

THE ROLE OF MINDFULNESS AND SELF-COMPASSION IN THE NEURAL
MECHANISMS OF ATTENTION AND SELF-MONITORING

by

IDA MOADAB

A DISSERTATION

Presented to the Department of Psychology
and the Graduate School at the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

September 2013

DISSERTATION APPROVAL PAGE

Student: Ida Moadab

Title: The Role of Mindfulness and Self-Compassion in the Neural Mechanisms of Attention and Self-Monitoring

This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Psychology by:

Dr. Don Tucker	Chair
Dr. Phil Fisher	Member
Dr. Elliot Berkman	Member
Dr. Marjorie Woollacott	Outside Member

and

Kimberly Andrews Espy	Vice President for Research & Innovation/Dean of the Graduate School
-----------------------	--

Original approval signatures are on file with the University of Oregon Graduate School.

Degree awarded September 2013

© 2013 Ida Moadab

DISSERTATION ABSTRACT

Ida Moadab

Doctor of Philosophy

Department of Psychology

September 2013

Title: The Role of Mindfulness and Self-Compassion in the Neural Mechanisms of Attention and Self-Monitoring

The present study sought to investigate the effects of meditation practice on the neural mechanisms of attention and self-monitoring by comparing a group of experienced meditators to matched controls. Self-report measures of mindfulness and self-compassion were assessed to examine whether meditation-related improvements in attention and self-monitoring were linked to increases in these qualities. Thus, differences between groups (meditator versus control) on all variables and relationships among variables (attention, self-monitoring, self-compassion, and mindfulness) were explored. Results indicate that individuals with meditation experience showed enhancement in neural networks related to selective attention and attentional allocation, as evidenced by larger P1/N1 and P3b amplitudes, relative to controls. Meditators also showed improved self-monitoring of their errors, as indexed by enhanced Pe amplitudes, when compared to controls. Importantly, greater number of years of meditation experience was linked to larger Pe amplitudes, providing evidence that more practice with meditation was associated with greater error awareness. At the same time, meditators showed greater levels of mindfulness and self-compassion when compared to controls. Importantly, each of the neural indices was linked to greater levels of mindfulness and self-compassion.

Specifically, self-kindness was correlated with each of these ERP components and to percentage of alpha power during meditation, and the mindfulness facet of ‘observing’ fully mediated the relationship between meditation experience and P1 amplitudes. These findings suggest that the qualities that are enhanced with meditation are associated with enhancements in attentional control and awareness of errors. This study is an exciting step toward future intervention studies that combine multiple sources of information (self-report, neural measures, and behavior) to clarify the nature of the associations among these variables so that the mechanisms of mindfulness can be more fully understood.

CURRICULUM VITAE

NAME OF AUTHOR: Ida Moadab

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
University of California, San Diego

DEGREES AWARDED:

Doctor of Philosophy, Clinical Psychology, University of Oregon, 2013
Master of Science, Psychology, University of Oregon, 2008
Bachelor of Arts, Psychology, University of California, San Diego, 2004

AREAS OF SPECIAL INTEREST:

Meditation and Mindfulness
Self-Regulation and Emotion Regulation
Electrophysiology
Neuropsychology

PROFESSIONAL EXPERIENCE:

Clinical Psychology Intern, VA Puget Sound, American Lake Division, August
2012 – August 2013
Clinician, Direction Service Counseling Center, July 2010 – May 2012
Clinical Assessor, Private Neuropsychology Practice, April 2011 – April 2012
Clinical Assessor, OHSU Child Development and Rehabilitation Center,
September 2010 – March 2011
Instructor, Department of Psychology, University of Oregon, July 2008, July
2009, July 2010, and July 2011
Human Subjects Coordinator, Department of Psychology, University of Oregon,
September 2009 – June 2012
Clinician, University of Oregon Child and Family Center, September 2008 – June
2009
Clinician, University of Oregon Psychology Clinic, September 2007 – June 2010
Graduate Teaching Assistant, Department of Psychology, University of Oregon,
September 2006-June 2007
Project Coordinator, Genetics of Adolescent Drug Dependence, University of
California, San Diego, 2004-2006
Mental Health Worker, Sharp Mesa Vista Psychiatric Hospital, San Diego, CA,
2001 – 2006

GRANTS, AWARDS, AND HONORS:

Psychology Department Research Award, University of Oregon, 2011
Clarence and Lucille Dunbar Scholarship, University of Oregon, 2010-2011
Development, Etiology, Ecology, and Psychopathology (DEEP) Training Grant,
University of Oregon, 2007-2009
Graduate School Fighting Funds Fellowship, University of Oregon, 2006-2007
Phi Beta Kappa Honors Society, 2004
Magma Summa Cum Laude with High Honors in Psychology, 2004
Undergraduate Research Scholarship, University of California, San Diego, 2003
Regents Scholarship, University of California, San Diego, 2000-2004

PUBLICATIONS:

- Moadab, I., & Tucker, D. M. (in press). *Learning mechanisms of depression*. In *The Encyclopedia of the Sciences of Learning*. Springer.
- Moadab, I., Gilbert, T., Dishion, T. J., & Tucker, D. M. (2010). Frontolimbic activity in a frustrating task: Covariation between patterns of coping and individual differences in externalizing and internalizing symptoms. *Development and Psychopathology, 22*, 391-404.
- Lewis, M. D., Granic, I., Lamm, C., Zelazo, P. D., Stieben, J., Todd, R. M., Moadab, I., & Pepler, D. (2008). Changes in the neural bases of emotion regulation associated with clinical improvement in children with behavior problems (2008). *Development and Psychopathology, 20*, 913-939.
- Anderson, K. G., Tapert, S. F., Moadab, I., Crowley, T. J., & Brown, S. A. (2007). Personality risk profile for conduct disorder and substance use disorders in youth. *Addictive Behaviors, 32*, 2377-2382.
- Nagel, B. J., Medina, K. L., Yoshii, J., Schweinsburg, A. D., Moadab, I., & Tapert, S. F. (2006). Age-related changes in prefrontal white matter volume across adolescence. *Neuroreport, 17*, 1427-1431.

ACKNOWLEDGMENTS

I am sincerely grateful to many people who provided guidance and encouragement throughout my graduate education at the University of Oregon. First, I would like to thank my advisor, Don Tucker, for his mentorship, patience, and big picture approach to science. I am grateful to Phil Fisher for inspiring me to always think about the translational implications of my research. I would like to thank Elliot Berkman for providing statistical feedback and neuroimaging expertise on this and other projects. I am also thankful for the direction offered by Marjorie Woollacott at multiple points in the development of this project.

I am indebted to a number of people at EGI and in the Brain Electrophysiology Lab who were involved in the development, data collection, and analysis phases of this study. Thanks to Colin Davey for his help with coding the stimulus presentation and troubleshooting. I would especially like to thank Barbara Novak, the undergraduate assistant who went above and beyond in giving her time and effort to data collection. I am grateful to both Phan Luu and Cathy Poulsen for leaving their doors open for my data analysis questions. Lastly, the mental and project support provided by labmates Allison Waters and Joey Nelson was tremendous, and I am sincerely appreciative.

I would also like to thank my clinical supervisors for inspiring me daily to be a better clinician. I am grateful for Ryann Watson-Stites, whose intelligence and poise motivate me daily. I am appreciative to David Northway for his generosity in providing me with training in neuropsychological assessment. I am indebted to Jay Buckley for modeling humor, compassion, and joy in his approach to psychotherapy and supervision.

I am so grateful to the support provided by my family and friends. I am indebted to my parents, who taught me to be curious, compassionate, and stubborn in all my endeavors, all of which were essential for completing my graduate degree. Thanks to both Cara Bohon and Erica Musser for their numerous supportive gchats. Thanks to Eddie Ester for patiently imparting attention based knowledge for this paper. I am grateful to Amber and Erich Thalamayer for their consistent friendship, generosity, and overall wonderfulness. Lastly, I would like to thank Gabriel Yospin for his steadfast effort to put a smile on my face even when confronted with tremendous obstacles.

TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION	1
Overview.....	1
What Is Mindfulness?	2
Meditation Practice	2
Mindfulness Facets	3
Self-Compassion.....	5
Mindfulness and Self-Compassion: Relationship with Attention.....	8
Effects of Meditation on Attention	9
How Is Attention Being Altered?	12
Evidence From the Neuroimaging Literature	14
Self-Compassion and Self-Monitoring.....	16
Neural Mechanisms of Attention and Self-Monitoring	18
Present Study	18
Event-Related Potentials (ERPs)	18
Selective Attention: P1/N1	19
Attention Allocation: P3b	20
Self-Monitoring: ERN, Pe, and FRN	22
Spectral Analysis	25
Design and Hypotheses.....	27
Attention Hypotheses.....	29
Self-Monitoring Hypotheses.....	29
Spectral Analyses.....	30
Source Analyses.....	30
II. METHODS	31
Participants.....	31

Chapter	Page
Stimulus and Procedure	32
Meditation/Relaxation Manipulation	34
Measures	35
EEG Data Acquisition and Analysis.....	37
ERP Coding	37
Spectral Analysis	38
Source Analysis	39
III. RESULTS	41
Self-Report Questionnaires.....	41
Behavioral Analysis	44
Accuracy	44
Reaction Time.....	45
ERP Analysis	46
Response-Locked ERPs.....	46
Error-Related Negativity (ERN).....	47
Error-Positivity (Pe).....	48
Feedback-Locked ERP.....	51
Stimulus-Locked ERPs.....	54
P1 Component.....	55
N1 Component.....	58
P1/N1 Complex.....	61
P3b Component.....	63
Relationship among ERP Components.....	65
Spectral Analysis	66
Length of Experience with Meditation	67
Source Analysis	68
P1 Timepoint (123 ms Post-Stimulus Onset)	68
N1 Timepoint (194 ms Post-Stimulus Onset).....	70
P3b Timepoint (437 ms Post-Stimulus Onset)	71

Chapter	Page
Pe Timepoint (259 ms Post-Response).....	72
ERN Timepoint (59 ms Post-Response).....	73
IV. DISCUSSION.....	74
Mindfulness and Self-Compassion.....	74
Accuracy and Reaction Time.....	76
Attention.....	77
Self-Monitoring.....	83
Implications for Psychological Well-Being.....	87
Limitations and Future Directions.....	90
Summary and Conclusions.....	92
 APPENDICES	
A. GRAND AVERAGED ERP COMPONENTS ACROSS THE ENTIRE SCALP.....	94
B. MEDITATION AND RELAXATION INSTRUCTIONS.....	98
C. STUDY MEASURES.....	100
 REFERENCES CITED.....	 105

LIST OF FIGURES

Figure	Page
1. Channels Included in the Spectral Analysis.....	39
2. Topo-Map View at the ERN Timepoint and Channels Selected for ERN Analysis.....	47
3. Topo-Map View at the Pe Timepoint and Channels Selected for Pe Analysis.....	48
4. Error-Locked Waveforms Displayed Separately for Meditator and Control Participants	49
5. Mediation Model results Exploring the Mediating Roles of Self-Kindness and Nonreactivity on the Relationship Between Group and Pe_{diff}	51
6. Topo-Map View at the FRN Timepoint and Channels Selected for FRN Analysis.....	52
7. Negative Feedback-Locked Waveforms Separately for Meditator and Control Participants	53
8. Topo-Map View at the P1 Timepoint and Channels Selected for P1 Analysis.....	55
9. Stimulus-Locked ERP Waveform Separately for Right and Left Hemisphere and for Trial Type.....	56
10. Mediation Model Results Exploring the Mediating Role of Observe and Self-Kindness on the Relationship Between Group and P1 Amplitude	58
11. Topo-Map View at the N1 Timepoint and Channels Selected for N1 Analysis.....	59
12. Response-Locked Waveforms Separately for Block and Group	60
13. Stimulus-locked ERPs Separately for Meditator and Control Participants.....	62
14. Topo-Map View at the P3 Timepoint and Channels Selected for P3 Analysis.....	63
15. Stimulus-locked Waveforms Separately for Trial Type and Group	64
16. Percentage of Alpha Power Plotted with P1/N1 Amplitude.....	67

Figure	Page
17. Pe_{diff} Plotted by Years of Meditation Experience	68
18. Source Results at 123 ms Post-Stimulus Onset, the Timepoint of the P1 Peak.....	69
19. Source Results at 194 ms Post-Stimulus Onset, the Timepoint of the N1 Peak.....	70
20. Source Results at 437 ms Post-Stimulus Onset, the Timepoint of the P3 Peak.....	71
21. Source Results at 259 ms Post-Response, the Timepoint of the Pe Peak	72
22. Source Results at 59 ms Post-Response, the Timepoint of the ERN Peak	73

LIST OF TABLES

Table	Page
1. Gender, Age, and Educational Achievement for All Participants	31
2. Average of Meditation Practice in the Meditator Group	32
3. Correlations Among Factors off the Five Factor Mindfulness Questionnaire.....	41
4. Correlations Among Factors of the Self-Compassion Scale (SCS).....	42
5. Correlations between subscales of the FFMQ and SCS	42
6. Correlations Between the FFMQ and SCS with the Positive and Negative Affect Schedule and the Adult Temperament Questionnaire.....	43
7. Results Comparing Meditator and Control Participants on Self-Report Measures.....	44
8. Gender, Age, and Educational Achievement for Participants Included in Response-Locked Analyses.....	46
9. Gender, Age, and Educational Achievement for Participants Included in Feedback-Locked Analysis	52
10. Gender, Age, and Educational Achievement for Participants Included in Stimulus-Locked Analysis	54

CHAPTER I

INTRODUCTION

Overview

Mindfulness interventions have become widely used by the psychotherapeutic community to help individuals with a diverse array of psychological and health-related problems. Research has provided evidence for the efficacy of mindfulness interventions for treating a number of psychological disorders, including anxiety (Hofmann, Sawyer, Witt, & Oh, 2010; Goldin & Gross, 2010); Evans et al., 2008), depression (Teasdale et al., 2000; Kingston, Dooley, Bates, Lawlor, & Malone, 2007), and substance abuse (Bowen et al., 2006). Mindfulness has also been successfully used in the treatment of medical disorders such as chronic pain (Grossman, Tiefenthaler-Gilmer, Raysz, & Kesper, 2007), psoriasis (Kabat-Zinn et al., 1998), and improving mood in individuals with cancer (Specia, Carlson, Goodey, & Angen, 2000). Mindfulness-based interventions also improve wellbeing in healthy participants, decreasing negative affect (Chambers, Lo, & Allen, 2008), lowering psychological distress (Rosenzweig, Reibel, Greeson, Brainard, & Hojat, 2003), and increasing positive mood (Jain et al., 2007). While evidence that mindfulness practice improves psychological wellbeing is mounting, the mechanism by which mindfulness promotes emotional health is less well understood.

A number of researchers have investigated the effects of meditation on attention, and some evidence suggests that attentional changes may lead to improvements in psychological wellbeing (Chiesa, Calati, & Serretti, 2010). Few, however, provide evidence for *how* mindfulness practice improves attention. While the importance of

cultivating mindfulness and self-compassion during meditation may be discussed in these studies, investigations of these qualities with alterations in attention are rare. Thus, this study aims to expand the scientific study of meditation and attention by investigating the potential roles of self-reported mindfulness and self-compassion.

What Is Mindfulness?

Meditation Practice

Meditation practices are united as attempts to cultivate “moment by moment non-judgmental awareness” (Kabat-Zinn, 1990). The practice of meditation often takes the form of sitting meditation, which can be divided into focused-attention and open-monitoring approaches (Lutz, Slagter, Dunne, & Davidson, 2008). Focused-attention meditation involves focusing attention on an object, which is often the breath or a mantra. Open-monitoring meditation is a more advanced technique, and involves observation of the content of experience from moment to moment without any specific focus of attention. In addition to these sitting meditations, the most common mindfulness interventions, Mindfulness Based Stress Reduction (MBSR) and Mindfulness Based Cognitive Therapy (MBCT), provide instruction to more fully attend to and engage with seemingly mundane daily activities, like brushing teeth or doing dishes, in order to cultivate mindfulness in daily life (Williams, Teasdale, Kabat-Zinn & Segal, 2007). Importantly, across all practices, a nonjudgmental stance is emphasized. Awareness of distraction in focused-attention meditation and awareness of painful thoughts or emotions in open-monitoring meditation are given equal attention as awareness of focused moments and joyful feelings. Through training, it is postulated that practitioners are able to increase their capacity to experience all that encompasses the present moment –

including positive and negative thoughts, feelings, sensations, and interactions with the world – with awareness, objectivity, and self-compassion (Chambers, Gullone, & Allen, 2009).

Through this nonjudgmental attitude, the practice of mindfulness may bring a shift in the quality of awareness. The practice of attending to all experiences without elaboration or judgment cultivates the capacity to experience mental phenomena (including thoughts, feelings, and reactions) objectively, without engaging in them, judging oneself or others, or overly identifying with their content (Shapiro, Carlson, Astin, & Freedman, 2006). Attention is kept “at the bare registering of the facts observed” for both internal phenomena and external events (Brown, Ryan, & Creswell, 2007). This may result in enhanced acceptance for all of one’s experiences, facilitating healthy engagement with emotions, decreasing avoidance, and increasing cognitive and behavioral flexibility (Brown, Ryan & Creswell, 2007). Individuals shift from seeking positive experiences and avoiding negative events to emphasizing the observation and acceptance of all events regardless of valence and intensity (Chambers, Gullone, & Allen, 2009).

Mindfulness Facets

A number of research groups have attempted to measure this shift in awareness by identifying facets of mindfulness using self-report methods (Mindful Attention Awareness Scale: Brown & Ryan, 2003; Freiburg Mindfulness Inventory: Buchheld, Grossman, & Walach, 2001; Kentucky Inventory of Mindfulness Skills: Baer, Smith & Allen, 2004; Cognitive and Affective Mindfulness Scale: Hayes & Feldman, 2004; Mindfulness Questionnaire: Chadwick, Hember, Mead, Lilley, & Dagnan, 2005). Factor

analysis of the combined pool of items from these questionnaires suggests that there are five facets of mindfulness (FFMQ: Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). These include: (1) Observing, which includes items related to noticing and paying attention to external and internal events, including sounds, sensations, and emotions; (2) Describing, which includes items related to the ability to easily describe experiences in words; (3) Acting with Awareness, which includes items related to attentional abilities, particularly to present experiences; (4) Non-Judging of Inner Experience, which includes items related to not criticizing oneself for thoughts and emotions; and (5) Non-Reactivity to Inner Experience, which includes items regarding the ability to notice emotions and thoughts without reacting to them. Thus, based on psychometric data, it is hypothesized that the practice of meditation increases one's ability to observe, describe, and attend to the present moment while not judging or reacting to one's inner experiences.

There is some evidence that meditation practice and mindfulness interventions lead to increases in these facets of mindfulness, and that increases in self-reported mindfulness meditate improvements in wellbeing. Individuals with meditation experience showed higher levels of observing, describing, non-judging, and non-reactivity when compared to nonmeditators, and levels of observing, non-judging, and non-reactivity mediated the relationship between meditation experience and wellbeing (Baer et al., 2008). After MBCT treatment, mindfulness predicted the risk of relapse of depression after controlling for previous episodes and residual depressive symptoms (Michalak, Heidenreich, Meibert, & Schulte, 2008). Individuals with meditation experience displayed greater mindfulness when compared to controls, which mediated the relationship with lower rumination, lower fear of emotion, and greater behavioral

self-regulation (Lykins & Baer, 2009). Mindfulness mediated the relationship between meditation practice and psychological functioning (Carmody & Baer, 2008) and perceived stress and rumination (Shapiro, Oman, Thoresen, Plante, & Flinders, 2008). These findings suggest that self-reported mindfulness scales may be useful for measuring mindfulness facets that are thought to be enhanced with meditation, and that these qualities mediate improvements in psychological wellbeing.

Self-Compassion

In addition to increasing mindfulness, practicing meditation may also increase self-compassion. Self-compassion “involves being touched by and open to one’s own suffering, not avoiding or disconnecting from it... offering nonjudgmental understanding to one’s pain, inadequacies and failures, so that one’s experience is seen as part of the larger human experience” (Neff, 2003b). While mindfulness involves an acceptance of emotions, thoughts, and experiences in the present moment without judgment, self-compassion entails nonjudgmental acceptance of the person these experiences affect (Germer, 2009).

Neff (2003b) describes self-compassion as being composed of three facets that are exhibited in times of pain and failure: self-kindness, common humanity, and mindfulness. Self-kindness is the quality of extending kindness and understanding to all aspects of oneself rather than being overwhelmed by self-criticism and self-judgment. Self-kindness involves affirming of self-worth at all times, such that the view of oneself as deserving of happiness and esteem does not waiver in response to failure (Barnard & Curry, 2011). This is contrasted with self-judgment, which is the quality of being self-critical, disapproving, and intolerant of one’s flaws and mistakes. The pain caused by

self-judgment in response to flaws can even exceed the pain of the eliciting situation, and become a source of suffering by itself (Germer, 2009). Thus, becoming self-kind requires becoming aware of the impact of self-judgment on self-worth (Gilbert & Irons, 2005). The second facet of self-compassion is common humanity, which requires recognition that personal failures and challenges in life are part of the human condition. Accepting our common humanity necessitates forgiveness of ourselves for being fully human, which entails fallibility and imperfection. Seeing oneself as connected to a common humanity decreases feelings of isolation that result from the urge to withdraw when one attempts to hide inadequacies (Barnard & Curry, 2011). The third facet of self-compassion is mindfulness, which includes a nonjudgmental and receptive state of mind to see thoughts and feelings objectively. This is contrasted with the urge to over-identify with or avoid negative emotions and thoughts, both of which prevent experiencing the present moment fully. These six aspects of self-compassion (including the positive and negative components of the three facets) have been developed in the Self-Compassion Scale (SCS; Neff, 2003a).

Research examining the SCS has found that higher levels of self-compassion are related to a number of positive outcomes. Higher levels of self-compassion attenuate reactions to negative events, buffering against negative self-feelings when imagining distressing events or when being given ambivalent feedback (Leary, Tate, Adams, Batts, & Hancock, 2007). Increases in self-compassion are associated with increases in psychological well-being (Neff, Kirkpatrick, & Rude, 2007), and the association between self-compassion and wellbeing is above and beyond factors like goal management, stress, and availability of social support (Neely, Schallert, Mohammed, Roberts, & Chen, 2009).

Individuals who are more self-compassionate tend to have greater levels of positive affect, social connectedness, life-satisfaction, emotional intelligence, and lower levels of procrastination, anxiety, and depression (see Barnard & Curry, 2011 for review).

Importantly, the facet of mindfulness is given a central position in Neff's conceptualization of self-compassion (2003b). Mindfulness may be required before self-kindness and common humanity can arise, as it may be necessary to be able to observe thoughts and emotions in an objective way before it is possible to view them compassionately. In addition, a more balanced, objective view of experience could lessen self-criticism, contributing to the development of self-kindness. At the same time, self-kindness and common humanity are both thought to reduce the impact of negative thoughts and emotions, which increases the ability to fully experiencing them mindfully (Baer, 2010). Thus, mindfulness and self-compassion may interact to cultivate greater levels of both qualities.

