditation. *Acta Neuropsychiatrica, 19*(2), 76-91.

Jacobs, G. D., & Friedman, R. (2004). EEG spectral analysis of relaxation techniques. *Applied psychophysiology and biofeedback, 29*(4), 245-254.

Jain, S., Shapiro, S. L., Swanick, S., Roesch, S. C., Mills, P. J., Bell, I., & Schwartz, G. E. (2007). A randomized controlled trial of mindfulness meditation versus relaxation training: Effects on distress, positive states of mind, rumination, and distraction. *Annals of Behavioral Medicine, 33*(1), 11-21.

Jasper, H.H. (1958). The ten-twenty electrode system of the International

Federation. *Electroencephaolgraphy and Clinical Neurophysiology, 10*(2), 371-375.

Kabat-Zinn, J. (1990). *Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness***.** Delta Publishing.

Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice, 10*(2), 144-156.

Kasamatsu, A., & Hirai, T. (1966). An electroencephalographic study on the Zen meditation (Zazen). *Psychiatry and Clinical Neurosciences, 20*(4), 315-336.

Khare, K. C., & Nigam, S. K. (2000). A study of electroencephalogram in mediators. *Indian Journal of Physiology and Pharmacology, 44*(2), 173-178.

Lagopoulos, J., Xu, J., Rasmussen, I., Vik, A., Malhi, G. S., Eliassen, C. F., ... & Ellingsen, Ø. (2009). Increased theta and alpha EEG activity during nondirective meditation. *The Journal of Alternative and Complementary Medicine, 15*(11), 1187-1192.

Lazar, S.W., Kerr, C.E., Wasserman, R.H., Gray, J.R., Greve, D.N., Treadway, M.T., … Fischl, B. (2005). Meditation experience is associated with increased cortical thickness. *Neuroreport, 16*(17), 1893-1897.

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences, 12*(4), 163-169.

Maharishi Mahesh Yogi. (1969) *On the* Bhagavad Gita. Baltimore: Penguin.

Maharishi Mahesh Yogi. (2001). *Science of being and art of living: Transcendental meditation*. Plume Publishing.

Mehrmann, C., & Karmacharya, R. (2013). Principles and neurobiological correlates of concentrative, diffuse, and insight meditation. *Harvard Review of Psychiatry, 21*(4), 205-218.

Moore, N. C. (2000). A review of EEG biofeedback treatment of anxiety disorders. *Clinical EEG (Electroencephalography)*, 31(1), 1-6.

Murata, T., Koshino, Y., Omori, M., Murata, I., Nishio, M., Sakamoto, K., ... & Isaki, K. (1994). Quantitative EEG study on Zen meditation (zaZen). *Psychiatry and Clinical Neurosciences, 48*(4), 881-890.

Ospina, M.B., Bond, T.K., Karkhaneh, M., Tjosvold, L., Vandermeer, B., Liang, Y. … Klassen, T.P. (2007). *Meditation practices for health: State of the research.* Rockville, MD: Agency for Healthcare Research and Quality.

Peck, T. (2010). The effects of mindfulness meditation on sleep duration and EEG. Unpublished masters thesis.

Peck, T., Lester, A., Lasky, R., & Bootzin, R.R. (2011). Multi-component measures of mindfulness meditation skill and their effects on sleep. Poster presented at the Mind and Life Summer Research Institute, Garrison, NY.

Peng, C.K., Henry, I.C., Mietus, J.E., Hausdorff, J.M., Khalsa, G., Benson, H., & Goldberger, A.L. (2004). Heart rate dynamics during three forms of meditation. *International Journal of Cardiology, 95*, 19-27.

Peniston, E. G., & Kulkosky, P. J. (1991). Alpha-theta brainwave neurofeedback for Vietnam veterans with combat-related post-traumatic stress disorder. *Medical Psychotherapy, 4*(1), 47-60.

Pickert, K. (2014, Feb 4). The mindful revolution. *Time Magazine,* cover.

Raymond, J., Varney, C., Parkinson, L. A., & Gruzelier, J. H. (2005). The effects of alpha/theta neurofeedback on personality and mood. *Cognitive Brain Research, 23*(2), 287-292.

Ryan, C. (2007). British outpatient norms for the Brief Symptom Inventory. *Psychology and Psychotherapy: Theory, Research and Practice, 80*(2), 183-191.

Salzberg, S. (2002). *Lovingkindness: The revolutionary art of happiness.* Boston, MA: Shambhala.

Saxton, E.S., & Peniston, E. G. (1995). Alpha-theta brainwave neurofeedback training: An effective treatment for male and female alcoholics with depressive symptoms. *Journal of Clinical Psychology,* 51(5).

Sayadaw, Mahasi. (1998). *Progress of insight: Treatise on Buddhist satipathana meditation.* Sri Lanka: Buddhist Publication Society of Sri Lanka.

Schönbrodt, F. D., & Perugini, M. (2013). At what sample size do correlations stabilize? *Journal of Research in Personality, 47*, 609-612

Segal, Z.V., Williams, J.M.G., & Teasdale, J.. (2002). *Mindfulness-based cognitive therapy for depression: A new approach to preventing relapse*. Guilford Press.

Takahashi, T., Murata, T., Hamada, T., Omori, M., Kosaka, H., & Kikuchi, M., … Wada, Y. (2005). Changes in EEG and autonomic nervous activity during meditation and their association with personality traits. *International Journal of Psychophysiology, 55*(2), 199-207.

Teasdale, J. D., Segal, Z. V., Williams, J. M. G., Ridgeway, V. A., Soulsby, J. M., & Lau, M. A. (2000). Prevention of relapse/recurrence in major depression by mindfulness-based cognitive therapy. *Journal of Consulting and Clinical Psychology, 68*(4), 615.

Thrangu, K. (2002). *Essential practice: Lectures on Kamalashila's stages of meditation in the middle way school*. (J.B. Levinson, trans.). Snow Lion.

Travis, F., & Shear, J. (2010). Focused attention, open monitoring and automatic self-transcending: Categories to organize meditations from Vedic, Buddhist and Chinese traditions. *Consciousness and Cognition, 19*(4), 1110-1118.

Ward, L. M. (2003). Synchronous neural oscillations and cognitive processes. *Trends in Cognitive Sciences, 7*(12), 553-559.

Williams, P., & West, M. (1975). EEG responses to photic stimulation in persons experienced at meditation. *Electroencephalography and Clinical Neurophysiology, 39*(5), 519-522.