Self-compassion plays an important role in many meditation techniques. In loving-kindness or compassion meditation, cultivating compassion is the primary goal (Germer, 2009). Within the context of traditional focused-attention and open-monitoring approaches, self-compassion is strongly emphasized as well. The importance of the compassionate, gentle redirection of attention when distracted during meditation is highlighted across approaches. Practitioners are encouraged that "whenever you notice that your mind has wandered off, bring it back with gentleness and kindness" (Hölzel et al., 2011); "notice that your mind has wandered and gently and lovingly bring it back" (Lucas, 2012); "this wandering and getting absorbed in things is simply what minds do; it is not a mistake or a failure" (Siegel, 2010). As attention drifts from a focused object or

one loses objectivity about a difficult thought, one must be both vigilant enough to notice the shift, and kind enough to not berate oneself over the loss of focus. Again and again, one fails (loses focus), and returns to the task without judgment. This compassionate response to one's loss of focus, and more objective response to one's thoughts and emotions, may generalize such that individuals are overall more kind and less critical of themselves and others, increasing compassion for self and others.

As hypothesized, evidence suggests that mindfulness practice increases self-compassion, which mediates improvements in psychological wellbeing. Long-term meditators displayed higher levels of self-compassion on all subscales compared to nonmeditators (Lykins & Baer, 2009), and the duration of meditation experience has been linked to greater levels of self-compassion (Orzech, Shapiro, Brown, & McKay, 2009). Mindfulness interventions also increase self-compassion. Moore (2008) demonstrated that brief mindfulness exercises in a group of first-year trainees in clinical psychology resulted in an increase in self-kindness. After an MBSR intervention, individuals in the intervention group had greater self-compassion scores relative to controls (Shapiro, Astin, Bishop, & Cardova, 2005; Shapiro, Brown, & Biegel, 2007). After MBCT treatment, increases in self-compassion mediated the effect of MBCT on depressive symptoms at 15-month follow-up (Kuyken et al., 2008). Additionally, self-acceptance was the strongest mediator in the relationship between dispositional mindfulness and decreases in depressive symptoms (Jimenez, Niles, & Park, 2010).

Mindfulness and Self-Compassion: Relationship with Attention

There is growing evidence that mindfulness practice increases facets of mindfulness and self-compassion as measured by self-report, and that these increases

mediate improvements in psychological wellbeing. Concomitantly, research has investigated the effect of mindfulness practice on attentional abilities. There is little overlap across these areas of study, such that few studies investigating attention report relationships to measures of mindfulness and self-compassion.

Effects of Meditation on Attention

Research exploring the effects of meditation on attention indicates that individuals who practice mindfulness display superior attention regulation. Most consistently, individuals who practice mindfulness show improvements in sustained attention. Sustained attention is the ability to attend to stimuli over an extended period of time. Long-term and short-term meditators showed superior performance on sustained attention when compared to controls, and long-term meditators performed better than short-term meditators (Valentine & Sweet, 1999). This improvement in sustained attention has been linked to enhanced theta-band phase consistency, which may lead to reduced variability in attention when attending to target stimuli (Lutz, Slagter, Rawlings, Francis, Greischar, & Davidson, 2009). Meditators have also demonstrated improvements in perceptual sensitivity and vigilance when compared to nonmeditators, which may reduce the resource demands required by target discrimination and make it easier to sustain attention voluntarily (MacLean et al., 2010). Similarly, individuals who participated in a mindfulness intervention were better at target discrimination on a signal detection task when compared to relaxation and wait-list control groups (Semple, 2010). Improvements in sustained attention with mindfulness practice are not always found, however, either when comparing long-term meditators to controls (Josefsson & Broberg, 2011), or when

comparing performance before and after an MBSR intervention (Anderson, Lau, Segal, & Bishop, 2007).

Changes to executive attention with mindfulness practice have also been demonstrated, with evidence of superior executive attention in meditators relative to controls. Executive attention involves top-down goal-oriented attention, and includes processes like action planning, error detection, self-monitoring, and inhibition. After a 3-month meditation retreat, meditators displayed improvements in a response inhibition task when compared to waitlist controls (Sahdra et al., 2011). After a 10-day retreat, meditators compared to controls had greater digit span backwards scores and improvements in reaction time during an internal switching task (Chambers, Lo, & Allen, 2008). After a short mindfulness intervention, individuals demonstrated improvements on a verbal fluency and an n-back task compared to controls (Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). On the Attention Network Test (ANT), meditators compared to controls had greater conflict monitoring and orienting scores (Jha, Krompinger, & Baime, 2007; van den Hurk, Gionmi, Gielen, Speckens, & Barendregt, 2010), while those in an IBMT training group compared to relaxation training group demonstrated greater improvement in conflict scores (Tang et al., 2007). Evidence for improvement on the Stroop task with mindfulness practice has been more mixed. Some studies indicate that those with meditation experience had reduced Stroop interference compared to controls (Chan & Woollacott, 2007; Moore & Malinowski, 2009) while others find no difference between groups (Semple, 2010; Josefsson & Broberg, 2011; Anderson, Lau, Segal, & Bishop, 2007).

Individuals with meditation training have also demonstrated improvements on other attention measures. After a one-month meditation retreat, compared to a control group, meditators displayed improved working memory performance on a complex visual task, demonstrating significantly less variability in reaction time as well as overall faster reaction times (van Vugt & Jha, 2011). After an 8-week mindfulness intervention, individuals with greater practice times in between classes showed improvements in working memory on the Ospan task, and the relationship between practice time and positive affect was mediated by working memory capacity (Jha et al., 2010). Jensen and colleagues (2012) provide evidence that individuals in an MBSR treatment group display greater working memory capacity when compared to a relaxation control, incentive control, and non-incentive control group. In addition, meditators showed a reduction in attentional blink compared to controls (van Leeuwen, Müller, & Melloni, 2009; Slagter et al., 2007), as well as displaying smaller and even absent intersensory facilitation effects when compared to control participants (van den Hurk et al., 2010).

While the evidence for improvements in attention regulation with mindfulness practice is compelling, few studies control for motivational differences when comparing meditators to controls. Individuals who have meditation experience, or who have taken part in a mindfulness intervention, are likely more motivated to perform optimally in a behavioral task than control participants who do not have anything to prove. In a well-controlled study, Jensen and colleagues (2012) investigated attentional abilities across four groups of subjects: (1) a typical MBSR intervention group; (2) a Non-Mindfulness Stress Reduction group, which was an active control that taught stress reduction skills without any mindfulness techniques; (3) an inactive control group that received no

manipulation; and (4) an incentive-control group, which received additional monetary compensation for superior performance. Results indicate that there were no differences among the MBSR, NBSR, and incentive-control group on attention measures across tasks of executive attention and selective attention. However, only the MBSR group showed improvements in the d2 test of sustained attention, a working memory capacity task, and on a measure of visual threshold. Thus, while some of the attentional alterations found when comparing meditators to controls may be related to motivation differences, there are still significant improvements to attention with mindfulness practice when compared to more appropriate control groups.

How Is Attention Being Altered?

The current literature on the effects of meditation on attention seems to suggest that mindfulness training is a method of improving self-control through practice. In reviewing a special issue on mindfulness in *Psychological Inquiry*, Masicampo and Baumeister (2007) assert that meditation practice is comparable to other self-control practices. Self-control can be viewed as a limited resource that can be strengthened through practice (Baumeister, Gailliot, DeWall, & Oaten, 2006). Participants who were instructed to increase self-control in one area (e.g. posture control, physical exercise, and money management) showed greater self-control on unrelated areas as well, and were more resilient against ego depletion and self-control failure. Meditation can be viewed as a self-control exercise, as it requires repeated self-control of attention for the purpose of goal attainment, and has implications for self-regulated behavior outside of the meditation session.

Are meditation practitioners more practiced at regulating attention and thus better at self-control, or are they making use of strategies that are fundamentally different from how nonmeditators attend? Mindfulness practice could improve attention by: improving conflict monitoring related to the detection of mind-wandering; enhancing attention switching capabilities when disengaging from distracting stimuli to return to the target object; increasing inhibitory control of cognitive processes that are not the current focus of attention; and increasing the overall level of sustained attention (Chiesa, Calati, & Serretti, 2011). In this model, individuals with mindfulness training are attending in the same way as nontrained individuals but have superior attentional control. This model of change proposes that meditators have quantitatively increased their attentional capacity, thus improving self-control, as Masicampo and Baumeister (2007) suggest.

Alternatively, meditation may qualitatively alter how meditation practitioners pay attention. As described earlier, meditation practice is thought to not only improve attention, but also alter awareness in general, changing how individuals regulate attention and emotion. There is some evidence that increases in self-reported mindfulness are related to improvements in attention. Jensen and colleagues (2012) found that improvement in the d2 test of sustained attention was associated with an increase in self-reported mindfulness. Moore and Malinowski (2009) showed that self-reported mindfulness was associated with a higher processing speed, improved inhibitory control, increased coordination of speed with accurate responses, and fewer errors. Increases in mindfulness after MBSR treatment were correlated with improvements in object detection (Anderson et al., 2007). More research is needed, but the relationship between self-reported mindfulness and attentional gains provide some evidence that the cultivation

of mindfulness is important to the attention gains made with meditation practice.

Evidence From the Neuroimaging Literature

The neuroimaging literature provides evidence for both quantitative and qualitative changes to brain function related to meditation practice. The quantitative changes are indicated by the alterations to regions implicated in attentional control. Meditators showed increases in activation in regions involved with attention, including increases in activation in dlPFC and parietal cortices, hippocampus/parahippocampus, temporal lobe, pregenual ACC, striatum, and pre- and post-central gyri (Lazar et al., 2000), and greater activity in cingulate gyrus, OFC, dlPFC, and thalamus during meditation compared to at rest (Newberg et al., 2010). Structural changes in attention networks related to meditation practice have also been demonstrated. Individuals with meditation practice had greater cortical thickness in PFC and right anterior insula in meditators compared to controls (Lazar et al., 2005), and greater gray matter concentration was evidenced in right anterior insula, inferior temporal gyrus, and right hippocampus (Hölzel et al., 2008). Meditators also had increased gray matter in dorsal ACC and in bilateral secondary somatosensory cortex, such that more years of experience with meditation associated with thicker grey matter in the ACC (Grant, Courtemanche, Duerden, Duncan, & Rainville, 2010). Meditators relative to controls had greater structural connectivity across the entire brain, with the largest difference in the corticospinal tract, the temporal component of the superior longitudinal fasciculus, and the uncinate fasciculus (Luders, Clar, Narr, & Toga, 2011). These alterations to attention networks related to meditation practice likely result in facilitation of processing during attention regulation.

At the same time, the neuroimaging literature provides some evidence for qualitative changes in awareness related to meditation practice. Several studies have shown decreases in activation in the default network, including the medial PFC (mPFC) and precuneus/posterior cingulate cortex (PCC), both during meditation and during self-relevant tasks. During meditation, meditators compared to controls displayed decreased activation in mPFC, bilateral precuneus, left ventral anterior cingulate cortex (vACC), and bilateral insula (Ives-Deliperi, Solms, & Meintjes, 2011), less activation in the PCC and the mPFC compared to controls (Brewer et al., 2011), and greater anti-correlation between sensory and motor systems with the default network (including the precuneus, inferior parietal lobule, and mPFC) (Josipovic, Dinstein, Weber, & Heeger, 2012). During a sadness provocation, those who had participated in a mindfulness intervention had greater reductions in activity in the posterior cortical midline and in mPFC compared to controls (Farb et al., 2010). In response to emotional pictures while in a mindful state of awareness, experienced meditators compared to beginners demonstrated deactivations in the default mode (including medial PFC and posterior cingulate) across negative, positive, and neutral picture conditions (Taylor et al., 2011). Individuals with social anxiety disorder trained in mindfulness interventions completed a task encoding self-referential, valence, and orthographical features of social trait adjectives. After training, individuals in the intervention group showed decreased BOLD response in mPFC and language processing areas (left inferior frontal gyrus) for positive trait words (Goldin, Ramel, & Gross, 2009).

The decreased activity found in the default network in mindfulness practitioners has been interpreted as a decrease in self-relevant processing. Research suggests that

when individuals are processing self-relevant information, they show increases in the recruitment of the midline cortical structures in the default network (Northoff et al., 2006). Farb and colleagues (2007) provide evidence that individuals with mindfulness training are able to decrease the recruitment of these regions when asked to attend to experience mindfully. In this study, participants were asked to read trait-related adjectives and either reflect on what the adjective meant about them (the self-referential condition), or monitor their moment-to-moment experience in response to the adjectives (the experiential focus condition). In the experiential focus condition, participants with mindfulness experience showed significantly less activation in cortical midline structures and more activation in viscerosomatic areas like the insula and secondary somatosensory cortex when compared to controls (Farb et al., 2007). In concert with studies showing decreases in default network during meditation and self-relevant tasks, this study suggests that individuals with meditation experience can alter how they attend to information more readily than controls. Meditation practice may allow individuals to flexibly shift to a more detached, objective, sensory-based representation of events, rather than being tied to a subjective, reactive appraisal of affect and experience. Together, the evidence for alterations to attention networks and decreases in default network activity during self-relevant tasks indicates that meditation practice may alter attention both quantitatively (by increasing the efficiency of attention networks) and qualitatively (by providing the ability to shift from self-relevant processing to a mindful mode of awareness).

Self-Compassion and Self-Monitoring

While the neuroimaging literature has provided some evidence for both qualitative and quantitative changes to attention processing with meditation practice,

alterations to self-monitoring processes related to mindfulness experience are not well understood. Self-monitoring is the process by which individuals evaluate their performance, both against their own representation (internal self-monitoring), and against outside feedback (external self-monitoring). Internal self-monitoring requires close observation of performance for error production. Errors signal the need for a change in behavior to optimize performance. Similarly, external self-monitoring requires vigilance toward negative feedback, which may signal that alterations in behavior are needed. Adaptive self-monitoring is of great importance to self-regulated behavior. Both over-vigilance and under-vigilance in monitoring processes have been linked to maladaptive behavior and psychopathology (Hajcak, McDonald, & Simons, 2004; Brazil et al., 2009).

The practice of meditation requires vigilant internal self-monitoring. During meditation, individuals must notice lapses in attention so that they can return to their focus of attention. At the same time, the nonjudgmental stance that is emphasized during mindfulness practice may alter the self-monitoring process. Instead of responding reactively and judgmentally to lapses in attention, practitioners may view their errors with more objectivity and self-kindness, as simply a neutral cue to refocus on the meditation goals. With repetition, individuals may become less reactive and more compassionate not only to losses of attention and to their own internal states during meditation, but also in daily life such that their responses to errors and negative feedback are attenuated. Given the relationship between over-vigilance in self-monitoring with anxiety (Hajcak, McDonald, & Simons, 2004), this change in self-monitoring may provide resilience against developing internalizing problems. To my knowledge, there

are no published studies investigating alterations to self-monitoring, and the influence of self-compassion, as a result of meditation practice.

Neural Mechanisms of Attention and Self-Monitoring

Present Study

This dissertation study seeks to investigate the effects of meditation practice on attention and self-monitoring. Specifically, I seek to explore whether the cultivation of mindfulness and self-compassion affect attention regulation and self-monitoring processes. Importantly, attention and self-monitoring will be assessed with neural measures using EEG and ERP methodology, as neural measures can more sensitively index different aspects of the attention and self-monitoring than behavioral measures alone. This study seeks to use objective measures to investigate whether improvements in attention and self-monitoring related to meditation experience can be linked to increases in mindfulness and self-compassion.

Event-Related Potentials (ERPs)

Event-Related Potentials (ERPs) methods involve recording electroencephalography (EEG) signals at the scalp and time-locking them to the presentation of stimuli or to motor responses. Multiple time-locked trials are averaged so that background brain activity unrelated to the task is averaged out, and the neural response to the event of interest can be identified. Importantly, different components of the ERP waveform have been linked to distinct aspects of attention and self-monitoring, and a number of ERP components are known to be sensitive to individual differences. Thus, ERPs may provide a useful way to measure the effects of mindfulness practice on attention and self-monitoring while also investigating relationships with self-reported

mindfulness and self-compassion. The sensitivity ERPs provide in investigating different aspects of attentional capacity and self-monitoring abilities allow for careful comparisons between groups. Specifically, ERPs related to attention (P1/N1 and P3) and to self-monitoring (ERN, Pe, and FRN) are likely to show effects of meditation practice.

Selective attention: P1/N1. Practicing mindfulness may increase an individual's ability to amplify neural activity within currently attended sensory processing areas, while simultaneously suppressing activity and access to unattended regions, improving mechanisms of selective attention. The effects of selective attention on stimulus processing have been examined by looking at two early components of the ERP waveform, the P1 and the N1. The P1 is a positive potential between 60 and 150 ms post stimulus onset in lateral occipital regions, and the N1 is the following negative deflection that appears 150-250 ms after stimulus onset. The P1 and N1 are both enhanced for attended compared to unattended stimuli (Hillyard, Vogel, & Luck, 1998). The P1 and N1 have been differentiated, in that evidence shows that the P1 may reflect suppression of unattended stimuli, while the N1 amplitude facilitates processing of attended information (Talsma & Woldorff, 2005; see Hillyard, Vogel, & Luck, 1998 for a review). While the P1 and N1 may subserve different functions, they are both influenced by the degree of visual attention a stimulus receives. In addition, research shows that the P1 is influenced by emotional salience, such that larger P1 amplitudes are evoked for threat-related stimuli relative to neutral stimuli (Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Even at this early stage of processing, processing of emotional stimuli results in a gain control effect similar to the typical of selective attention effects (Pourtois, Schettino, & Vuilleumier, 2012).

Source localization has suggested a similar generator for both the P1 and N1, both in ventral-lateral extrastriate cortex (Martinez et al., 1999; Di Russo, Martinez, & Hillyard, 2003; Mishra & Hillyard, 2009; Moran & Desimone, 1985). Additional sources have been found in the mid-occipital gyrus, mid-temporal gyrus, and fusiform gyrus, and parietal lobe (Novitskiy et al., 2011).

To my knowledge, no study has been published investigating alteration in P1/N1 amplitude related to meditation experience. We hypothesize that mindfulness practitioners will show larger P1/N1 amplitudes relative to controls, indexing enhancement of selective attention to stimuli as a result of meditation practice. We expect self-report mindfulness and self-compassion to mediate these effects, providing evidence for the importance of these qualities in the alterations to attention seen with meditation.

Attention allocation: P3b. The P3b component is a positive-going wave that occurs more than 250 ms following stimulus presentation and is related to memory processing and evaluation of stimuli that require a response. The P3b is evoked during stimulus processing and indexes brain activity related to context-updating and subsequent memory storage (Polich, 2007). Specifically, the P3b indexes the maintenance of target features in working memory for comparison with the current stimulus. In addition, the amount of attention allocated to the task modulates the P3b amplitude, such that greater cognitive demands are related to larger P3b (Polich, 2007). Thus, the P3b is thought to index increased processing when attentional resources are recruited to promote memory operations.

Source analysis has implicated the temporal-parietal area (Polich, 2007), the medial temporal lobe, ventrolateral PFC, and superior parietal cortex (Halgren et al, 1998), the parietal, inferior temporal, and insular cortex (Bledowski et al., 2004), and inferior parietal lobe, temporoparietal junction, and supramarginal gyrus (Linden, 2005) as generators for the P3b component. The P3b likely indexes temporoparietal activity reflecting attentional allocation to stimuli that contributes to memory processing (Polich, 2007).

Evidence suggests that meditation experience modulates the latency and amplitude of the P300. P300 latency is shorter for the meditators compared to controls on auditory tasks (Cahn & Polich, 2006; Sarang & Telles, 2006) and after visual tasks (Goddard, 1989). Larger P300 amplitudes have been found in practicing meditators (Banquet & Lesevre, 1980) and after meditation training during incongruent trials (Moore, Gruber, Derose, & Malinowski, 2012). With different task conditions, meditators have shown reductions in P300 amplitudes. Smaller T1-elicited P3b amplitudes were shown after a 3-month meditation retreat during an attentional blink task, which related to the greatest reduction in attentional blink (Slagter et al., 2007). A reduction in P3a amplitudes was found to distracter tones during meditation relative to a controlled thought period during a three-stimulus auditory oddball task (Cahn & Polich, 2009).

It is expected that during a simple attention task, meditators will have larger P3b amplitudes relative to controls, indexing increased attentional allocation to stimuli in order to facilitate memory retrieval and task performance. Self-reported mindfulness and self-compassion are expected to mediate the effect.

Self-monitoring: ERN, Pe, and FRN. Self-monitoring is essential for optimal performance on a task. Individual differences in self-monitoring result from the evaluation of ongoing behaviors with respect to internal factors, like goals and motivation, and external contingencies, like expectancies and feedback. Self-monitoring is often assessed in speeded and/or high conflict tasks where individuals have to monitor their actions for errors and feedback to optimize performance. Neurophysiologically, a number of ERP components have been linked to different facets of performance-monitoring, and have been used to elucidate different aspects of the self-monitoring process.

Error-related negativity (ERN). Much attention has been made to self-monitoring of errors, as how an individual monitors and responds to errors is of great importance to performance. To perform optimally, errors must be noticed and behavior altered such that speed is adjusted on the next trials to increase accuracy. However, too much weight given to errors can lead to overvigilance and slowed reaction times.

The Error-Related Negativity (ERN), a negative deflection in the ongoing EEG waveform occurring 50-100 ms after individuals make an incorrect response, is noted in the medial-frontal region of the brain after errors and is thought to index error-monitoring (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ERN amplitude plays an evaluative role, such that it varies depending on the importance the subject puts on avoiding mistakes and/or making a correct response (Taylor, Stern, & Gehring, 2007). Individuals with OCD (Gehring, Himle, & Nisenson, 2000), and those higher in negative affect (Luu, Collins & Tucker, 2000) and anxiety (Hajcak et al., 2004; Hajcak, McDonald, & Simons, 2003) show larger

ERNs, suggesting that the ERN amplitude is sensitive to the amount of distress caused by making errors, or how important it is for the individual to avoid mistakes.

Simultaneously, evidence suggests that the ERN is enhanced in individuals who are high in conscientiousness, perhaps because highly conscientious individuals are more motivated to correctly respond (Pailing & Segalowitz, 2004). Thus, having larger ERN amplitudes is not pathological; rather, the ERN it seems to provide a measure of error significance (Maier, Steinhauser, & Hubner, 2008). Given that individuals who practice mindfulness are thought to be less reactive to experience, it is expected that meditators will show smaller ERN amplitudes when compared to nonmeditating controls. We also expect greater self-reported mindfulness and self-compassion to be related to smaller ERN components.

The source of the ERN has been localized to the anterior cingulate cortex (ACC) (Dehaene, Posner, & Tucker, 1994; Herrmann, Rommler, Ehlis, Hidrich, & Fallgatter, 2004; Mathewson, Dywan, & Segalowitz, 2005; van Veen and Carter, 2002). However, some studies have shown additional generators in the ventral ACC, dlPFC, anterior insula, and lateral parietal lobe (see Taylor, Stern & Gehring, 2007 for review). The ventral ACC may process the emotional component of the error signal (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; van Veen & Carter, 2002). Patients with OCD have shown greater ventral ACC activation compared to healthy controls when making errors (Fitzgerald et al., 2005). It is expected that meditators to show dorsal ACC and dlPFC sources for the ERN, while nonmeditators may show sources in ventral ACC or OFC, suggesting a qualitative difference in how those with mindfulness practice process errors.

Error positivity (Pe). While the ERN seems to provide a measure of error significance, the Error Positivity (Pe), the positive deflection that occurs 200-300 ms after response, may index error awareness (Falkenstein et al., 1991). Evidence suggests that the ERN can occur without conscious awareness that an error occurred (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001), whereas the Pe requires conscious awareness of an error (Overbeek, Nieuwenhuis, and Ridderinkhof, 2005; Steinhauser & Yeung, 2010; O’Connell et al., 2007). The Pe is thought to vary with the saliency of the error-inducing stimuli (Davies, Segalowitz, Dywan, & Pailing, 2001; Ridderinkhof, Ramautar, & Wijnen, 2009). There have been few studies that have explored the source of the Pe, but those that have shown generators in the anterior medial-frontal cortex, and rostral ACC (Hermann et al., 2004; Mathewson et al., 2005; van Veen and Carter, 2002).

Few studies have examined individual differences in Pe amplitudes. A recent study demonstrated that individuals with a growth mind-set, who believe intelligence develops through effort, compared to those with fixed mind-set, showed larger Pe amplitudes. In addition, Pe amplitude mediated the relationship between growth-mindset and post-error accuracy (Moser, Schroder, Heeter, Moran, & Lee, 2011). Thus, awareness of one’s errors likely plays an adaptive role in improving performance. Given that mindfulness practice is thought to increase awareness of all experiences, it is expected that individuals with mindfulness practice to show larger Pe amplitudes relative to control participants. In addition, it is expected that self-compassion and self-reported mindfulness to mediate the relationship between mindfulness practice and Pe amplitude.

Feedback-related negativity. An important aspect of self-monitoring is the ability to respond quickly and make appropriate changes to behavior when given external

feedback about one's performance, especially negative feedback. The feedback-related negativity (FRN) has been identified as a negative deflection at frontocentral recording sites that peaks approximately 250 ms following negative feedback presentation, and reflects responses to negative feedback (Gehring & Willoughby, 2002). The FRN is observed following feedback that indicates an individual's performance was inaccurate, or that money was lost (Hajcak et al., 2004, Luu et al., 2003). Evidence from source-localization suggests that the FRN, like the ERN, is generated in areas of the medial prefrontal cortex, such as the anterior cingulate cortex (Holroyd & Coles, 2002).

Individuals with greater levels of depression and anxiety have larger FRN amplitudes (Gu, Ge, Jiang, & Luo, 2010). However, deficits in external monitoring, and very small FRN amplitudes, are also problematic. Individuals with ADHD have smaller FRNs to negative feedback relative controls, as these children have problems assigning motivational significance to the outcomes of their actions (van Meel, Heslenfeld, Oosterlan, Luman, & Sergeant, 2011). It is expected that mindfulness practitioners to show a smaller FRN when compared to nonmeditating controls, indexing decreases in reactivity to negative feedback. It is expected that self-reported mindfulness and self-compassion to mediate this relationship as well.

Spectral Analysis

EEG is a linear superposition of a set of different oscillatory components defined by their rhythmic activity. Spectral analysis provides a method to decompose the signal and identify the frequency bands that make up the ongoing EEG. A number of studies have shown increases in theta and alpha frequency bands during meditation using spectral analysis. Greater theta band activity was found in frontal areas during meditation (Baijal

& Srinivasan, 2010; Lutz, Slagter, Rawlings, Francis, Greischar, & Davidson, 2009; Kubota et al., 2001; Lagopoulos et al., 2009; Aftanas & Golocheikine, 2001; Takahashi et al., 2005). Increases in alpha band activity have been demonstrated in meditators at rest (Aftanas & Golosheykin, 2005) and during meditation (Lagopoulos et al., 2009; Yu et al., 2011). Greater levels of alpha in meditators have been found across the scalp (Aftanas & Golosheykin, 2005), in only frontal regions (Takahashi et al., 2005), and in greater levels in posterior regions (Lagopoulos et al., 2009). Given this previous research, it is expected that mindfulness practitioners will show greater alpha and theta band activity during meditation.

Frontal theta power has been implicated in attention and memory processes (Klimesch, 1999). Frontal theta power at rest has been negatively correlated with the default mode network of the brain, including with mPFC and the PCC (Scheeringa et al., 2008), suggesting that theta activity is greater during task performance. Phase locking in theta-band activity has been linked to long-term memory formation (Summerfield & Mangels, 2005), working memory (Lisman, 2010; Onton, Delorme, & Makeig, 2005), and attention (Green & McDonald, 2008). Most studies implicate frontal theta power with attention and memory, but distributed theta networks have also been linked to working memory performance (Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). Given that the ERN is dominated by partial phase-locking of intermittent theta-band EEG activity (Luu, Tucker, & Makeig, 2004), it may be that the increases in theta during meditation transfer to increases in ERN amplitude during the task. Thus, it is hypothesized that theta power during meditation will predict the amplitude of the ERN

during self-monitoring. Self-reported mindfulness and self-compassion may mediate this relationship.

Individual variations in alpha frequency at rest have been linked to a number of cognitive abilities. Peak frontal alpha frequency was related to working memory capacity (Richard Clark et al., 2004; Angelakis, Lubar, Stathopoulou, & Kounios., 2004) and speed of information retrieval from memory (Klimesch, 1997). In addition, stimulus locked alpha band phase correlations are involved in attention, top-down modulation, and sensory awareness (Palva & Palva, 2007). In particular, evidence suggests that the P1/N1 components are generated primarily by phase synchronization of frequencies in the alpha range (Makeig et al., 2002; Gruber, Klimesch, Sauseng, & Doppelmayr, 2005). Given that mindfulness practitioners evidence greater alpha during meditation, it is anticipated that alpha power during meditation will predict the amplitude of the P1/N1 during an attention task. Self-reported mindfulness and self-compassion may mediate this relationship.

Design and Hypotheses

This dissertation study seeks to explore how meditation practice affects attention and self-monitoring during a modified flanker task (Eriksen and Eriksen, 1974) by comparing a group of experienced meditators to age-, gender-, and education-matched control participants. In addition, self-reported mindfulness and self-compassion scores will be assessed in relation to neural measures of attention and self-monitoring.

Differences between groups (meditator versus control) on all variables, and relationships among variables (attention, self-monitoring, self-compassion, and mindfulness), will be explored.

Importantly, the choice to assess a group of self-selected experienced meditators required careful study design. First, all participants will be informed that they will receive an additional monetary incentive if they perform quickly and accurately. The incentive will be provided to encourage all participants to perform optimally and is specifically aimed at decreasing meditators potential motivational advantage. Secondly, a meditation period will be added into the study design to examine the direct effects of a meditation practice on attention and self-monitoring. In between blocks of the flanker task, participants will complete five-minute periods of instructed meditation and relaxation. Enhancement in neural mechanisms after meditation (relative to after relaxation and control periods) in the experienced meditator group would suggest that meditation itself, and not a quality related to choosing to meditate, affects attention and self-monitoring. Lastly, information from meditators was collected about the length of their meditation experience. If the practice of meditation itself, and not a quality related to choosing to meditate, affects attention, then the number of years of meditation experience should predict levels of attention, self-monitoring, mindfulness, and self-compassion.

Across neural measures, it is expected that experienced meditators will show increases in attentional allocation, decreases in reactivity, and increases in awareness, with stronger effects after a period of meditation. Additionally, it is anticipated that these relationships will be mediated by self-reported mindfulness and self-compassion, suggesting that enhancement of these qualities is important to altering attentional mechanisms. Specific hypotheses for the neural measures are stated below.

Attention Hypotheses

1.1 It is expected that individuals with long-term meditation experience will show larger P1/N1 and P3 amplitudes overall when compared to nonmeditators across conditions.

1.2 It is expected that meditators will show greater enhancement after a meditation period relative to a relaxation period a no manipulation condition.

1.3 It is expected that the P1/N1 and P3 amplitudes will be related to self-reported mindfulness and self-compassion, such that individuals with greater mindfulness and self-compassion will show larger P1/N1 and P3 amplitudes.

1.4 It is expected that greater alpha during meditation will predict P1/N1 amplitudes.

Self-Monitoring Hypotheses

2.1 It is expected that individuals with long-term meditation experience will show smaller ERN and FRN amplitudes and larger Pe amplitudes when compared to nonmeditators across conditions.

2.2 It is expected that meditators will show greater decreases in ERN and FRN amplitudes, and greater enhancement in the Pe, after a meditation period relative to a relaxation period and to a no manipulation condition.

2.3 It is expected that the ERN, FRN, and Pe amplitudes will be related to self-reported mindfulness and self-compassion, such that individuals with greater self-reported mindfulness and self-compassion will show smaller ERN and FRNs and larger Pe amplitudes.

2.4 It is expected that greater theta power during meditation will predict ERN amplitudes.

Spectral Analysis

3. It is expected that meditators will show increases in alpha and theta power during meditation when compared to control participants.

Source Analysis

4. It is expected that mindfulness practitioners will show greater activity overall relative to controls in the source solutions, evidencing greater utilization of attention and self-monitoring networks. Source analyses are exploratory in nature, and there are not explicit hypotheses for differences for most of the ERP components.

CHAPTER II
METHODS

Participants

A total of 27 meditators and 25 matched control subjects participated in the study. Four subjects in the meditator condition were not included in the analysis: three meditators had no useable EEG data because of a computer error, and one meditator was dropped because based on questionnaire data asking about meditation experience, the participant did not meet criteria to be included in the meditator group. Two control subjects had no useable data because of a high level of eye-artifact in the EEG. Thus, 23 meditators and 23 control participants were included in the analysis. Groups were matched for age, education, and gender (See Table 1 for demographics separately for each group). However, because participants were dropped due to poor data quality, gender was not equally matched across groups.

Table 1. Gender, age, and educational achievement separately for all meditator and control participants.

	Meditator	Control
N	23	23
Gender	12(F)	11(F)
Age	M=46.78, SD=17.77	M=46.43, SD=17.37
Education	M=17.57, SD=2.42	M=17.37, SD=2.51

All subjects were recruited from the Eugene, Oregon community. Subjects were screened for history of head injury, uncorrected vision problems, and abnormal use of their hands. Subjects were screened for meditation experience via a phone interview. To be eligible, participants in the meditator group had to practice meditation at least three times a week for at least the last three years. Table 2 provides information about the average meditation experience of the meditation group. Control participants could not have a current or past practice of meditation, yoga, or Tai Chi to be included in the study.

Table 2. Average and standard deviation of meditation practice in the meditator group.

	Mean	Standard Deviation
# Years meditation	16.02	13.39
Ave # days per week	5.83	1.34
# days in last month	24.8	5.48
Typical minutes per day	46.70	26.80

Stimulus and Procedure

Subjects were seated in a comfortable chair facing a computer screen placed 60 cm from the subject’s face. The experimental task was a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974). In this task, subjects were asked to make right- or left-hand button-presses to indicate the direction that the central arrow was pointing in a five-arrow stimulus array. Target characters consisted of arrows pointing either to the right or to the left. Flanker arrows were either congruent or incongruent with the center target, resulting in a set of four target arrays that occurred with equal frequency across the task as a whole: “←←←←←,” “→→→→→,” “←←→←←,” and “←→→←→.”

Subjects were instructed to respond to the direction of the central arrow via button press. If the central arrow was pointing to the right, participants were instructed to respond by pressing the rightmost button with the right index finger; if the central arrow was pointing to the left, they were instructed to respond with the leftmost button with the left index finger. Button-press responses were registered on a response box positioned in front of the subject on the table in front of the monitor. To enhance the difficulty of the task and thereby ensure a sufficient number of errors for ERP purposes, the target stimulus was presented on the screen for only 300 ms. Participants had a total of 1000 ms to respond after the presentation of the array.

Subjects were also presented with feedback on their speed and accuracy. Accuracy feedback was presented in the form of a visual cue presented 1000 ms after stimulus presentation on all incorrect trials and on 25% of correct trials. On 25% of correct responses, participants received positive feedback in the form of a happy face, while after every incorrect response participants received negative feedback in the form of a frowning happy face. Accuracy feedback was presented in the center of the display for 500 ms. In addition to accuracy feedback, speed feedback was presented every 30 trials. Subjects' average speed across thirty trials was compared to their speed in the preceding block of thirty trials. If subjects' speed had decreased over the preceding block of thirty trials, the phrase "Speed Slow" was presented in the center of the display. If their average speed had increased, subjects were presented with the phrase "Good Speed" on the center of the display. To increase motivation, participants were informed that quick and accurate performance on the task would lead to an additional financial incentive.

Each trial had the same structure. A variable fixation point appeared for 600-1000 ms, with a mean time of 800 ms. The stimulus appeared on the screen for 300 ms, after which there is a blank screen for another 700 ms. After 1000 ms total, on some trials, accuracy feedback was presented for 500 ms. Prior to the experiment, each subject completed a practice session to become familiar with the experimental protocol, which included 30 trials and no reaction time feedback. Subjects were instructed to respond as quickly and accurately as possible to each target array. The experimental task consisted of 6 blocks of 200 trials each.

This study was approved by the University of Oregon Institutional Review Board and informed consent was obtained from each participant prior to entry into the study.

Meditation/Relaxation Manipulation

After the second and fourth blocks of the flanker task, subjects were presented with a scripted progressive relaxation (Leahy & Holland, 2000) or focused-attention meditation (Siegel, 2009) (see Appendix B for scripts). A research assistant read the script and instructed participants to follow the instructions for a five-minute period in which EEG data would continue to be collected. After this period, subjects were once again instructed to complete a block (or 200 trials) of the flanker task. Following this block, subjects were instructed to complete five minutes of relaxation or meditation, depending on counterbalancing. The order of the meditation and relaxation block was counterbalanced across participants based on subject number. This resulted in 10 minutes of EEG data during meditation and during relaxation. In addition, the flanker task was divided into three blocks of 400 trials each: (1) control block, made up of the flanker trials before instructed meditation or relaxation; (2) meditation block, made up of

the flanker trials after instructed meditation; (3) relaxation block, made up of the flanker trials after instructed relaxation. The ERPs during the flanker task were analyzed separately by block type when sufficient trials were available.

Measures

Participants completed a series of questionnaires prior to the lab session. Some participants completed questionnaires by hand after receiving them via US postal mail. Other participants completed questionnaires via the Qualtrics online survey system prior to their lab session. Participants completed the following questionnaires:

Meditation Experiences Questionnaire: This 10-item questionnaire asked about frequency of meditation experience, including minutes of daily practice, days of weekly practice, and years of lifetime practice. The questionnaire also collected information about the type of meditation practiced in free response format.

Positive and Negative Affect Schedule-T-R (PANAS-T-R; Watson and Clark, 1994): This 20-item self-report measure assesses how individuals have felt about themselves over the past few weeks. This scale includes single emotion words, including *active*, *guilty*, and *excited*, and based on subject responses, computes scores on two scales of emotionality: Positive Affect (PA) and Negative Affect (NA).

Adult Temperament Questionnaire-Short Form (ATQ-SF; Evans & Rothbart, 2007): A 77-item self-report form that assesses temperamental fear, sadness, discomfort, frustration, inhibitory control, activational control, attentional control, extraversion, sociability, high intensity pleasure, positive affect, neutral perceptual sensitivity, affective perceptual sensitivity, and associative sensitivity. From these lower order scales, factor scales for the constructs of Negative Affect, Extraversion, Effortful Control, and

Orienting are created. Self-report ratings are made on a scale from 1 (extremely untrue of you) to 7 (extremely true of you). Of particular interest were the Effortful Control and Orienting scales.

Five-Factor Mindfulness Questionnaire (FFMQ: Baer et al., 2006). This 39-item questionnaire is based on a factor analytic study of five independently developed mindfulness questionnaires. The analysis yielded five factors of mindfulness, including: Observing, which includes items related to noticing and paying attention to sounds, sensations, and emotions; Describing, which includes items about being able to describe experiences in words; Acting with Awareness, which includes items about attending to the present moment; Non-Judging of Inner Experience, with items related to not criticizing oneself for thoughts and emotions; and Non-Reactivity to Inner Experience, which includes items regarding the ability to notice emotions and thoughts without reacting to them and to emotion-regulation. Self-report ratings are made on a scale from 1 (never or very rarely true) to 5 (very often or always true).

Self-Compassion Scale, Short Form (Neff, 2003a; Raes, Pommier, Neff, & van Gucht, D., 2010). This 12-item questionnaire measures the ability to be kind and nonjudgmental toward oneself. In addition to a composite measure of self-compassion, subscales include: Self-Kindness, which includes items related to being understanding and caring to oneself; Self-Judgment, which includes items related to judging oneself for believed flaws; Common Humanity, which includes items related to seeing one's failings as part of a larger human condition; Isolation, which includes items related to feeling alone with one's failings; Mindfulness, which includes items related to keeping emotions in balance; and Over-Identification, which includes items related to fixating on negative

emotions. Ratings are made from a scale of 1 (almost never) to 5 (almost always).

EEG Data Acquisition and Analysis

The EEG was recorded from 256 scalp electrodes using the HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene OR), a device that positions a dense array of sensors in a regular pattern over the head surface (Tucker, 1993). The 256-channel Net provides improved density of sampling and improved coverage of the lower head surface in relation to sparse sensor arrays. Application was made with reference to skull landmarks, and impedances were maintained below 100 k Ω . To avoid saline bridges between adjacent sensors (Tenke and Kayser, 2001), we placed the sensors below the hair, directly on the scalp. The data was recorded (0.1 – to 100.0 Hz bandpass, 250 samples per second) with a vertex reference and average referenced off-line (Bertrand, Perrin & Pernier, 1985). The EEG was digitally filtered offline with 0.3 high-pass and 30 Hz low-pass filters using a finite impulse response (FIR) with zero phase distortion. The filters were set with a pass band attenuation of 0.1 dB and stop band attenuation of 40 dB with a 4 Hz transition band. Artifacts were screened with automatic detection methods (Net Station, Electrical Geodesics, Inc.), as well as with visual inspection, and epochs with movement, eye-blink, or eye-movement artifacts were excluded from the analysis.

ERP Coding

ERPs were extracted separately for each block, and were only included in the analysis if they contained more than 15 useable trials. Epochs of (1) 200 ms before and 500 ms after incorrect response, (2) 200 ms before and 800 ms after feedback presentation, and (3) 200 ms before and 1000 ms after stimulus presentation were segmented from the continuous recording for analysis of (1) response-locked ERPs, (2)

feedback-locked ERPs, and (3) stimulus-locked ERPs, respectively. The ERPs were extracted from the single subject averaged EEG by taking the peak amplitude in the time window suggested in previous research. Trials in each block for each ERP of interest were averaged for each subject, and the average EEG was then baseline corrected using the 100 ms window prior to stimulus or response.

Spectral Analysis

The EEG data recorded during the two 5-minute meditation blocks were extracted, resulting in ten-minutes of continuous EEG during instructed meditation. The EEG was visually inspected for ocular and muscle artifact. Multiple artifact-free epochs 10-seconds in length were selected from the two meditation sessions. Power spectral analysis was performed with a fast Fourier transform (FFT) using a Hanning window on the average referenced data to yield a spectrum over the range of 2-29.67 Hz. The resulting power spectra reflect the average power of the EEG over multiple 1-second epochs, which ranged in length depending on the availability of artifact-free data. The amplitude (square root of the spectral power) for each frequency was interpolated using spherical splines and was mapped topographically. The absolute spectral amplitude was computed for delta (2-4.2 Hz), theta (4.8-7.8 Hz), alpha (8.7-12.7 Hz), and beta (13.29-29.67 Hz) frequency bands. The spectral percentage amplitude was computed for alpha and theta frequency bands by dividing the amplitude for alpha and theta band separately by the total amplitude across delta, theta, alpha, and beta frequency bands. The FFT was computed at each channel site, which were divided and averaged within 4 regions, (frontal, central, parietal, and occipital), and 2 hemispheres (right and left), for a total of 8

regions. See Figure 1 for channels used in the spectral analysis. The results are reported for spectral percentage amplitude values calculated for theta and alpha frequency bands.

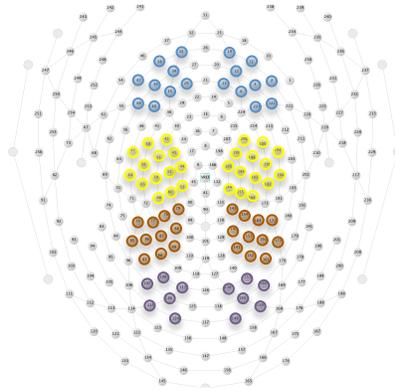


Figure 1. Channels included in the spectral analysis. Each color represents a separate region: Blue, frontal; Yellow, central; Red, parietal; Purple, occipital.

Source Analysis

Estimated neural sources of the scalp ERP effects were computed using a linear inverse minimum norm solution using the standardized Low Resolution Brain Electromagnetic Tomography (sLORETA; Pascual-Marqui, 2002). Source estimates were implemented on the grand-averaged scalp ERPs using Geosource, Version 2.0, software (Electrical Geodesics, Eugene, OR). The forward model within Geosource uses a finite difference model (FDM) for accurate computation of the lead field in relation to head tissue. The head model for the FDM requires a high-resolution T1-weighted MRI image and whole-head computed tomography (CT) scan for tissue segmentation. Tissue compartments for the default FDM used in this study were constructed from the Colin27 MRI average (Holmes et al., 1998) and a whole head CT scan of this same individual,

whose Talairach-transformed head closely matches the Montreal Neurological Institute average MRI (MNI305). Conductivity values used in the FDM are as follows: 0.25 S/m (Siemens/meter) for brain, 1.8 S/m for cerebral spinal fluid, 0.018 S/m for skull, and 0.44 S/m for scalp. Placement of the distributed dipoles was based on the probabilistic map of the MNI305 average brain. Cortical gray matter of this probabilistic atlas was parceled into 7 mm voxels, each serving as a dipole source location with three orthogonal orientations. This resulted in a total of 2,447 source dipole triplets.

The resulting estimated source activation voxel intensities and orientations were displayed superimposed on MRI slice views of the Talairach-transformed Colin27 brain. Source localization was carried out at the timepoint of ERPs of interest. We were particularly interested in comparing source solutions for ERP components for which there were group differences at the scalp. For each ERP of interest, sources were thresholded such that only the top 30% of voxel intensities are displayed on MRI slice views of a Talairach-transformed brain. Source regions corresponding to the scalp ERP effects were identified through visual inspection of these source activation maps.

CHAPTER III
RESULTS

This section will describe the analyses completed to examine differences between meditator and control participants on self-report measures, ERP components, spectral amplitude, and neural generators. In addition, relationships among neural measures and self-report scales will be explored and mediation models that may explain group differences will be tested.

Self-Report Questionnaires

Pearson correlation coefficients were computed to assess the relationships among self-report measures. Correlations between subscales within the Five Factor Mindfulness Questionnaire (FFMQ) are presented in Table 3, and correlations among subscales within the Self-Compassion Scale (SCS) are presented in Table 4. Correlations among subscales were often high, especially within the SCS, suggesting potential overlap in the constructs.

Table 3. Correlations among factors of the Five Factor Mindfulness Questionnaire.

	Observe	Describe	Act with Awareness	Nonjudge	Nonreact
Observe	1	.261	.248	.204	.421**
Describe		1	.517**	.337*	.394**
Act with Awareness			1	.495**	.571**
Nonjudge				1	.723**
Nonreact					1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlations among factors of the Self-Compassion Scale.

	Self-Kindness	Self-Judgment	Common Humanity	Isolation	Mindfulness	Over-Identification
Self-kindness	1	-.620**	.505**	-.561**	.548**	-.667**
Self-judgment		1	-.409**	.815**	-.437**	.727**
Common Humanity			1	-.444**	.489**	-.532**
Isolation				1	-.526**	.823**
Mindfulness					1	-.654**
Over-Identification						1

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Correlations between subscales of the FFMQ and SCS are displayed in Table 5.

There are significant correlations among acting with awareness, nonjudging, and nonreacting from the FFMQ with all subscales of the SCS.

Table 5. Correlations between subscales of the FFMQ and SCS.

	FFMQ				
	Observe	Describe	Act with Awareness	Nonjudge	Nonreact
Self-Kindness	0.241	0.205	0.254	.599**	.581**
Self-Judgment	-0.21	-0.272	-.389**	-.687**	-.577**
Common Humanity	0.166	0.056	.404**	.494**	.640**
Isolation	-0.139	-0.107	-.379**	-.738**	-.674**
Mindfulness	.428**	0.193	.345*	.604**	.704**
Over-Identification	-0.224	-0.054	-.408**	-.716**	-.724**

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Correlations between the FFMQ and SCS with the Positive and Negative Affect Schedule (PANAS) and Effortful Control and Orienting scales off the Adult Temperament Questionnaire were also explored (see Table 6). Greater levels of mindfulness and self-compassion across a number of subscales were related to greater positive affect and lower negative affect.

Table 6. Correlations between the FFMQ and SCS with the Positive and Negative Affect Schedule (PANAS) and the Adult Temperament Questionnaire (ATQ).

		PANAS		ATQ	
		Negative Affect	Positive Affect	Effortful Control	Orienting
FFMQ	Observe	-.419**	.376**	.010	.717**
	Describe	-.259	.292*	-.067	.188
	Act with Awareness	-.539**	.289	-.120	.200
	Nonjudge	-.662**	.407**	-.100	.093
	Nonreact	-.596**	.475**	-.154	.291
SCS	Self-Kindness	-.452**	.263	.106	.116
	Self-Judgment	.526**	-.510**	.145	.000
	Common Humanity	-.362*	.204	-.126	.066
	Isolation	.577**	-.524**	.191	.006
	Mindfulness	-.536**	.488**	.124	.208
	Over-Identification	.593**	-.376*	.130	-.087

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Separate one-way ANOVAs were used to test for differences between meditators and control subjects on each of the self-report measures. There were significant differences between groups on components of mindfulness, self-compassion, and attention (see Table 7). As expected, self-reported mindfulness scores (specifically,

observing and nonreactivity) were greater in meditators relative to controls. Meditators also showed greater self-compassion scores (including greater self-kindness, greater common humanity, greater mindfulness, and lower overidentification) relative to controls. Additionally, meditators had greater attentional orienting scores compared to control participants.

Table 7. Mean, standard deviation, and one-way ANOVA results comparing meditator and control participants on self-report measures.

Measure			Meditators	Controls	F Statistic
ATQ	Orienting	Mean:	5.41	4.85	F(1, 44)=5.10, p=.02
		SD:	0.82	0.84	
FFMQ	Observe	Mean:	3.94	3.49	F(1, 44)=5.80, p=.02
		SD:	0.63	0.63	
	Nonreact	Mean:	3.70	3.26	F(1, 44)=4.57, p=.038
		SD:	0.73	0.67	
Self-Compassion	Self-compassion (overall)	Mean:	3.68	3.11	F(1, 44)=5.63 p=.022
		SD:	0.74	0.87	
	Self-Kindness	Mean:	4.09	3.17	F(1,44)=17.48, p<.001
		SD:	0.54	0.9	
	Common Humanity	Mean:	4.00	3.22	F(1, 44)=6.75, p=.013
		SD:	0.95	1.09	
Mindfulness	Mean:	4.46	3.78	F(1, 44)=8.55, p=.005	
	SD:	0.5	0.99		
Overidentification	Mean:	2.41	3.11	F(1, 44)=6.31, p=.012	
	SD:	0.86	1.01		

Behavioral Analysis

Accuracy

A three-way repeated measures ANOVA was used to test for the effects of block (control, meditation, and relaxation block), trial type (congruent and incongruent type), and group (meditators and control participants) on accuracy during the flanker task. As

expected, there was a significant main effect of trial type, $F(1, 42)=100.32$, $p<.001$, such that subjects were more accurate on congruent trials ($M=.98$, $SE=.006$) relative to incongruent trials ($M=.89$, $SE=.012$). There was also a significant main effect of block, $F(2, 84)=5.214$, $p<.01$. Helmert contrasts indicate that accuracy in the control block was significantly better than accuracy in the average of the meditation and relaxation block, $F(1, 42)=7.80$, $p<.01$, such that participants were significantly more accurate in the control block than in the following two blocks. There was also an interaction between block and trial type, $F(2, 84)=9.29$, $p<.001$. There was not a main effect of group, $F(1, 42)=.153$, ns, indicating that experienced meditators and control participants were equally accurate on the task.

Reaction Time

A three-way repeated measures ANOVA was used to test for the effects of block, trial type, and group on reaction time during the flanker task. There was a significant effect of block, $F(2, 84)=24.04$, $p<.001$. Helmert contrasts indicate that subjects were slower in the control block compared to the average of the relaxation and meditation block, $F(1, 42)=29.93$, $p<.001$, and were faster in the meditation than the relaxation block, $F(1, 42)=7.29$, $p=.01$. There was a significant main effect of trial type, $F(1, 42)=485.75$, $p<.001$, such that subjects were faster when responding to congruent ($M=427.89$, $SE=10.25$) than incongruent trials ($M=487.47$, $SE=11.88$). There was not a main effect of group, $F(1, 42)=.157$, ns, suggesting that meditator and control participants did not differ in reaction time.

ERP Analysis

As described in the methods section, ERPs were computed only when there were greater than 15 useable trials to be included in the individual subject average. There was an insufficient number of trials to compute the error-and negative-feedback locked ERPs separately for meditation, relaxation, and control blocks. This was due to insufficient error-production as well as high levels of eye-blink artifact. Thus, response- and feedback-locked ERPs were analyzed across blocks, and not separately for each block. Some subjects still had an insufficient number of trials to create composite ERP measures. Thus, only participants who had a sufficient number of trials were included in the analysis.

Response-Locked ERPs

20 meditator and 18 control participants retained sufficient error-related data to compute error-related negativities, and were included in this analysis. Comparisons between meditators and control participants included in this analysis on age, education, and gender are displayed in Table 8. There were not significant differences between groups on these demographic factors. The response-locked waveforms across the entire scalp are displayed separately for correct and incorrect responses in Appendix A.

Table 8. Gender, age, and educational achievement separately for meditator and control participants included in response-locked analyses.

	Meditator	Control
N	20	18
Gender	10(F)	8(F)
Age	M=47.6, SD=18.57	M=43.56, SD=15.78
Education	M=17.5, SD=2.74	M=17.44, SD=2.55

Error-related negativity (ERN). The Error-Related Negativity (ERN) and Correct-Related Negativity (CRN) were computed as the largest negative deflections 50-150 ms post error- and correct-response, respectively. Visual inspection of the topography of the scalp potentials demonstrated that the ERN was maximal at 59 ms and showed a central distribution, with a peak near Cz (see Figure 2). Based on visual inspection of the topography, the peak negative amplitudes of 12 channels near Cz were averaged separately for the ERN and CRN.

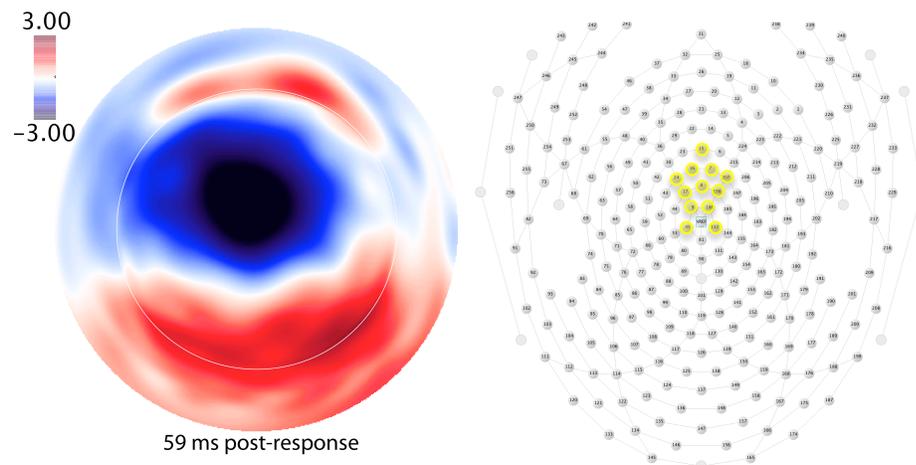


Figure 2. Topo-map view at the ERN timepoint and channels selected for ERN analysis. Darker blue regions signify greater negativity, while darker red indicates greater positivity at the scalp, with the scale spanning from $-3 \mu\text{V}$ to $3 \mu\text{V}$. At 59 ms post-response, the ERN is revealed in dark blue at the medial-central region of the scalp. Channels corresponding to the region that were selected for analysis are displayed in yellow.

A two-way repeated measures ANOVA was used to test for the effects of error type (correct and incorrect) and group (meditator and control) on amplitude. As expected, ERN amplitudes ($M=-4.83$, $SE=0.568$) were significantly larger than CRN

amplitudes ($M=-.186$, $SE=0.318$) across blocks, $F(1, 36)=58.97$, $p<.001$. However, there was no difference between meditator and control participants in either their ERN or CRN amplitude, $F(1, 36)=.191$, ns. There were also no significant correlations between the ERN amplitude with either mindfulness or self-compassion scales.

Error Positivity (Pe). The Error Positivity (Pe) and Correct Positivity (Ce) were computed as the largest positive deflection 100-400 ms post error- and correct-response, respectively. Visual inspection of the topography of the scalp potentials demonstrated that the Pe had a medialcentral distribution near Cz extending back to CPz (see Figure 3) that peaked approximately 239 ms post-response. The peak positive amplitudes of 13 channels in this area were averaged together across blocks for the Pe and Ce.

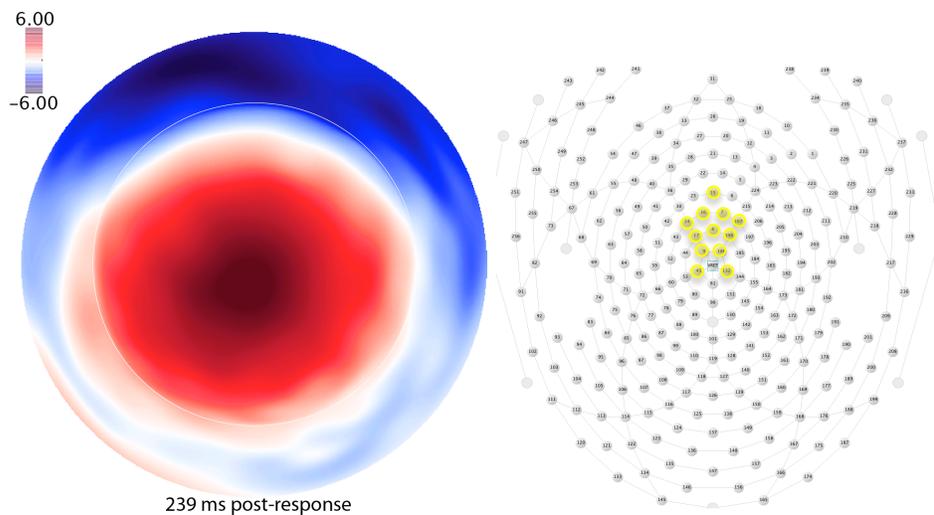


Figure 3. Topo-map view at the Pe timepoint and channels selected for Pe analysis. Darker blue regions signify greater negativity, while darker red indicates greater positivity at the scalp, with the scale spanning from $-6 \mu\text{V}$ to $6 \mu\text{V}$. At 239 ms post-response, the Pe is revealed in dark red in the medial-central region of the scalp. 13 channels corresponding to the region that were selected for Pe analysis are displayed in yellow.

A two-way repeated measures ANOVA was used to test for the effects of error type (correct and incorrect) and group (meditation and control) on amplitude. As expected, there was a main effect of error type, such that the Pe ($M=5.81$, $SE=0.533$) was significantly larger than the Ce ($M=1.93$, $SE=0.384$), $F(1, 36)=62.51$, $p<.001$. There was a marginally significant main effect of group, $F(1, 36)=4.06$, $p=.05$, such that across both the Pe and Ce, amplitudes were marginally larger for meditators ($M=5.81$, $SE=0.533$) than for controls ($M=1.93$, $SE=0.984$).

There was a significant interaction between group and trial type, $F(1,36)=5.67$, $p<.05$. Posthoc one-way ANOVAs indicate that meditators have significantly larger Pe amplitudes ($M=7.19$, $SD=3.16$) relative to controls ($M=4.42$, $SD=3.40$), $F(1, 36)=6.70$, $p<.05$, but do not differ from controls in Ce amplitudes, $F(1, 36)=.305$, ns. Response locked waveforms for 13 channels in the medial-central regions are displayed in Figure 4 to demonstrate the group differences in the Pe.

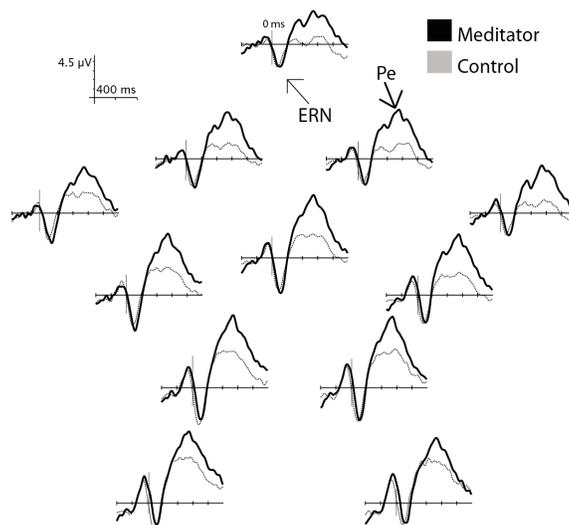


Figure 4. Error-locked waveforms displayed separately for meditator and control participants at 13 channels in the medial-central region of the scalp.

A difference measure (Pe minus Ce) was computed to explore the relationship between the Pe_{diff} amplitude with self-report measures. A number of significant relationships were revealed. Two scales from the FFMQ were positively related to the Pe_{diff} amplitude: nonreactivity, $r(38)=.360$, $p<.05$; and acting with awareness, $r(38)=.441$, $p<.01$. Self-kindness from the SCS was also positively correlated with Pe_{diff} , $r(38)=.354$, $p<.05$. Negative affect from the PANAS was negatively correlated with the Pe_{diff} amplitude, $r(38)=-.391$, $p<.05$.

To test the hypothesis that facets of mindfulness and self-compassion mediated the relationship between meditation experience and neural measures of attention, the procedures outlined by Baron and Kenny (1986) were used. To establish a mediation effect, four conditions must be met. First, the predictor variable must correlate significantly with the criterion variable. Second, the predictor must correlate with the proposed mediator. Third, the proposed mediator must correlate with the criterion. Finally, the correlation between the predictor and the outcome must be decreased when controlling for the mediator, while the mediator variable must still significantly predict the criterion.

Given the relationship between nonreactivity and self-kindness with Pe_{diff} , and the significant difference between meditator and control participants in the Pe_{diff} amplitude, mediation procedures were followed to determine if either nonreactivity or self-kindness mediated the relationship between meditation experience and Pe_{diff} . See Figure 5 for mediation results. Neither nonreactivity nor self-kindness mediated the relationship between group and Pe_{diff} amplitude.

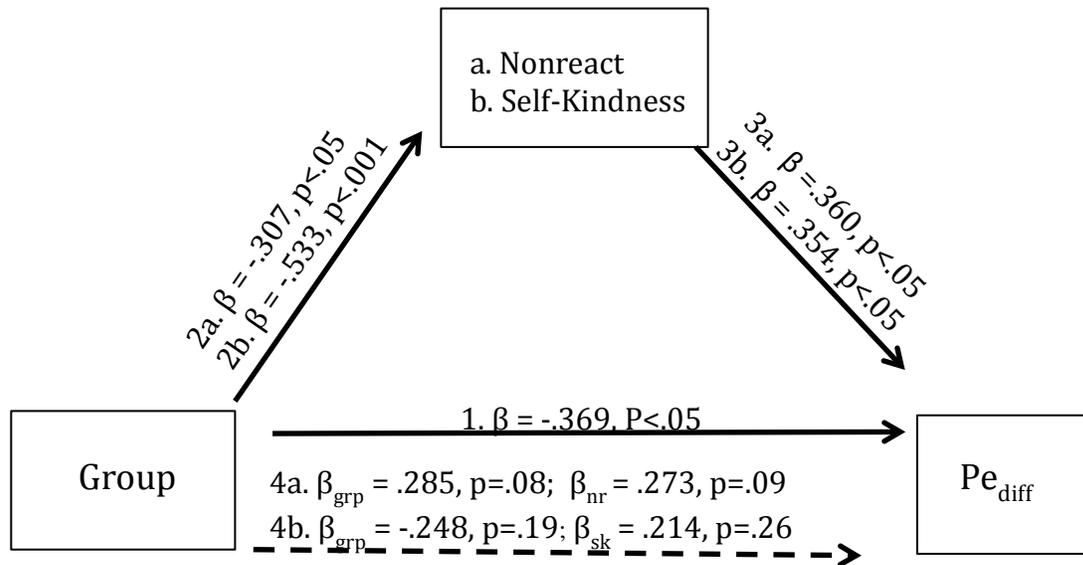


Figure 5. Mediation model results exploring the mediating roles of self-kindness and nonreactivity on the relationship between group and Pe_{diff}. (1) Step 1: Group was a significant predictor of Pe amplitude. (2) Step 2: Group was a significant predictor of both nonreact and self-kindness. (3) Step 3: Nonreact and self-kindness were significant predictors of Pe amplitude (4a) Step 4: Neither group nor nonreact were significant predictors when both were entered into the regression model. (4b) Neither group nor self-kindness were significant predictors when both were entered into the regression model.

Feedback-Locked ERP

A total of 13 meditator and 16 control participants retained sufficient negative-feedback trials to be included in the analysis. Subject demographics are displayed separately for meditator and control participants in Table 9. There were not significant differences between groups on demographic factors. Given the larger number of females in the control group for this analysis, we ran all repeated-measures ANOVAs with gender as a covariate and found no effects related to gender. For simplicity, data are presented without gender included in the model. The feedback-locked ERP across the entire scalp is displayed separately for incorrect- and correct-feedback in Appendix A.

Table 9. Gender, age, and education achievement separately for meditator and control participants included in feedback-locked analysis.

	Meditator	Control
N	13	16
Gender	6(F)	8(F)
Age	M=41.62, SD=19.11	M=42.94, SD=16.61
Education	M=16.85, SD=1.77	M=17.69, SD=2.60

The Incorrect Feedback- (FRN) and Correct Feedback- (CFRN) Related Negativity were computed as the largest negative deflection 200-400 ms post incorrect-feedback and correct-feedback, respectively. Visual inspection of the topography of the scalp potentials demonstrated that the FRN was maximal 239 ms post feedback at medial-frontal channels, near FCz (see Figure 6). The peak amplitudes of 13 electrodes in this area were averaged together across blocks for both the FRN and CFRN.

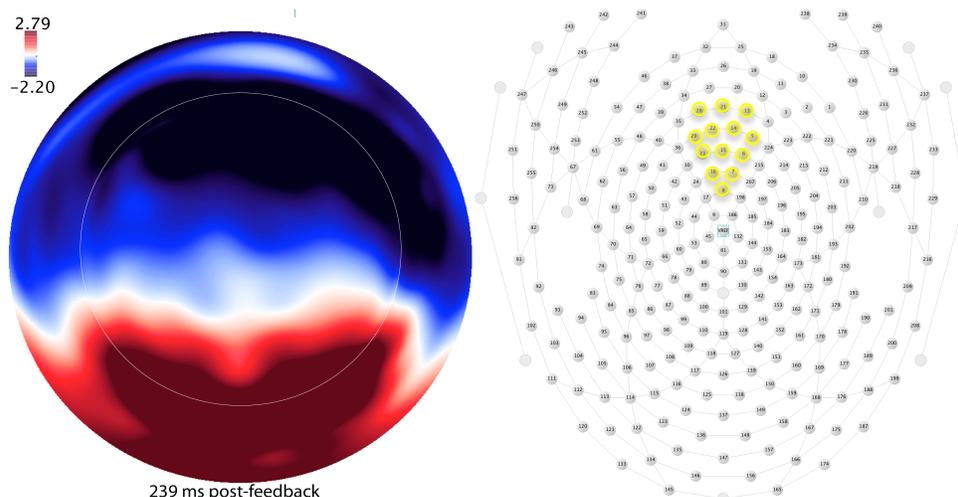


Figure 6. Topo-map view at the FRN timepoint and channels selected for FRN analysis. Darker blue regions signify greater negativity, while darker red indicates greater positivity at the scalp, with the scale spanning from $-2.20 \mu\text{V}$ to $2.79 \mu\text{V}$. At 239 ms post-feedback, the FRN is revealed in dark blue in the medial-frontal region of the scalp. 13 channels corresponding to the region that were selected for FRN analysis are displayed in yellow.

A two-way repeated measures ANOVA was used to test for the effects of feedback type (correct and incorrect) and group (meditation and control) on amplitude. Surprisingly, the magnitude of the negative deflection was not significantly larger for the FRN ($M=-2.56$, $SE=.610$) than for the CRN ($M=-2.47$, $SE=0.512$), $F(1, 27)=.032$, ns. This may suggest that the FRN is an unreliable measure of response to negative feedback because of the low number of trials that make up the averages. There was no group differences when comparing meditators to controls, $F(1, 27)=1.33$, ns. FRNs are displayed separately for meditators and controls in Figure 7.

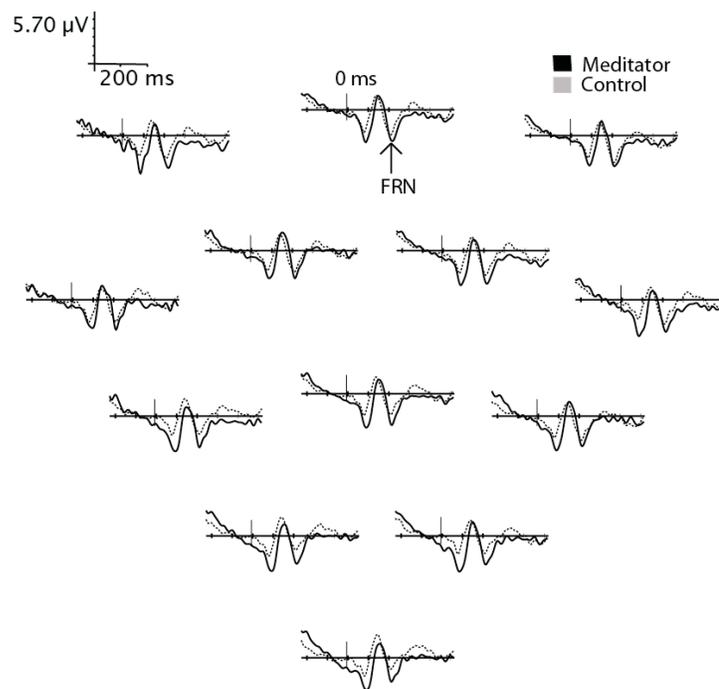


Figure 7. Negative feedback-locked waveforms separately for meditator and control participants at 13 channels in the medial-central region of the scalp.

Stimulus-Locked ERPs

Unlike the feedback- and error-related components, stimulus-locked components do not require subjects to incorrectly respond, and therefore there were more trials available for averaging. Thus, data for stimulus-locked components were analyzed for each block (Control, Meditation, and Relaxation) to determine if there was an effect of the block manipulation and any state effects of the meditation period.

A total of 20 meditators and 21 control participants were included in the analysis, as some data was lost due to artifact or computer error. Group demographics are displayed in Table 10. Given the larger number of females in the meditation group for this analysis, we ran all repeated-measures ANOVAs with gender as a covariate and found no differences related to gender. For simplicity, we are presenting the data without gender included in the model. The stimulus-locked ERP across the entire scalp is displayed separately for congruent- and incongruent trial type in Appendix A.

Table 10. Gender, age, educational achievement separately for meditator and control participants included in stimulus-locked analyses.

	Meditator	Control
N	20	21
Gender	11(F)	9(F)
Age	M=48.0, SD=18.29	M=45.76, SD=16.01
Education	M=17.50, SD=2.74	M=17.33, SD=2.48

For the P1, N1, and P1/N1 analyses, four-way repeated measures ANOVAs were used to test for the effects of laterality (right and left), trial type (congruous and incongruous), block (control, meditation, and relaxation), and group (meditation and control) on amplitude.

P1 component. The P1 was computed as the largest positive deflection 50-150 ms post-stimulus separately for congruent and incongruent trials. Visual inspection of the grand averaged waveform suggests a peak at 127 ms at lateral occipital sites, and appeared to be right lateralized (see Figure 8). Five channels in the right and five matched channels on the left near O3/O4 were averaged separately for block and trial type.

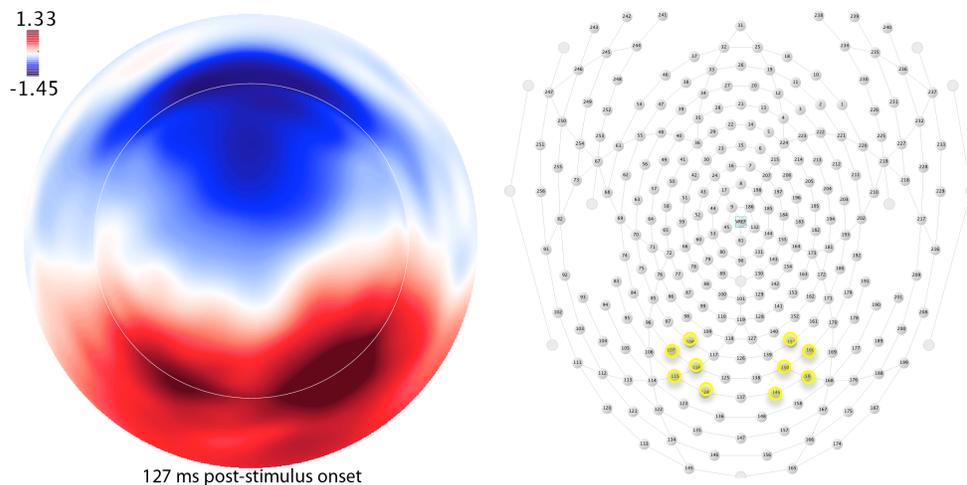


Figure 8. Topo-map view at the P1 timepoint and channels selected for P1 analysis. See Darker blue regions signify greater negativity, while darker red indicates greater positivity at the scalp, with the scale spanning from -1.45 μV to 1.33 μV . At 127 ms post-stimulus, the P1 is revealed in dark red at lateral occipital regions of the scalp. 10 channels corresponding to the right and left lateralized regions that were selected for P1 analysis are displayed in yellow.

There was a significant main effect of region, $F(1, 39)=14.29$, $p<.005$, such that P1 amplitudes were larger in the right hemisphere ($M=3.16$, $SE=.295$) than in the left hemisphere ($M=2.35$, $SE=.248$). There was also a main effect of block, $F(2, 78)=9.36$, $p<.001$. Helmert contrasts indicate that P1 amplitudes in the control block were significantly different than the average of the P1 amplitudes in the relaxation and meditation blocks, $F(1, 39)=17.15$, $p<.001$. Marginal means show that the P1 in the control block is smaller than in the relaxation and meditation blocks. There was no main effect of group, $F(1, 39)=2.05$, ns.

There was a significant interaction between trial type and group, $F(1, 39)=4.71$, $p<.05$ (See Figure 9 for ERP waveforms separately for trial type and group). Posthoc one-way ANOVAs suggests that meditators showed larger P1 amplitudes relative to controls in the congruent condition, $F(1, 40)=4.133$, $p<.05$, but not in the incongruent condition, $F(1, 40)=1.03$, ns.

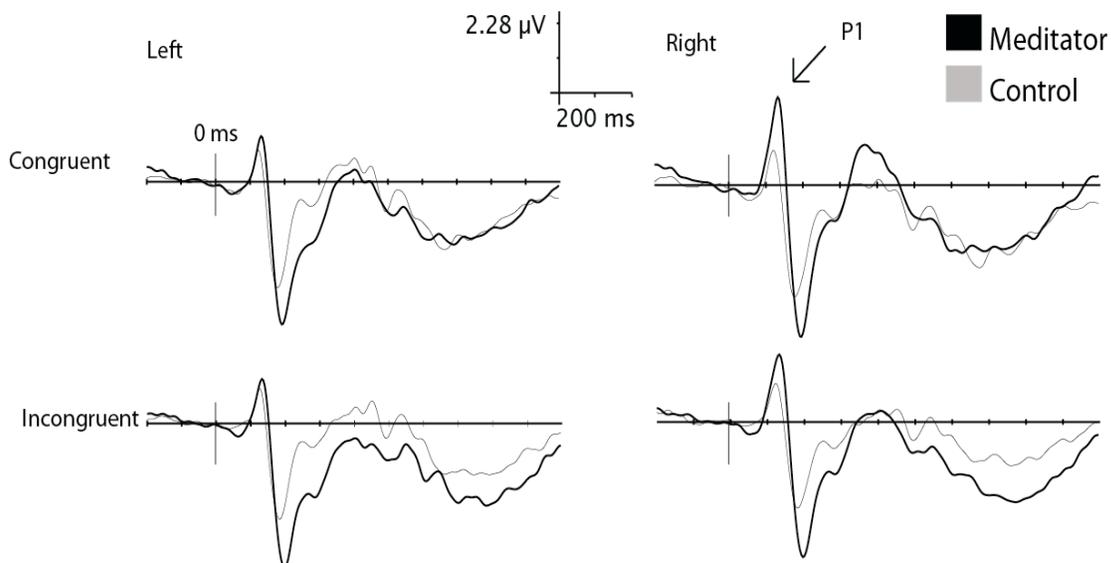


Figure 9. Stimulus-locked ERP waveform separately for right and left hemisphere and for trial type (congruent versus incongruent), with meditators and control participants displayed separately.

Given that there were no interactions between block or region with group on P1 amplitudes, and given that the difference between meditators and controls seem to occur only on congruent trials, a composite measure of the P1 was created across block and region on congruent trials to explore relationships with self-report measures. The observe scale from the FFMQ was significantly correlated with P1 amplitude in congruent trials, $r(41) = .451$, $p < .005$. Both positive and negative affect from the PANAS were also related to P1 amplitude. Negative affect was negatively related to P1 amplitude, such that greater negative affect was related to a smaller P1 amplitude on congruent trials $r(41) = -.402$, $p < .01$. Positive affect was positively related to P1 amplitude on congruent trials, $r(41) = .365$, $p < .05$. Orienting attention from the ATQ was positively correlated to P1 on congruent trials as well, $r(41) = .339$, $p < .05$. Lastly, self-kindness from the SCS was positively correlated with P1 amplitudes in congruent trials, $r(41) = .310$, $p < .05$.

Given the relationship between observe and self-kindness with P1 amplitudes, and the significant difference between meditator and control participants on observe, self-kindness, and the P1 during congruent trials, mediation procedures were followed to determine if either observe or self-kindness mediated the relationship between meditation experience and P1 amplitude. See Figure 10 for mediation results. Observe fully mediated the relationship between group and P1 amplitudes in congruent trial types, while there was no evidence that self-kindness was a mediator.

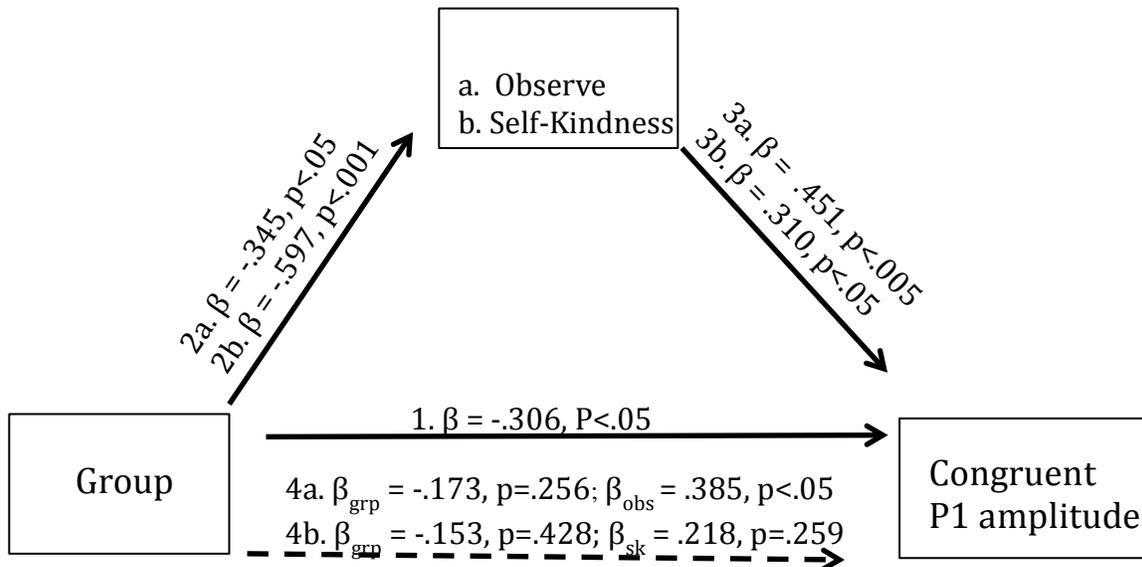


Figure 10. Mediation model results exploring the mediating role of observe and self-kindness on the relationship between group and P1 amplitude during congruent trials. (1) Step 1: Group was a significant predictor of P1 amplitude. (2) Step 2: Group was a significant predictor of both observe and self-kindness. (3) Step 3: Observe and self-kindness were significant predictors of P1 amplitude. (4a) Step 4: Group no longer predicted P1 amplitudes when controlling for observe, while observe remained a significant predictor, providing evidence for full mediation. (4b) Neither group nor self-kindness were significant predictors when both were entered into the regression model.

N1 component. The N1 was computed as the largest negative deflection 150-250 ms post-stimulus separately for congruent and incongruent trials. Visual inspection of the grand averaged waveform suggests a peak at about 195 ms across the entire occipital region (see Figure 11). Five channels on the right and five matched channels on the left near O3/O4 were averaged separately for block and trial type.

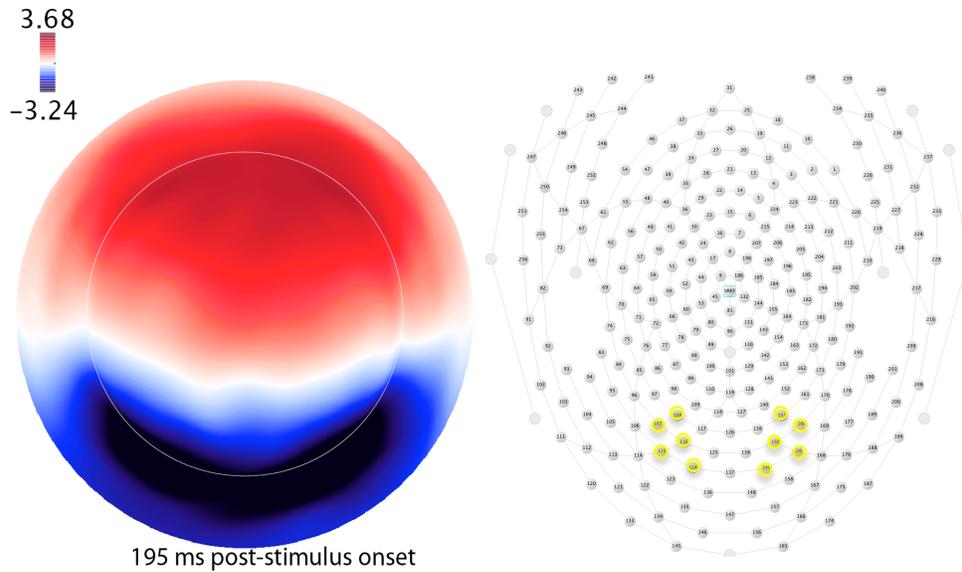


Figure 11. Topo-map view at the N1 timepoint and channels selected for N1 analysis. Darker blue regions signify greater negativity, while darker red indicates greater positivity at the scalp, with the scale spanning from $-3.24 \mu\text{V}$ to $3.68 \mu\text{V}$. At 195 ms post-stimulus onset, the N1 is revealed in dark blue at occipital regions of the scalp. 10 channels corresponding to the right and left lateralized regions that were selected for N1 analysis are displayed in yellow.

For the effect of block, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated ($\chi^2(2) = 8.753, p < .05$). Thus, for effects of block, the Greenhouse-Geisser corrected degrees of freedom were used to determine significance.

There was a main effect of trial type, $F(1, 39) = 7.88, p < .01$, such that subjects showed larger N1 amplitudes in the congruent condition ($M = -5.45, SE = .382$) compared to the incongruent condition ($M = -5.15, SE = .418$). There was also a main effect of block, $F(1.66, 78) = 26.27, p < .01$. Helmert contrasts indicate that this effect is due to the difference between the N1 amplitude in the control block compared to the average of the meditation and relaxation block, $F(1, 39) = 38.08, p < .001$. Marginal means indicate that

the N1 amplitude is smaller in the control block when compared to relaxation and meditation block.

There was a marginally significant effect of group on N1 amplitude, $F(1, 39)=3.76$, $p=.06$, such that N1 amplitudes were larger for meditators ($M=-6.07$, $SE=.454$) than for controls ($M=-4.53$, $SE=.554$). There was a marginally significant interaction between block and group, $F(1.66, 78)=3.062$, $p=.06$. This interaction was explored with three separate one-way ANOVAs, one for each block, investigating the effect of group. Group difference in N1 amplitude was only significant in the relaxation block, $F(1, 39)=5.57$, $p<.05$, such N1 amplitudes were larger in the meditator group ($M=-6.67$, $SD=3.12$) than in the control group ($M=-4.71$, $SD=2.14$). No group differences were found in N1 amplitudes during the control or meditation block (see Figure 12).

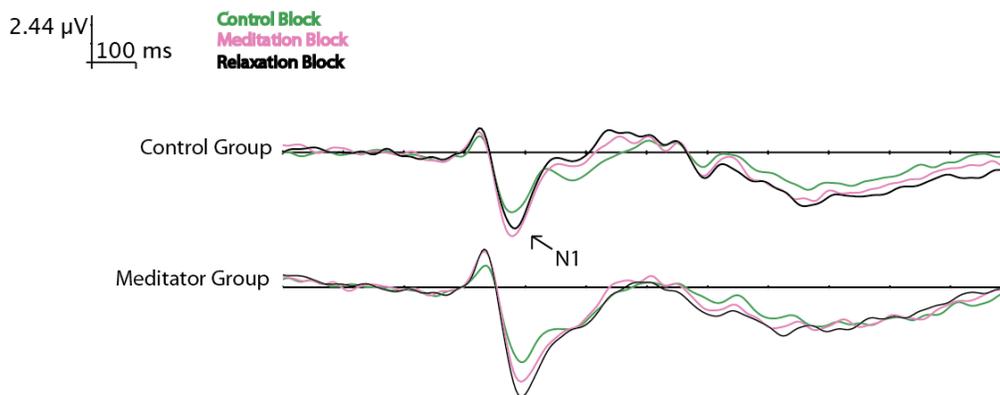


Figure 12. Response-locked waveforms separately for block and group.

Given that there were no interactions between trial type or region with group on the N1 amplitude, and the difference between meditators and controls seem to be most evident during the relaxation block, we created a composite measure of the P1 across trial type and region during the relaxation block to explore relationships with self-report measures. Self-kindness was marginally correlated with N1 amplitudes during relaxation block, $r(41)=-.296$, $p=.06$. Once again, a mediation model was tested. There was no evidence of mediation.

P1/N1 complex. To explore selective attention effects across both the P1 and N1, the P1/N1 was computed by subtracting the N1 amplitude from the P1 amplitude. There was a main effect of region, $F(1, 39)=5.20$, $p<.05$, such that the P1/N1 was larger in the right ($M=8.59$, $SE=.583$) compared to the left ($M=7.52$, $SE=.483$) hemisphere. There was a main effect of trial type, $F(1, 39)=5.60$, $p<.05$, such that the P1/N1 was larger to congruent ($M=8.18$, $SE=.486$) than to incongruent ($M=7.93$, $SE=.482$) trials. There was a main effect of block, $F(2, 78)=28.73$, $p<.001$. As with the P1 and N1 amplitudes, Helmert contrasts indicate that this was driven by a smaller P1/N1 in the control block compared to the average P1/N1 in the relaxation and meditation blocks, $F(1, 39)=48.93$, $p<.001$. There was a main effect of group, $F(1, 39)=5.48$, $p<.05$, such that meditators ($M=9.18$, $SE=.689$) showed a larger P1/N1 when compared to controls ($M=6.93$, $SE=.672$) (See Figure 13).

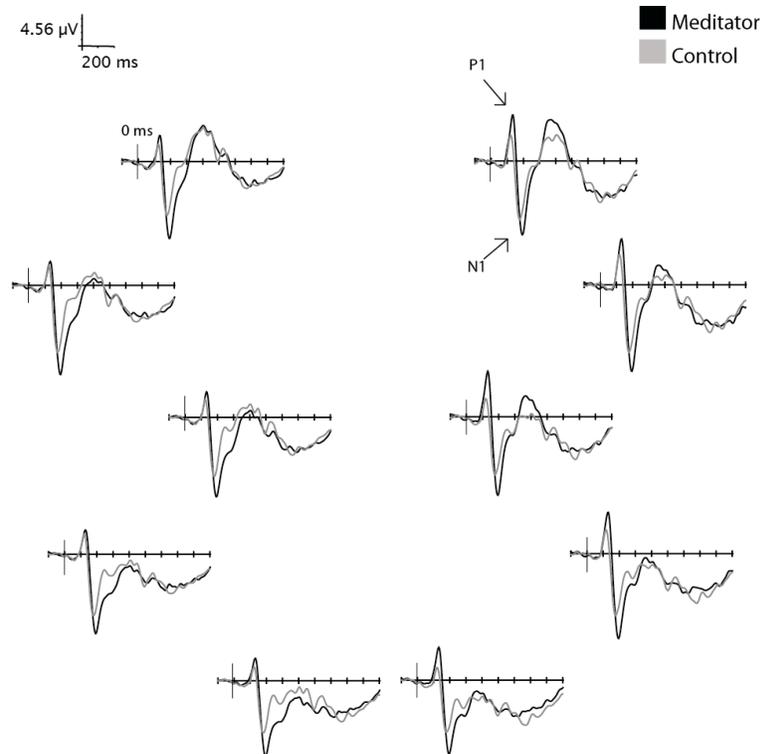


Figure 13. Stimulus-locked ERPs for left and right lateral occipital channels separately for meditator and control participants.

Given that there was no interaction between trial type, region, or block with group on the P1/N1, we created a composite measure to get one P1/N1 total score. We explored the relationship between self-report measures on the P1/N1 composite score. Negative affect from the PANAS was negatively associated with the P1/N1, $r(41)=-.327$, $p<.05$, such that individuals with greater negative affect had a smaller P1/N1. Self-kindness was positively associated with the P1/N1, $r(41)=.362$, $p<.05$, such that individuals with greater levels of self-kindness showed a larger P1/N1. Effortful control from the ATQ was positively related to the P1/N1, $r(41)=.330$, $p<.05$, such that individuals with greater levels of effortful control showed a larger P1/N1.

Given that meditators showed significantly greater self-kindness scores, and showed a larger P1/N1, we tested a mediation model to determine if self-kindness mediated the relationship between group and P1/N1. There was no evidence that self-kindness mediated the relationship between group and P1/N1.

P3b component. The P3b was computed as the largest positive deflection 300-550 ms post-stimulus separately for congruent and incongruent trials. Visual inspection of the waveform demonstrated a diffuse component that was maximal at 439 ms post stimulus at central channels (see Figure 14). Five central channels from this region were selected and averaged separately for each block and trial type.

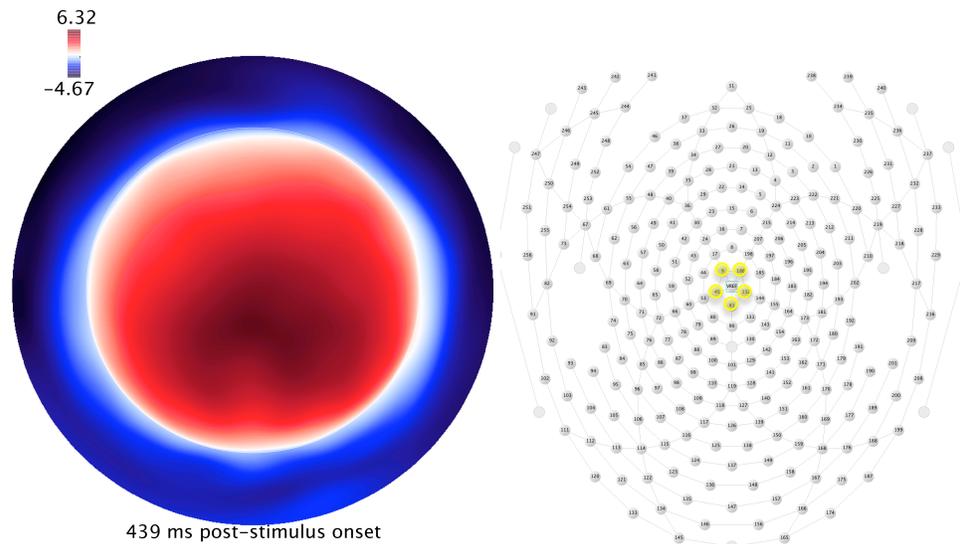


Figure 14. Topo-map view at the P3 timepoint and channels selected for P3 analysis. Darker blue regions signify greater negativity, while darker red indicates greater positivity at the scalp, with the scale spanning from $-4.67 \mu\text{V}$ to $6.32 \mu\text{V}$. At 439 ms post-stimulus onset, the P3 is revealed in dark red at central of the scalp. 5 corresponding central regions that were selected for P3 analysis are displayed in yellow.

A three-way repeated measures ANOVA was used to test for the effects trial type (congruous and incongruous), block (control, meditation, and relaxation), and group (meditation and control) on P3 amplitude.

There was a main effect of block, $F(2, 39)=42.87, p<.001$. Helmert contrasts suggest that this was driven by a difference between the P3 in the control block compared to the average of the relaxation and meditation block, $F(1, 39)=81.135, p<.001$. Marginal means demonstrate that the P3 in the control block is smaller than in the relaxation and meditation block.

There was a significant interaction between trial type and group, $F(1, 39)=5.81, p<.05$ (see Figure 15). Posthoc analyses on a composite congruent P3 and a composite incongruent P3 averaged across blocks shows that the difference between meditators and controls is evident for congruent trial types, $F(1, 39)=5.58, p<.05$, but not for incongruent trial types, $F(1, 39)=.71, ns$. During congruent trials, meditators showed larger P3 amplitudes ($M=8.40, SE=.611$) relative to controls ($M=6.38, SE=.645$).

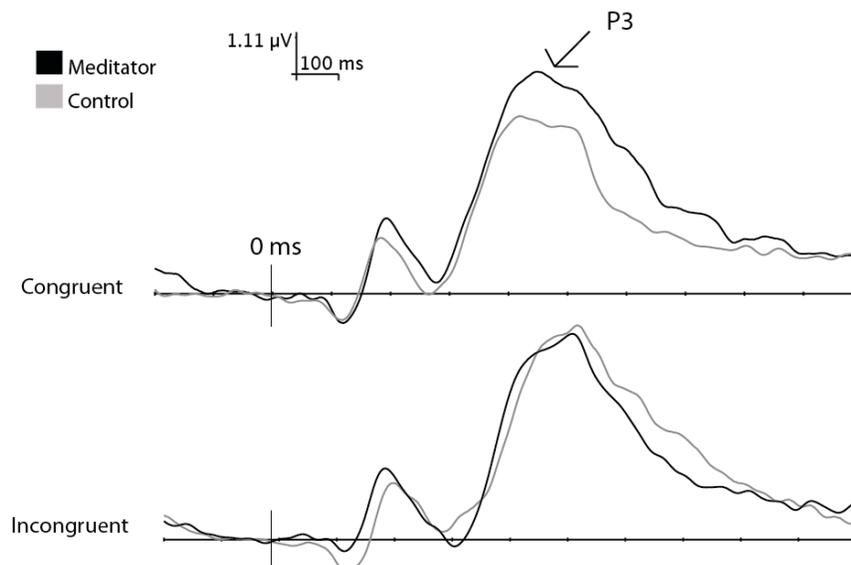


Figure 15. Stimulus-locked waveforms separately for trial type (congruent versus incongruent) and group (meditator versus control).

Given that there was no interaction between block and group on P3 amplitudes, and that the difference between meditators and controls seem to be evidence only during the congruent trials, we created a composite measure across block for congruent trial types to explore relationships with self-report measures. Only self-kindness was related to P3 amplitude in the congruent condition, $r(41)=.312$, $p<.05$. Once again, we tested a mediation model to determine if self-kindness mediated the relationship between group and P3 amplitudes, but did not find evidence of partial or full mediation.

Relationships among ERP Components

We explored relationships among the ERP components. P3 amplitudes during congruent trials were significantly correlated with the difference between the P1 to congruent trials than the P1 to incongruent trials, $r(41)=-.451$, $p<.005$, such that individuals with larger P3 amplitudes had larger P1 amplitudes to congruent than incongruent trials. Congruent P3 was also related to Pe amplitudes, $r(36)=.360$, $p<.05$, such that larger P3 amplitudes were related to larger Pe amplitudes. Congruent P3 was also related to N1 amplitudes across blocks and trial type, $r(41)=-.392$, $p<.05$, such that individuals with larger P3 amplitudes also showed larger N1 amplitudes.

In addition to the relationship with the congruent P3, Pe was significantly related to ERN amplitudes, $r(36)=-.468$, $p<.005$, such that those with larger Pe amplitudes had larger ERN amplitudes as well. Pe amplitude was also significantly correlated with N1 amplitude, $r(36)=.574$, $p<.001$, such that those with larger Pe amplitudes showed larger N1 amplitudes.

Spectral Analysis

The analysis of percentage alpha and theta spectral power was completed by performing a three-way repeated measures ANOVA to test for the effect of group (meditator and control), laterality (left versus right) and cortical zone (frontal, central, parietal, and occipital) separately for theta and alpha frequency bands.

For percentage theta power, there were no main effects or interactions. There was no main effect of group, $F(1, 40)=1.21$, ns.

For percentage alpha power, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated for both region ($\chi^2(5) = 18.63, p < .01$) and for region x laterality ($\chi^2(5) = 15.5, p < .01$). For these comparisons, the Greenhouse-Geisser corrected degrees of freedom were used. There was a marginally significant main effect of region, $F(2.28, 120)=2.89, p=.05$, such that alpha was larger in occipital and parietal regions compared to central and frontal regions. There was also a significant interaction between region and laterality, $F(2.41, 120)=3.16, p<.05$. Importantly, there was a main effect of group, $F(1, 40)=5.88, p<.05$, such that meditators ($M=.218, SE=.009$) showed greater percentage alpha power relative to controls ($M=.190, SE=.008$).

Given that there was no interaction between group, region, or laterality, a composite percentage alpha score was computed across region and laterality to explore relationships with self-report measures. The only significant relationship between alpha and self-report measures was with self-kindness, $r(42)=.313, p<.05$, such that individuals with greater alpha power during meditation reported greater levels of self-kindness.

We also explored the relationship between alpha and theta band activity during meditation with ERP measures. There were no significant relationship between theta

band activity and ERP measures. There was a significant positive relationship between the P1/N1 and alpha power, $r(39)=.337$, $p<.05$, such that individuals with greater alpha power during meditation showed larger P1/N1 components during the task (See Figure 16).

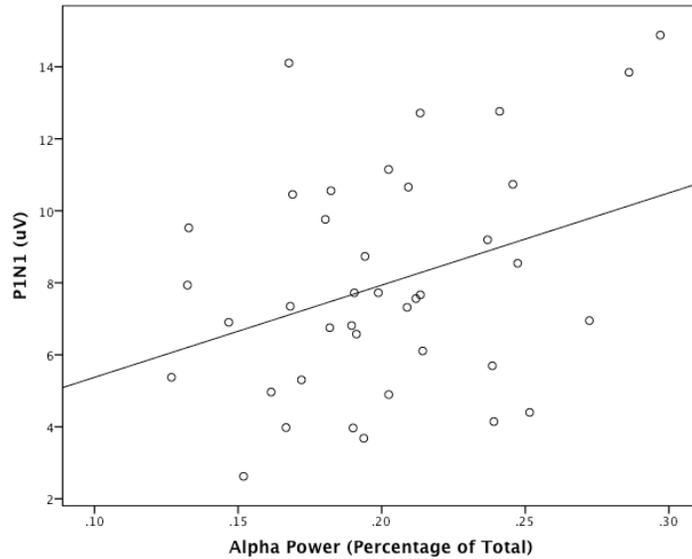


Figure 16. Percentage of alpha power plotted with P1/N1 amplitude.

Length of Experience with Meditation

We explored relationships between the number of years of practice meditators endorsed and self-report measures. After controlling for age, years of practice significantly predicted self-reported self-kindness, $\beta=.629$, $p<.05$.

We also explored relationships between the number of years of practice meditators endorsed with ERP measures and alpha power. Total years of meditation was significantly related to the Pe_{diff} score, $r(20)=.2445$, $p<.05$, such that individuals with

more experience showed a larger difference between their Pe and Ce amplitudes (see Figure 17). Controlling for age, the relationship becomes marginally significant, $\beta = .543$, $p = .06$.

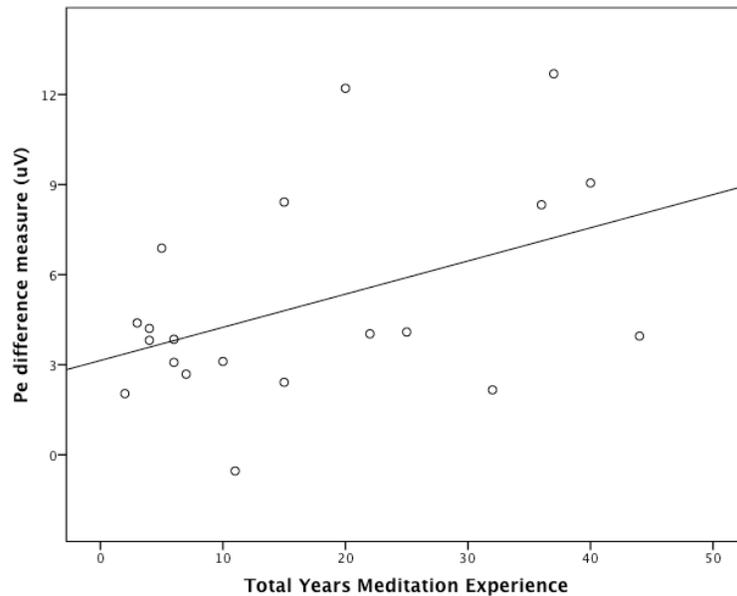


Figure 17. Pe_{diff} plotted by years of meditation experience.

Source Analysis

We explored significant scalp differences in source space by comparing the source solutions for meditator and control participants.

P1 Timepoint (123 ms Post-Stimulus Onset)

Given the marginally significant interaction between trial type and group on the P1 during congruent trials, we explored the P1 to congruent trials in source space separately for meditators and controls (See Figure 18). As expected based on previous research examining the source of the P1, meditators and control participants both had a

maximal source in extrastriate cortex, in both BA 18 and 19. Sources were stronger on the left than the right hemisphere. Compared to controls, meditators demonstrated stronger sources overall. In addition to sources in extrastriate cortex, meditators also showed a source in the posterior cingulate cortex, a source that was not evident in the control group at this timepoint.

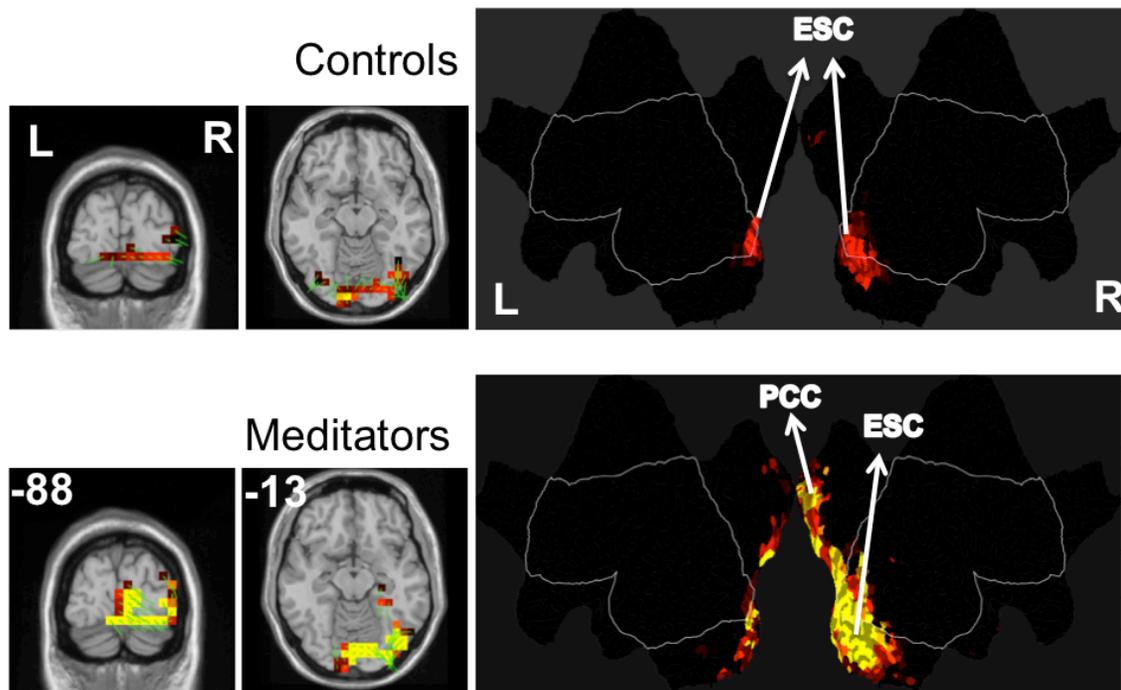


Figure 18. Source results at 123 ms post-stimulus onset, the timepoint of the P1 peak. ESC: Extrastriate Cortex; PCC: Posterior Cingulate Cortex.

N1 Timepoint (194 ms Post-Stimulus Onset)

We compared the source solutions for meditator and control participants at the maximal peak of the N1 at 194 ms during the relaxation block (See Figure 19). As expected, both groups showed sources in BA 18 and 19, in extrastriate regions. However, the strongest sources were in the mid-occipital gyrus for both groups. There was also a source in the posterior cingulate cortex. Sources were similar in both groups, but like at the P1 timepoint, were much stronger for the meditator group.

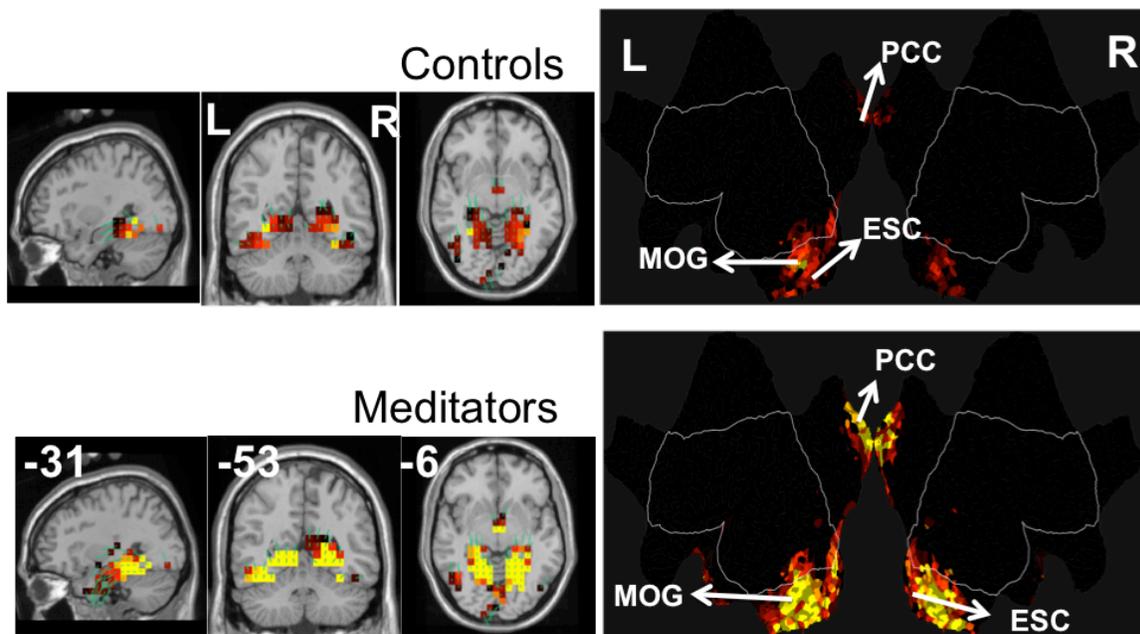


Figure 19. Source results at 194 ms post-stimulus onset, at the timepoint of the N1 peak. ESC: Extrastriate Cortex; PCC: Posterior Cingulate Cortex; MOG: Mid-Occipital Gyrus.

P3b Timepoint (437 ms Post-Stimulus Onset)

We explored the source solutions for meditator and control participants during congruent trials at the maximal peak of P3b at 437 ms post-stimulus onset. Both groups demonstrated sources maximal in the temporal lobe, including superior temporal, mid-temporal, inferior temporal, and the temporopolar cortex. Both groups displayed parahippocampal and entorhinal sources as well. In addition to these temporal sources, meditator and control participants had a source in the subgenual ACC. As evidenced in Figure 20, meditators showed much greater activity overall compared to controls. In addition, meditation practitioners had additional sources in ventrolateral PFC and the PCC.

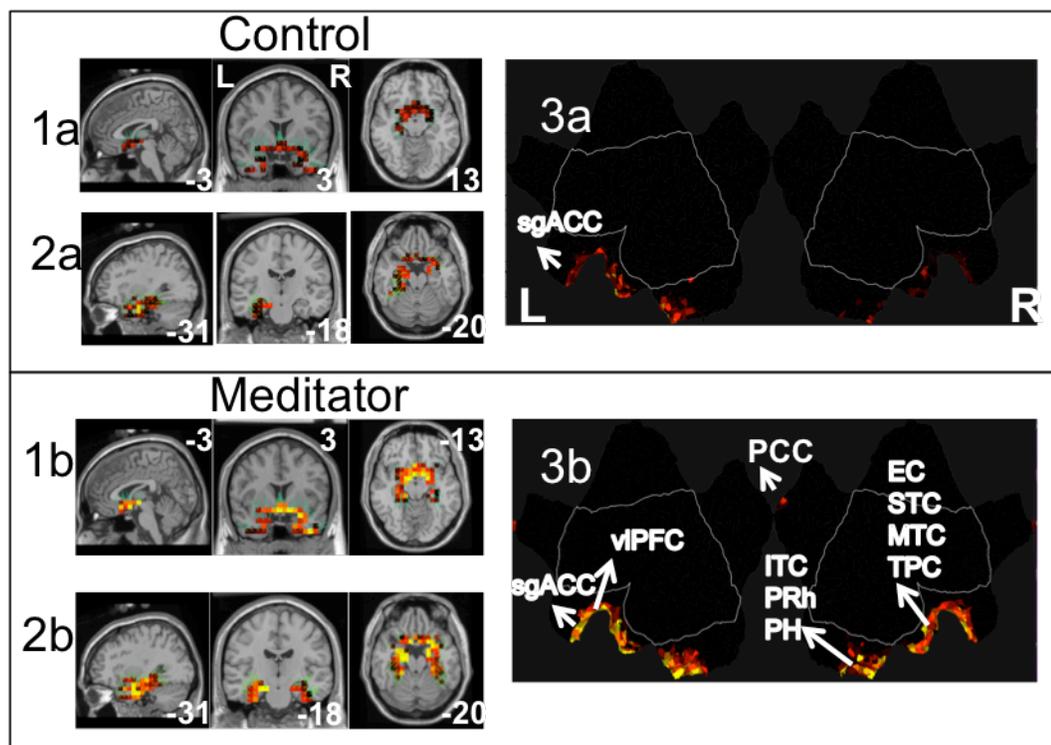


Figure 20. Source results at 437 ms post-stimulus onset, the timepoint of the P3 peak. (1) medial sources were maximal. (2) medial-temporal sources were maximal. 3) PCC: Posterior Cingulate Cortex; ITC: inferior temporal; PRh: Perirhinal; PH: Parahippocampal; EC: entorhinal; STC: superior-temporal cortex; MTC: mid-temporal; TPC: temporal-polar cortex; vIPFC: ventrolateral prefrontal cortex;

Pe Timepoint (259 ms Post-Response)

We explored the source solutions for meditator and control participants during incorrect trials at 259 ms post-response, the peak of the Pe. We expanded our threshold for activation for the Pe because leaving only the top 30% of the variance resulted in no sources reaching threshold for the control group. Thresholding for the Pe and ERN included the top 50% of sources. Both meditators and control participants demonstrated sources in the medial temporal lobe, including sources in the inferior-temporal, medial-temporal, and temporal pole (see Figure 21). Both groups had sources in subgenual ACC as well. Once again, meditator participants showed greater activity across all regions. In addition to these sources, meditators frontal sources extended to the orbital frontal cortex (OFC), which were not evident in the thresholded control participants source results.

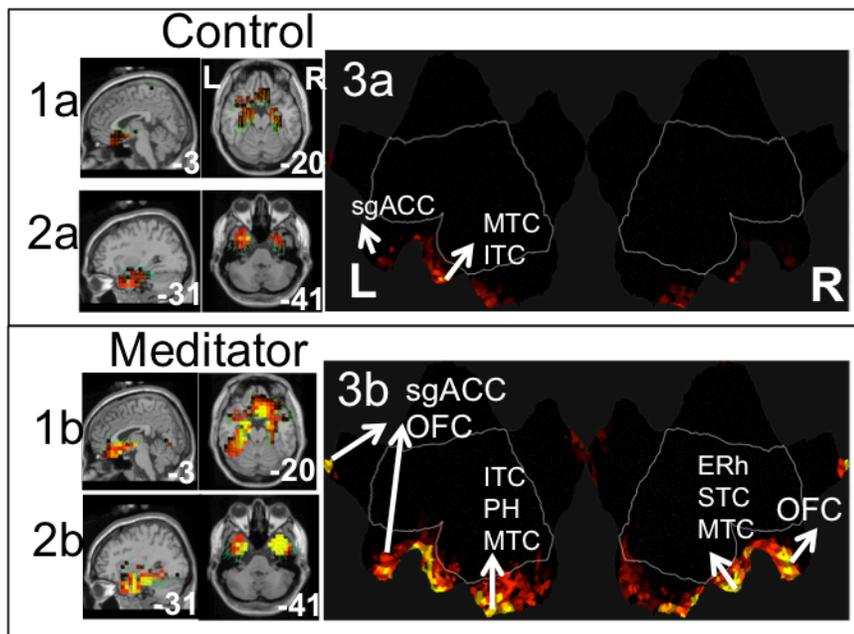


Figure 21. Source results at 259 ms post-response, at the timepoint of the Pe peak. (1). medial sources were maximal. (2) medial-temporal sources were maximal. 3) OFC: orbitofrontal cortex; see figure 20 for abbreviation key.

ERN Timepoint (59 ms Post-Response)

While there were not significant differences at the scalp for the ERN, *a priori* hypotheses about source results led us to explore differences in source space for meditator and control participants. These results are exploratory in nature and should be interpreted with caution. We explored the source solutions for meditator and control participants during incorrect trials at 59 ms post-response, the peak of the ERN (see Figure 22). Meditators and controls both demonstrated a large source in the midcingulate region. In addition to this source, meditators had an additional source in the posterior cingulate cortex, a source in the mid-temporal lobe, as well as an additional source in the left dlPFC. Control participants did not show sources in dlPFC or the posterior cingulate. Instead, controls showed an additional source in the OFC.

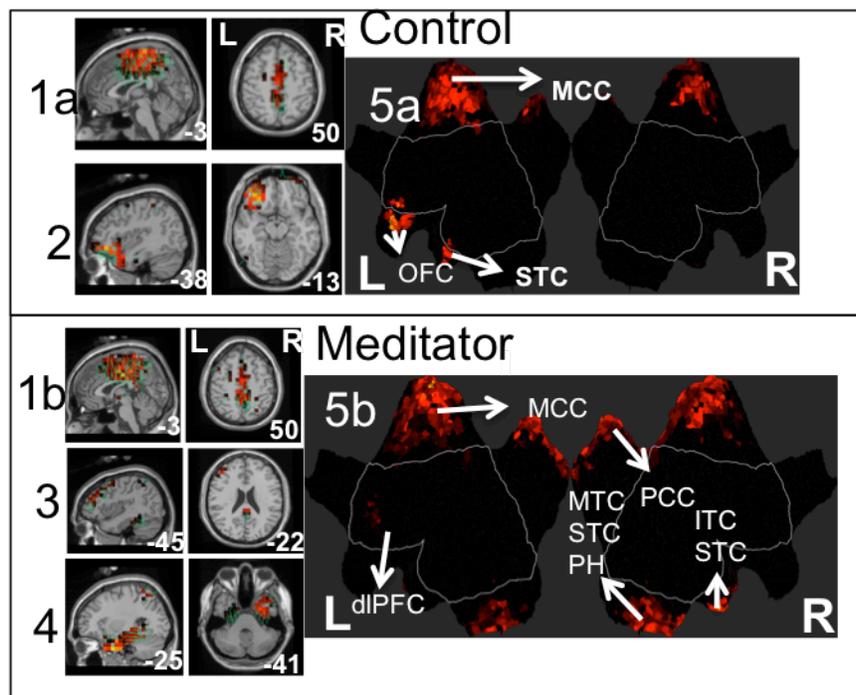


Figure 22. Source results at 59 ms post-response, at the timepoint of the ERN peak. (1). Maximal midcingulate sources. (2) orbitofrontal sources for control group. (3) left dorsolateral prefrontal source in meditator group. (4) mid-temporal sources (5) MCC: midcingulate cortex; See figure 20 for additional abbreviation key.

CHAPTER IV

DISCUSSION

The purpose of this dissertation was to explore how meditation practice affects attention and self-monitoring. By integrating self-report and neural measures of attention and self-monitoring into a single study design, a more thorough investigation was made into the alterations in attention and self-monitoring related to meditation practice. Group comparisons revealed interesting differences in ERP measures, alpha power, and source results when comparing meditator to control participants, and correlational analyses suggested a complicated relationship between mindfulness, self-compassion, and neural measures of attention. The current study provides valuable insights into how attention is altered with meditation practice, which may have implications for how mindfulness interventions improve psychological health and wellbeing.

Mindfulness and Self-Compassion

Individuals with meditation experience showed greater mindfulness and self-compassion on a number of subscales relative to controls. Meditators showed greater levels of observing, which indicates that they are better able to notice and pay attention to thoughts, emotions, and experiences than control participants. They also showed greater levels of nonreactivity, which suggests that they are better able to remain neutral and objective in the face of painful emotions and thoughts relative to controls. Previous research has found similar increases in these facets of mindfulness with meditation practice (Baer et al., 2008). Somewhat surprisingly, meditators did not show significantly greater levels of mindfulness as measured by the FFMQ scales acting with

awareness, describing, or nonjudgment of experiences. Thus, meditators were not superior to controls in attention to the present moment, in their ability to describe emotion, or in judgment of their thoughts and feelings.

Meditators were different from controls in four of the six facets of self-compassion, including self-kindness, common humanity, mindfulness, and over-identification. Specifically, meditators had greater self-kindness scores, which suggests that they are more understanding and caring to themselves compared to control participants. They had greater levels of common humanity, indicating that they see their own failings as part of a larger human condition more so than controls. Greater mindfulness scores suggest that they are better able to keep their emotions in balance relative to controls. Meditators lower levels of overidentification relative to controls indicate that they fixate on their negative emotions at a lower rate than control subjects. Importantly, more years practicing meditation was related to greater levels of self-kindness, suggesting that more time practicing meditation is related to the cultivation of greater self-compassion.

These findings support the development of some facets of mindfulness and self-compassion with meditation experience, which is consistent with previous research (Lykins & Baer, 2009; Orzech, Shapiro, Brown, & McKay, 2009). Meditators are better at observing the content of experience without reacting to or overidentifying with their content. This may lead to the development of self-kindness, as individuals feel some distance from their emotional experiences.

Facets of self-reported mindfulness and self-compassion were linked to higher positive affect and lower negative affect. Higher scores on all facets of the SCS and all

facets of the FFMQ except ‘describe’ were related to lower levels of negative affect. Higher scores on all factors of mindfulness except acting with awareness, greater levels of mindfulness from the SCS, and lower levels of self-judgment, isolation, and over-identification from the SCS were related to greater positive affect. While these qualities are linked to decreases in negative affect and increases in positive affect, it is unclear how they may be related to meditation experience given that the groups did not differ in their levels of positive and negative affect.

Accuracy and Reaction Time

The current study found no group differences in reaction time or accuracy. A number of studies assessing attention using the ANT task, which is modified from the flanker task, have shown superior performance on flanker trials in long-term meditators compared to controls (van den Hurk et al., 2010; Jha, Krompinger, & Baime, 2007). There are a number of potential reasons why the present study did not find differences between groups. Importantly, the increased monetary incentive provided to all participants may have led to superior motivation, thus equalizing performance differences across groups. As shown by Jensen and colleagues (2012), motivation plays an important role in the attention differences found when comparing individuals with mindfulness experience to a control group. In their study, comparisons to a control group who received monetary compensation to increase motivation showed far fewer differences in performance across attention tasks. Thus, in the present study, providing an incentive may have equalized performance by equalizing motivation. In addition, the task included salient accuracy and speed feedback, which encouraged participants to increase their reaction time as their speed slowed, and be more aware of their errors to increase

accuracy. With different task demands (i.e., no incentive to motivate superior performance and no feedback about accuracy and reaction time), group differences may have been evident.

Attention

Individuals with meditation experience relative to control participants showed enhanced attentional capacity across a number of neural measures of attention. This is consistent with behavioral research demonstrating superior performance in meditators relative to controls on a number of attention tasks and improved performance on measures of attention after mindfulness intervention (Chiesa, Calati, & Serretti, 2011). The pattern of difference between groups, and relationship with self-report measures, provide additional insight into how attention is altered with meditation experience.

Overall, experienced meditators showed a larger P1/N1 complex relative to controls. The P1/N1 has been implicated in selective attention, and is enhanced to attended stimuli relative to unattended stimuli (Hillyard, Vogel, & Luck, 1998). This finding suggests that individuals with mindfulness experience were able to amplify neural activity in sensory processing areas to increase attentional capacity toward the stimulus. Source solutions for the P1/N1 provide evidence for this increase in neural activity in meditators, who demonstrated greater activity in extrastriate cortex, a region implicated in selective attention (Mishra & Hillyard, 2009), relative to controls. The practice of meditation may repeatedly engage mechanisms of selective attention, and this repetition may allow practitioners to flexibly deploy selective attention in novel tasks.

When looking at the P1 and N1 amplitudes separately, instead of as a singular complex, a more specific mechanism is suggested, such that meditation may facilitate

early visual processing in the absence of interference. P1 amplitudes were enhanced in the meditation group relative to control participants during congruent trials, but not during incongruent trials. The target matches the flankers during congruent trials, unlike in incongruent trials, where the target is dissimilar to the flankers. Incongruent trials put greater demands on the participant by increasing the level of conflict in stimulus processing. Subjects are generally less accurate and slower to respond during incongruent trials, as greater attention is allocated to the stimulus to determine the appropriate response. In contrast, less attention may be necessary to correctly respond to congruent trials. This may suggest that meditators were able to allocate greater attention to the flanker array when task difficulty decreased, while control participants decreased attentional deployment with lower conflict. Importantly, the P1 is enhanced when individuals are suppressing attention to unattended stimuli (Talsma & Woldorff, 2005). Thus, it may be that meditators were better able to suppress attention to distractions under conditions of lower conflict. This suppression may have been related to activity in the posterior cingulate cortex (PCC), a source revealed in the source solution for meditator participants but not for controls. The involvement of the PCC in visual attention has been reported in several studies (Bussey, Muir, Everitt, & Robbins, 1997; Turak, Louvel, Buser, & Lamarche, 2002), and has been implicated in directing the focus of visual attention (Lynch, Mountcastle, Talbot, & Yin, 1977), potentially through covert spatial orienting (Corbetta et al., 1998; Dean, Crowley, & Platt, 2004). Activation of the PCC in meditator participants, as well as increased activity in extrastriate regions, may have facilitated early visual processing in the absence of conflict.

Interestingly, the N1 amplitude was most enhanced in meditators relative to controls during the relaxation block. Across trial type and block, N1 amplitudes were larger in meditators relative to controls. The N1 has been shown to facilitate processing of attended information (Hillyard, Vogel, & Luck, 1998). Thus, meditators were able to facilitate processing to attended information across the task, for both congruent and incongruent trial types. However, the difference between groups was greatest in the relaxation block. It may be that after progressive relaxation, the state of relaxation led to lower facilitation of processing to attended stimuli for control participants, while meditators were able to enhance their attentional deployment. Source results provide evidence of sources in extrastriate cortex, mid-occipital gyrus, and posterior cingulate gyrus in the meditator group in both groups, with greater activity across all regions for meditator participants. Extrastriate and mid-occipital sources for the N1 to selective attention have been demonstrated in previous studies (Novitskiy et al., 2011; Martinez, Ramanathan, Foxe, Javitt, & Hillyard, 2007; Mangun, Buonocore, Girelli, & Jha, 1998). The source results demonstrate that regions associated with selective attention are more active in meditator participants, particularly after relaxation, suggesting that they may be utilizing more processing resources relative to controls.

Similarly, P3b amplitudes were enhanced only during congruent trials in meditators relative to controls. The P3b indexes the maintenance of target features in working memory for comparison with the current stimulus (Polich, 2007). Individuals with meditation experience maintained a higher level of attention to the stimuli in order to determine the identity of the target stimulus during congruent trials. This is consistent with research that has found greater peak P300 amplitudes after meditation relative to

before meditation (Sarang & Telles, 2006) and in meditation practitioners relative to controls (Banquet & Lesevre, 1980). Source solutions reveal greater activity across the temporal lobe as well as in hippocampal and parahippocampal regions in both groups. These findings are supported by previous research on the sources of the P3b (Bledowski et al., 2004; Halgren et al., 1998), which implicates the medial temporal lobe in generating the P3b. The activity in the temporal lobe and parahippocampal regions is likely involved in memory processes, as participants seek to identify the target by comparing to representations held in memory to determine the correct response. Across these regions, meditator participants showed greater activity relative to controls, suggesting greater utilization of these regions for facilitating late attentional processes in the absence of conflict.

Individuals with mindfulness experience also showed a greater percentage of alpha power during meditation relative to controls. Greater alpha power has been linked to attentional control (Palva & Palva, 2007). Thus, individuals who have a mindfulness practice were likely better able to attend during the instructed breath meditation exercise, providing some evidence that they are in fact utilizing attentional mechanisms during meditation. In addition, greater percentage of alpha power during meditation was related to an enhancement in the P1/N1 complex during the attention task. This is consistent with previous literature, which has shown that P1/N1 components are generated by phase synchronization of frequencies in the alpha range (Makeig et al., 2002; Gruber et al., 2005). The attentional capacity practiced during meditation is related to greater facilitation of early selective attention to stimuli during the flanker task, suggesting that

the attentional benefits of meditation may generalize outside of the meditation environment.

Together, meditators enhanced P1, N1, P3b amplitudes, and alpha power relative to controls suggest that individuals with mindfulness experience were able to facilitate processing in attentional networks to increase sustained attention and suppress distraction more readily than controls, especially without interference and after relaxation. There is some evidence for greater activation in regions related to attention in meditators relative to controls (Lazar et al., 2000). However, there is also conflicting research that suggest that practicing meditation decreases, not increases, resource demands imposed by target discrimination (MacLean et al., 2010), and that greater experience leads to less activation in areas related to attention, not more (Brefczynski-Lewis et al., 2007) during meditation. These differences could be related to different study methodologies; Maclean and colleagues (2010) used behavioral measures, while Brefczynski-Lewis and colleagues (2007) measured activation in attention regions during meditation, not during a behavioral task. Using neural measures during a behavioral task, this study provides evidence that meditators are able to more consistently facilitate visual attention to an attention task relative to control participants. Specifically, the amplitude of the ERP component can be viewed as a consistency measure: for ERP enhancement, the neural oscillation on each trial must be phase synchronous with the majority of other trials. Alternatively, if phase is shifted, the ERP amplitude will not be enhanced by averaging. Thus, it may be that meditator participants showed greater reliability in their neural signals relative to controls, suggesting that they are able to more reliably deploy visual attention on each trial to the task, especially during trials without interference and after

relaxation. Meditation practice thus may increase attentional flexibility in sustained attention such that individuals can choose to allocate attention to any stimulus regardless of the task demands.

In addition to these group differences, examination of correlations between self-report questionnaires and neural measures of attention revealed that greater self-kindness was related to enhanced attentional capacity. Greater self-kindness was related to larger overall P1/N1, enhanced P1 amplitude to congruent trials, larger N1 amplitude in the relaxation block, larger P3b amplitudes to congruent stimuli, and overall greater percentage of alpha power during meditation. While we did not find evidence for mediation, it is intriguing that self-kindness affects early and late attention regulation as well as attention during meditation. Self-kindness may bring gentleness to how meditators attend. Instead of responding to errors and momentary lapses in attention with anger and frustration, self-kindness may provide protection from these negative emotions by seeing errors simply as cues to refocus attention. This ability to view performance more neutrally may decrease anxiety, which has been implicated in decreasing attentional capacity, especially when task demands are low (Bishop, 2008). Correlational analyses did indicate that greater self-kindness was linked to lower levels of negative affect. Thus, increased self-kindness may lower anxiety and avoidance such that individuals are better able to flexibly allocate attention to the task.

Mediation analyses revealed that the mindfulness facet of observing mediated the relationship between group and P1 amplitude, suggesting that the quality of observing cultivated with meditation experience mediates the relationship between group and P1 amplitudes. It may be that the practice of noticing and paying attention to external and

internal events, including sounds, sensations, and emotions, increases meditators ability to pay attention, especially without interference and after relaxation. It may be that the goal of the task becomes the focusing of attention itself, more so than performance on the task, such that meditators are able to readily allocate visual attention.

The relationship between self-kindness and the P1/N1 and between the mindfulness facet of observing with P1 amplitudes in congruent trials are novel findings. These findings may help bridge the literature stressing the importance of the cultivation of these qualities with mindfulness practice in improving psychological health (Chiesa & Serretti, 2009), with research on the attentional gains and alterations in brain function acquired with meditation (Chiesa, Calati, & Serretti, 2011; Raffone & Srinivasan, 2010). By providing evidence for the importance of observing and self-kindness in attentional control, these findings indicate that the quality of awareness cultivated with meditation plays a role in the mechanisms by which mindfulness improves attention and psychological functioning.

Self-Monitoring

Individuals with meditation experience showed enhancement to some neural mechanisms of self-monitoring relative to controls, although not all of our hypotheses were supported. The study findings did not support alterations in ERN and FRN amplitudes with meditation experience, nor did we find relationships between these neural measures with self-reported mindfulness or self-compassion. Our results did support alterations to the Pe with meditation experience, however, suggesting that individuals with mindfulness practice have greater error awareness relative to controls.

The lack of group difference in the FRN amplitude could be a result of unreliable measurement and small sample sizes. Eye-blink artifact during feedback presentation was common, resulting in few participants who retained sufficient trials for ERP analysis. The FRN was not significantly larger than the corresponding correct feedback negativity, which is inconsistent with the literature on the FRN (Gehring & Willoughby, 2002). Thus, further research is necessary to determine if meditation experience alters processing of negative feedback.

The ERN, however, did seem to be a reliable measure of self-monitoring. The ERN was larger than the response-locked negativity to correct trials, as is evident in previous research (Falkenstein et al., 1991; Gehring et al., 1993). The ERN has been implicated as a measure of error significance (Maier, Steinhauser, & Hubner, 2008), and varies depending on the importance the subject puts on avoiding mistakes and/or making a correct response (Taylor, Stern, & Gehring, 2007). The lack of difference between groups in ERN amplitude may suggest that that meditation experience does not alter the significance individuals attribute to making errors. An error may be equally salient to a meditation practitioner, given that mistakes (such as lapses in attention) are quite significant to mindfulness practice, as individual needs to notice errors in order to regain focus. Thus, during performance-monitoring, errors retain comparable salience to both groups, as indexed by the amplitude of the ERN. However, source results suggest that mindfulness practitioners may activate different areas of the brain during error-monitoring relative to nonmeditators. In addition to the midcingulate source that both groups showed during the timepoint of the ERN, meditators showed a source in the dlPFC, while control participants revealed an additional generator in the orbital frontal

cortex (OFC). In previous studies of the ERN, sources in the ventrolimbic region, which includes subgenual ACC and OFC, were enhanced in emotional tasks (Bush, Luu, & Posner, 2000) and in individuals with greater anxiety (Luu et al., 2003), including individuals with OCD (Fitzgerald et al., 2005). In contrast, the dlPFC is implicated in executive attention and cognitive control (Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). Thus, while both meditators and control participants may place equal significance on the errors they make, meditators may activate regions of the brain related to cognitive control, suggesting a deliberative, neutral response to errors, while control participants utilized regions related to emotion and anxiety. These results should be interpreted with caution, given that the source results are based off of nonsignificant scalp differences, but are intriguing nonetheless.

While there were no group differences in ERN amplitudes, individuals with meditation experience did show larger Pe amplitudes relative to controls. In addition, individuals who had been meditating for longer showed the greatest enhancement in their Pe amplitudes. The Pe is implicated in error awareness, showing enhancement when subjects allocate more attention to mistakes (Falkenstein et al., 1991). Thus, greater Pe amplitudes in meditators relative to controls may suggest that error awareness increases with the practice of mindfulness. Pe amplitudes are enhanced in individuals with a growth mind-set relative to a fixed mind-set (Moser et al., 2011). Individuals with growth mind-sets view intelligence as incremental and as a quality that can be developed through learning. Instead of viewing errors as harmful to their sense of self, a growth mind-set allows an individual to view mistakes as instructive feedback and increases the likelihood that the individual can learn from mistakes. Similarly, individuals with

meditation experience may have learned that errors (e.g. distraction during focused-attention or attachment to positive experiences during open monitoring) are not harmful, but rather is “just what minds do” (Siegal, 2009). At the same time, awareness of lapses in attention during meditation is crucial. Practitioners are reminded that, “each time you notice that your mind is no longer on your breath, just see where it is. Then let go and come back to your belly and to your breathing.” (Kabat-Zinn, 1990). The practice of repeated awareness of mistakes during meditation for the purpose of goal-directed behavior and return to focused attention may increase error-awareness overall, as evidenced by enhanced Pe amplitudes relative to control participants.

Source analysis at the Pe timepoint suggests sources similar to those evident at the timepoint of the P3b. Both groups showed sources across the temporal lobe and hippocampal and parahippocampal cortex. Activity in the temporal lobe and hippocampal regions are likely related to memory operations, as participants compare their response to the stimulus representation and determine if they have responded accurately. In addition, both groups showed sources in the subgenual ACC, which has been displayed in previous research source localizing the Pe (Hermann et al., 2004; van Veen & Carter, 2002). In addition to these sources, meditators demonstrated an additional source in the right orbitofrontal cortex (OFC). Activity in the OFC during self-evaluation has been linked to more accurate predictions about one’s performance (Schnyer, Nicholls, & Verfaellie, 2005; Beer, Heerey, Keltner, Scabini, & Knight, 2003). OFC activation decreases when overconfident predictions about performance are made (Beer, Lombardo, & Palacios, 2009). Activity in the OFC has also been linked to intuition as it relates to coherence of fragmented objects (Luu et al., 2010). Thus, OFC

activity may facilitate accurate awareness and assessment of performance during error production, and may be increased in individuals with meditation experience.

In addition to these group differences, the Pe amplitude was related to greater self-reported acting with awareness, nonreactivity, and self-kindness. Acting with awareness measures attentional capabilities, and thus the relationship with the Pe suggests that individuals with greater attention in daily life are more aware of the errors they make. Interestingly, acting with awareness was not greater in individuals with meditation experience relative to controls. Nonreactivity measures the ability to remain objective and neutral in response to emotions and thoughts. Greater nonreactivity may allow individuals to more readily allocate attention to errors by more neutrally and objectively responding to error production. Similarly, self-kindness may provide for greater error awareness by more kindly viewing oneself when errors are made. Neither nonreactivity nor self-kindness mediated the relationship between group and Pe amplitude. Thus, these qualities do not fully explain how meditation experience may increase Pe amplitudes and error awareness. However, these qualities thought to be cultivated with mindfulness practice, and shown to be enhanced in meditators relative to controls in this study, are associated to improvements in error-monitoring, suggesting that they have some role in the mechanisms of meditation as they are linked to greater self-monitoring.

Implications for Psychological Well-Being

Meditator and control participants did not differ in their levels of positive and negative affect. Thus, the current study was unable to link facets of mindfulness, self-compassion, or attention measures to changes in emotional wellbeing related to

meditation experience. A number of studies have shown that levels of mindfulness and self-compassion mediate improvements in psychological wellbeing seen with meditation practice (Carmody & Baer, 2008; Neff, Kirkpatrick, & Rude, 2007), and mindfulness facets have also been linked to superior attention on behavior tasks (Moore and Milinowski, 2009; Anderson et al., 2007). How measures of attention, facets of mindfulness, and aspects of self-compassion interact to improve psychological wellbeing remains an open question. Importantly, the evidence that meditation practice increases functional and structural integrity of attention networks (Luders, Clark, Narr & Toga, 2011; Hölzel et al., 2011; Tang et al., 2010) suggests that overall attentional processing is facilitated. The practice of repeated attentional control during meditation likely promotes the development of structures important to executive attention and thus self-regulation. The ability to direct attention voluntarily provides a common resource for executive functioning and self-regulation (Kaplan & Berman, 2010), and enhanced self-regulation has been repeatedly linked to positive outcomes, like higher grade point average, lower reports of psychopathology, more fulfilling interpersonal relationships, and better emotional control (Tangney, Baumeister, & Boone, 2004). Thus, improvements in attentional control promote greater self-control and greater ability to engage in goal-directed behavior.

At the same time, the development of mindfulness and self-compassion during meditation promotes a healthier relationship with emotion, thoughts, and experiences by altering attentional goals. How an individual regulates attention to events provides the framework for subjective experience. The traditional view of healthy attentional deployment in service of emotion regulation has been to attend away from distressing

events toward pleasant stimuli (Gross, 2002). In this approach, interaction with negative information is minimized, thus increasing positive affect and psychological wellbeing. Wadlinger & Iwasaacowitz (2010) describe attention-training approaches for the purpose of improving emotion regulation, and focus on training programs that teach individuals to shift their gaze patterns such that they attend away from negative information toward neutral or positive information. This is fundamentally different from the approach taken in mindfulness techniques. Meditation practice alters the conscious control of subjective experience by increasing awareness of and attention to all experiences regardless of valence. Instead of avoiding negative experiences, the interpretation of all events is altered such that a more objective, experiential focus is emphasized, promoting decreases in reactivity and increases in self-compassion in response to emotions and thoughts that may be elicited. There are many negative events that cannot be avoided: the end of a relationship; the loss of a job; the death of a loved one. The ability to attend to all experiences regardless of valence promotes attentional flexibility and emotional resilience across the spectrum of life experiences, and thus likely increases psychological wellbeing even in hard times.

Thus, there is a complicated interrelation between the attentional gains related to repeated practice of directed attention, and the mindfulness and self-compassion goals that alter the quality of attention. Future research should attempt to elucidate these relationships in order to disentangle the contributions of mindfulness practice. A large mindfulness intervention study, which would allow for recruitment of individuals across the spectrum of negative and positive affect, that would utilize self-report measures of mindfulness and self-compassion and behavioral and neural measures of attention could

elucidate relationships between attention, mindfulness, and self-compassion. An intervention study would also provide the opportunity to measure self-report and neural measures before and after the intervention and more definitively look at change processes.

Limitations and Future Directions

While this study has a number of interesting findings, there are several limitations that may inform future research. Importantly, the current study compares a group of long-term meditators to control participants to investigate the effects of mindfulness practice. The lack of random assignment precludes claims about causality. Whether the differences between groups are due to mindfulness practice or other qualities linked to choosing to practice meditation long-term is unknown. By integrating a meditation period into the design, we sought to provide evidence for the effects of meditation practice on altering attention and self-monitoring. Improved attention after meditation compared to after a relaxation and control period would have provided evidence for direct effects of meditation. However, no effects of the meditation period on attention or self-monitoring were found. The relationship between the Pe, a neural measure of self-monitoring, with length of meditation experience provides some evidence that greater practice of meditation itself is linked to alterations in neural mechanisms. Given that greater experience was linked to greater error awareness, there is evidence that the length of practice of mindfulness likely contributes to self-monitoring. The interesting differences between groups suggests that future research should develop an appropriately controlled intervention study to examine the neural mechanisms of attention and self-monitoring with respect to self-reported mindfulness and self-compassion.

Another potential limitation is the relevant motivational differences between groups. Individuals with mindfulness experience were recruited based on their meditation practice, and thus were aware that the goals of the study were related to improvements as a result of meditation. Motivation plays an important role in subject's performance in lab tasks, and differences in motivation have been implicated in explaining some of the differences in attention found when comparing meditators to controls (Jensen et al., 2012). We attempted to equalize motivation by providing a monetary incentive to both groups so that performance was tied to actual reward. We did not find behavioral differences, suggesting that both groups may have been equally motivated. Thus, while meditators may initially have been more motivated than controls to perform well, the added monetary incentive may have increased the motivation of control participants such that performance was comparable.

An additional limitation was in the study design, which did not result in sufficient errors to find differences across the meditation and relaxation manipulation for either the response- or feedback-locked ERP components. The state manipulation may have provided evidence that self-monitoring was enhanced after meditation compared to relaxation and control in the mindfulness group, which would have afforded more convincing evidence that differences between groups were related to the practice of meditation itself. However, because of the study design, we were unable to investigate differences related to the manipulation. In addition, excessive eye-blink artifact during feedback presentation resulted in very few trials available for averaging and likely made the FRN an unreliable measure of feedback-monitoring. Thus, the lack of difference between groups in the FRN could not be interpreted. Investigations of self-monitoring

related to meditation practice requires a more difficult study which elicits errors and feedback more reliably. A more challenging study that would result in a greater number of useable trials would also provide the opportunity to look at self-monitoring after a meditation and relaxation period separately to determine if a meditation period improves error- and feedback-monitoring.

While this study was meant to determine alterations to very basic attention and self-monitoring mechanisms with meditation practice, future research exploring attention and self-regulation in response to emotional stimuli will more directly assess changes to processing of emotion eliciting information that are thought to be altered with meditation experience. A number of approaches can be made, from looking at attention to emotional faces, emotional words, or emotional pictures, each of which could elucidate meditators responses to negatively and positively valenced images. Linking alterations in meditator responses to emotional stimuli with self-reported mindfulness and self-compassion could provide additional insight into the mechanisms of mindfulness.

Summary and Conclusions

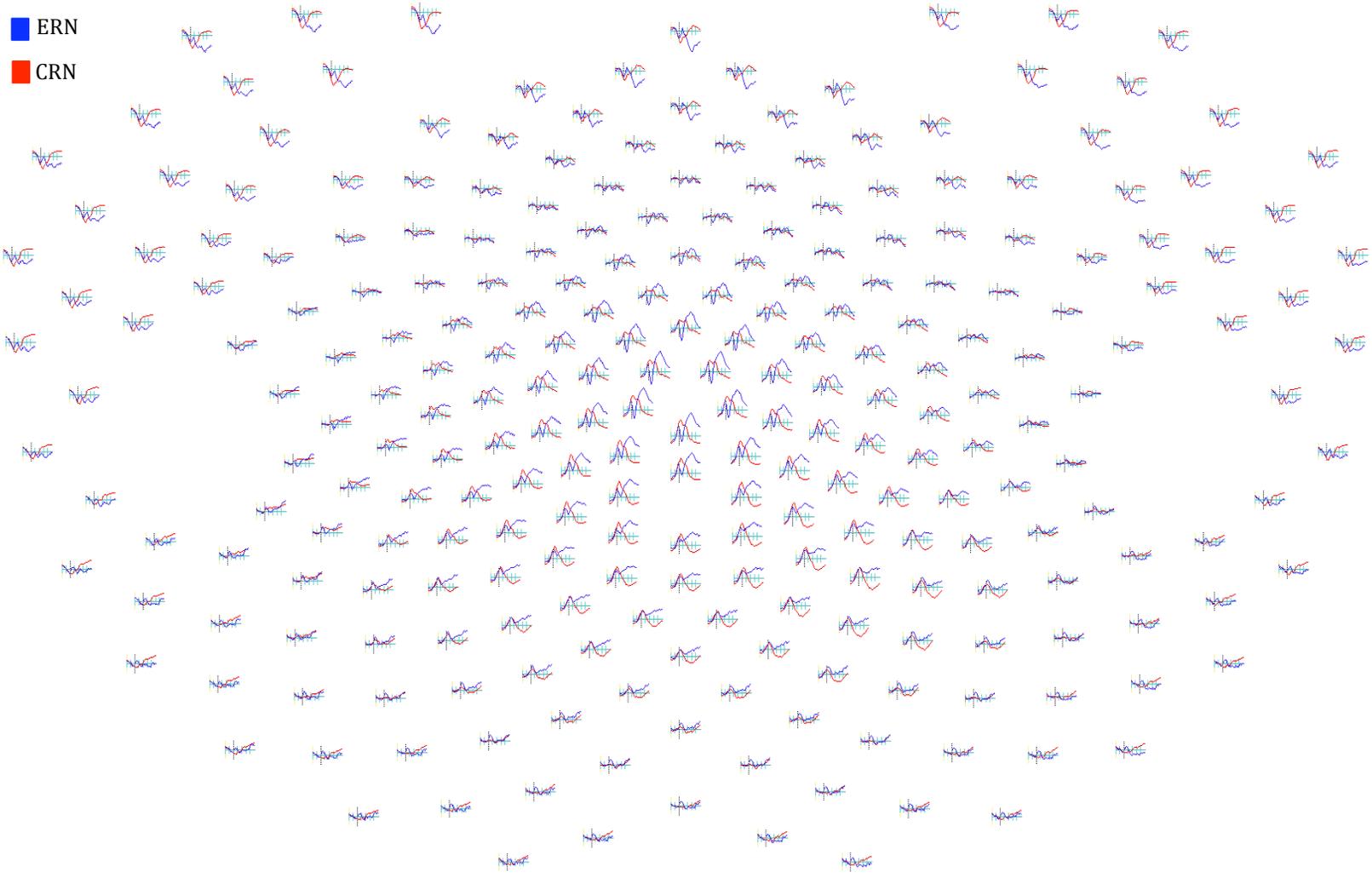
This study provides compelling evidence that meditation practice enhances attentional control and alters self-monitoring, and indicates that mindfulness and self-compassion play a role in these changes. Individuals with meditation experience showed enhancement in neural networks related to selective attention and attentional allocation, as evidenced by larger P1/N1 and P3b amplitudes, relative to controls. They also showed greater awareness of their errors, as indexed by their Pe amplitude, relative to controls. Importantly, each of these neural indices was related to greater mindfulness and self-compassion, qualities enhanced during meditation practice. Self-kindness in particular

was related to each of these ERP components, as well as with percentage of alpha power during meditation. The mindfulness facet of ‘observing’ fully mediated the relationship between meditation experience and P1 amplitudes. These findings suggest that the qualities that are enhanced with meditation (particularly self-kindness, observation, and nonreactivity) may alter attentional control in a way that is unique to mindfulness training. It is an exciting step toward future intervention studies that combine multiple sources of information (self-report, neural measures, and behavior) to clarify the nature of the associations among these variables so that the mechanisms of mindfulness can be more fully elucidated.

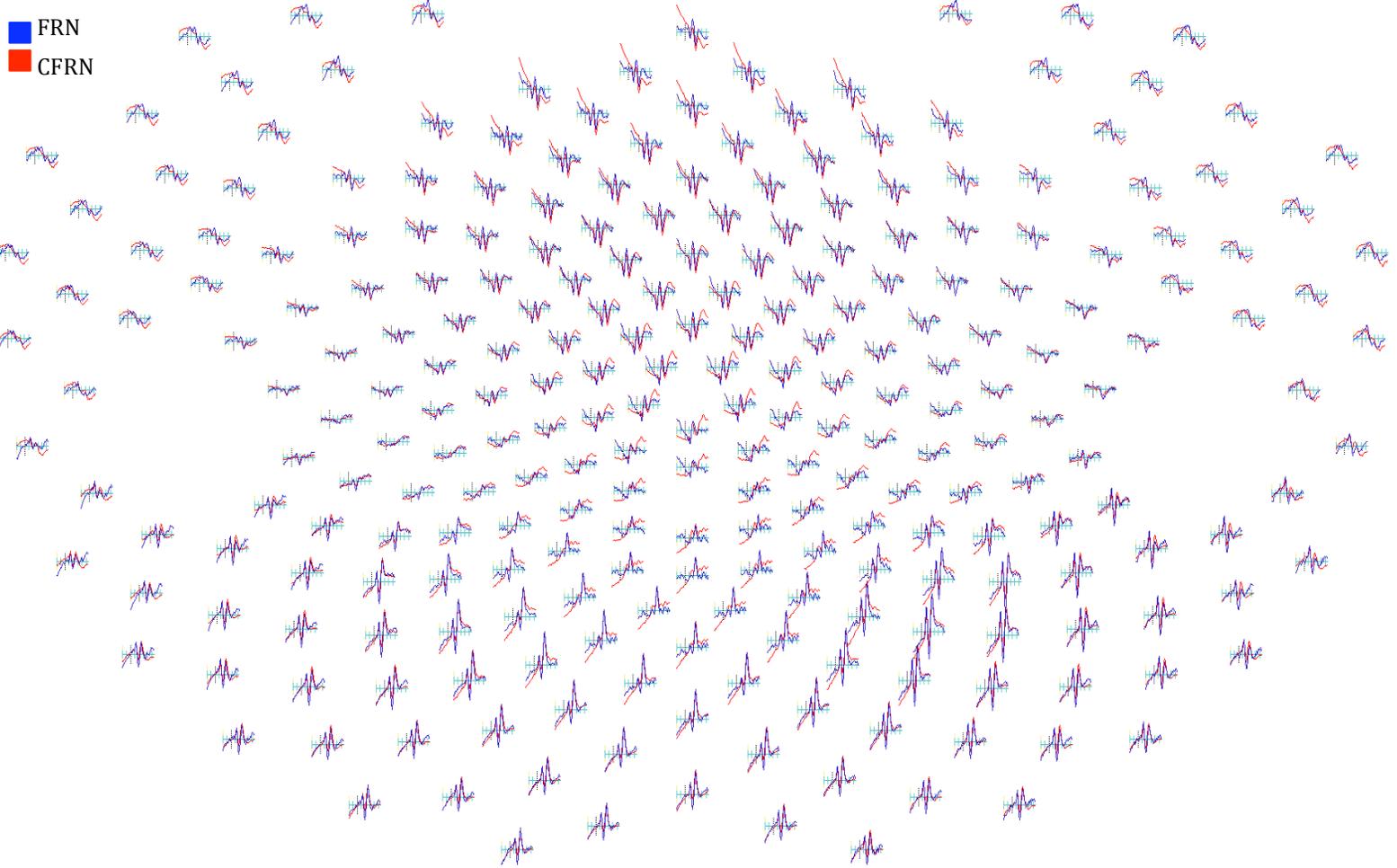
APPENDIX A

GRAND AVERAGED ERP COMPONENTS ACROSS THE ENTIRE SCALP

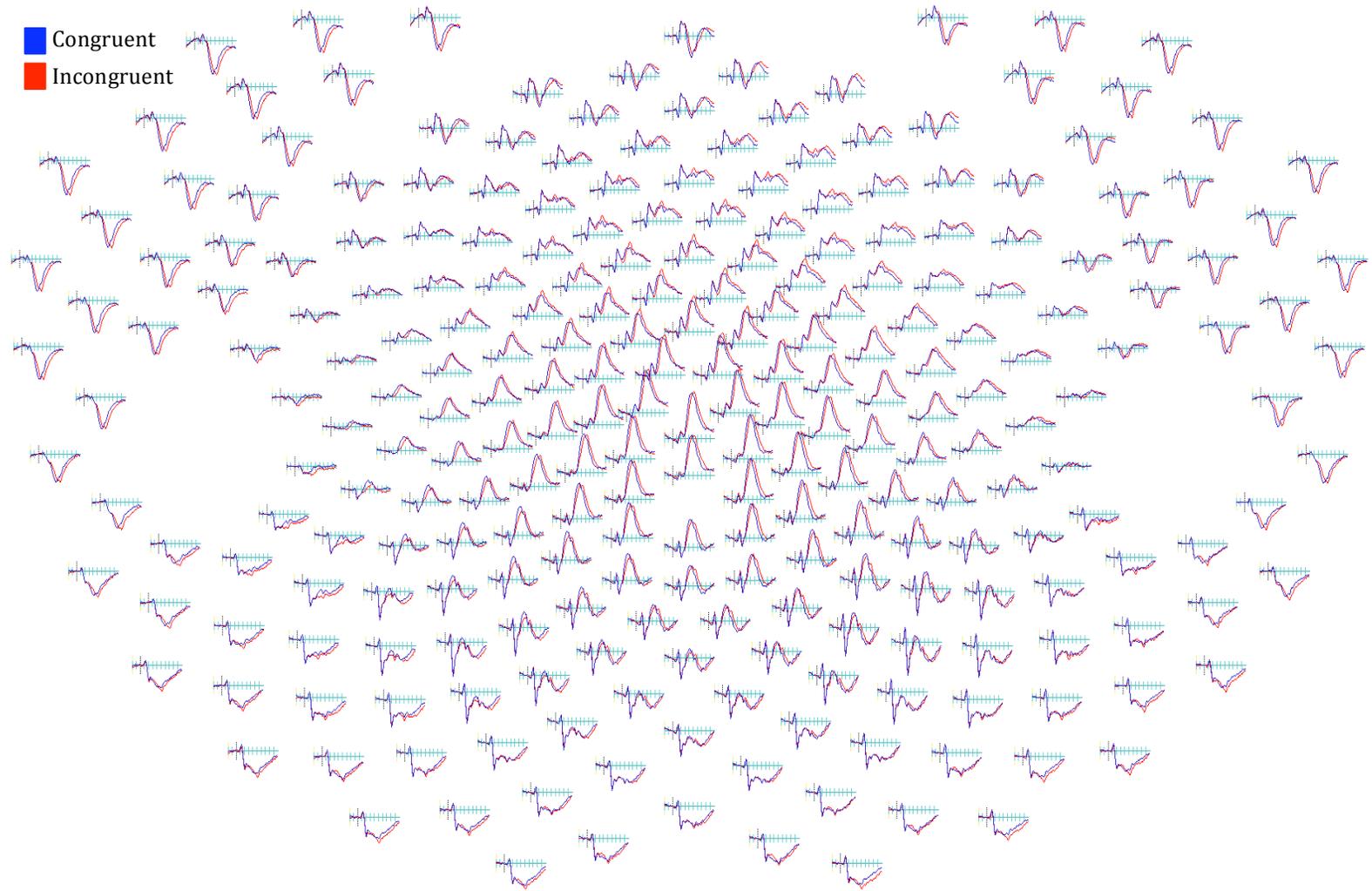
A1. Response-locked ERP waveforms separately for error-related (ERN) and correct-related (CRN) negativities. Waveforms start 200 ms prior to response and end 500 ms post-response. The response is displayed in the waveform with a vertical dotted line.



A2. Feedback-locked ERP waveforms separately for incorrect-feedback (FRN) and correct-feedback (CFRN) negativities. Waveforms start 200 ms prior to feedback and end 800 ms post-response. Feedback onset is displayed in the waveform with a vertical dotted line.



A3. Stimulus-locked ERP waveforms separately for congruent and incongruent trial types. Waveforms start 200 ms prior to stimulus onset and end 1000 ms post-stimulus onset. Stimulus onset is displayed in the waveform with a vertical dotted line.



APPENDIX B

MEDITATION AND RELAXATION INSTRUCTIONS

Relaxation Instructions

Close your eyes, and bring your attention to the sensations of your breath. While there are several places in the body where you might observe the breath, for this exercise, try bringing your attention to the rising and falling sensations in your belly that accompany each inhalation and exhalation. See if you can observe the breath through its entire cycle—from the beginning of an in-breath, to the point where the lungs are relatively full, back down to the point where they are relatively empty, and on to the beginning of the next cycle. You won't be trying to control the breath in any way. The breath may be short and shallow or long and deep. It may be one way one minute, and different the next. There is no need to regulate or change it. You're simply using the sensations of the breath in the belly to practice paying attention to what is happening right now.

Pretty soon you'll notice that your attention wanders, either to other sensations in the body or to thoughts. You may discover that your mind leaves the breath entirely for long stretches during which you are thinking about other things entirely. This is perfectly normal. This wandering and getting absorbed in things is simply what minds do; it is not a mistake or a failure. When you notice that this has happened, just gently return your attention to the breath. You might even congratulate yourself on becoming aware. However often you notice that the mind has wandered (and this will quite likely happen over and over and over again), each time take note of where the mind has been, then gently escort your attention back to the breath and simply resume attending to the breath.

Please begin.

Meditation Instructions

Become aware of your breathing, and notice how your abdomen rises and falls with each breath. Now take a long slow deep breath in through your nose, all the way down into your stomach. Hold the breath for just a moment, and then exhale through your mouth. Allow your breath to carry away all stress and tension as the air floods out of your lungs. Take another slow breath in through your nose. Fill your lungs completely. Hold it for a moment, and release the breath through your mouth. Empty your lungs completely with your out-breath. Now let your breathing rhythm return to normal and relax.

During this relaxation you will tense various muscles throughout your body. Please do this without straining. You do not need to exert yourself, just contract each muscle firmly but gently as you breathe in. If you feel uncomfortable at any time, you can simply relax and breathe normally.

Start at the feet and toes. Bring your awareness to your feet and toes. Breathe in deeply through your nose, and as you do, gradually curl your toes down and tense the muscles in the soles of your feet. Hold your breath for just a few seconds and then release the muscles in your feet as you breathe out. Feel the tension in your feet wash away as you exhale. Notice how different your feet feel when tensed and when they are relaxed.

Now bring your awareness to your calf muscles. As you draw in a nice deep breath, point your toes up towards your knees and tighten these muscles. Hold for just a moment, and then let those muscles go limp as you exhale. Feel your muscles relax, and feel the tension washing away with your out-breath.

Continue tensing each muscle, continuing with your knees, your thighs, etc, progressively tightening and relaxing your muscles one group at a time until you reach the top of the head. Continue taking deep breaths. Enjoy the sensation of release as you become more and more deeply relaxed. Once you reach the top of your head, stop and notice the feeling of relaxation for a few breaths, then reverse directions, and go back down to your toes, one muscle group at a time, until I ask you to stop.

APPENDIX C

STUDY MEASURES

SCS_SF

Please read each statement carefully before answering. To the left of each item, indicate how often you behave in the stated manner, using the following scale:

Almost
Always
never
always
5

1

2

3

4

_____ 1. When I fail at something important to me I become consumed by feelings of inadequacy.

_____ 2. I try to be understanding and patient towards those aspects of my personality I don't like.

_____ 3. When something painful happens I try to take a balanced view of the situation.

_____ 4. When I'm feeling down, I tend to feel like most other people are probably happier than I am.

_____ 5. I try to see my failings as part of the human condition.

_____ 6. When I'm going through a very hard time, I give myself the caring and tenderness I need.

_____ 7. When something upsets me I try to keep my emotions in balance.

_____ 8. When I fail at something that's important to me, I tend to feel alone in my failure

_____ 9. When I'm feeling down I tend to obsess and fixate on everything that's wrong.

_____ 10. When I feel inadequate in some way, I try to remind myself that feelings of inadequacy are shared by most people.

_____ 11. I'm disapproving and judgmental about my own flaws and inadequacies.

_____ 12. I'm intolerant and impatient towards those aspects of my personality I don't like.

FFMQ

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

- _____ 1. When I'm walking, I deliberately notice the sensations of my body moving.
- _____ 2. I'm good at finding words to describe my feelings.
- _____ 3. I criticize myself for having irrational or inappropriate emotions.
- _____ 4. I perceive my feelings and emotions without having to react to them.
- _____ 5. When I do things, my mind wanders off and I'm easily distracted.
- _____ 6. When I take a shower or bath, I stay alert to the sensations of water on my body.
- _____ 7. I can easily put my beliefs, opinions, and expectations into words.
- _____ 8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.
- _____ 9. I watch my feelings without getting lost in them.
- _____ 10. I tell myself I shouldn't be feeling the way I'm feeling.
- _____ 11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.
- _____ 12. It's hard for me to find the words to describe what I'm thinking.
- _____ 13. I am easily distracted.
- _____ 14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.
- _____ 15. I pay attention to sensations, such as the wind in my hair or sun on my face.
- _____ 16. I have trouble thinking of the right words to express how I feel about things
- _____ 17. I make judgments about whether my thoughts are good or bad.

- _____ 18. I find it difficult to stay focused on what's happening in the present.
- _____ 19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.
- _____ 20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.
- _____ 21. In difficult situations, I can pause without immediately reacting.
- _____ 22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.
- _____ 23. It seems I am "running on automatic" without much awareness of what I'm doing.
- _____ 24. When I have distressing thoughts or images, I feel calm soon after.
- _____ 25. I tell myself that I shouldn't be thinking the way I'm thinking.
- _____ 26. I notice the smells and aromas of things.
- _____ 27. Even when I'm feeling terribly upset, I can find a way to put it into words.
- _____ 28. I rush through activities without being really attentive to them.
- _____ 29. When I have distressing thoughts or images I am able just to notice them without reacting.
- _____ 30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.
- _____ 31. I notice visual elements in art or nature, such as colors, shapes, textures, or patterns of light and shadow.
- _____ 32. My natural tendency is to put my experiences into words.
- _____ 33. When I have distressing thoughts or images, I just notice them and let them go.
- _____ 34. I do jobs or tasks automatically without being aware of what I'm doing.
- _____ 35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.
- _____ 36. I pay attention to how my emotions affect my thoughts and behavior.

_____ 37. I can usually describe how I feel at the moment in considerable detail.

_____ 38. I find myself doing things without paying attention.

_____ 39. I disapprove of myself when I have irrational ideas.

REFERENCES CITED

- 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*(1), 57–60. doi:10.1016/S0304-3940(01)02094-8
- Aftanas, L., & Golosheykin, S. (2005). Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions. *International Journal of Neuroscience*, *115*(6), 893–909. doi:10.1080/00207450590897969
- Anderson, N. D., Lau, M. A., Segal, Z. V., & Bishop, S. R. (2007). Mindfulness-based stress reduction and attentional control. *Clinical Psychology & Psychotherapy*, *14*(6), 449–463. doi:10.1002/cpp.544
- Angelakis, E., Lubar, J. F., Stathopoulou, S., & Kounios, J. (2004). Peak alpha frequency: an electroencephalographic measure of cognitive preparedness. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *115*(4), 887–897. doi:10.1016/j.clinph.2003.11.034
- Baron, R. M., & Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173–1182.
- Baer, R. A., Smith, G. T., & Allen, K. B. (2004). Assessment of mindfulness by self-report: the kentucky inventory of mindfulness skills. *Assessment*, *11*(3), 191–206. doi:10.1177/1073191104268029
- Baer, R. A. (2010). Self-compassion as a mechanism of change in mindfulness and acceptance-based treatments. In R. A. Baer (Ed.), *Assessing mindfulness & acceptance processes in clients: Illuminating the theory & practice of change* (pp. 135-154). Oakland, CA: New Harbinger Publications.
- 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. doi:10.1177/1073191105283504
- Baer, R. A., Smith, G. T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S., Walsh, E., et al. (2008). Construct validity of the five facet mindfulness questionnaire in meditating and nonmeditating samples. *Assessment*, *15*(3), 329–342. doi:10.1177/1073191107313003
- Baijal, S., & Srinivasan, N. (2010). Theta activity and meditative states: spectral changes during concentrative meditation. *Cognitive Processing*, *11*(1), 31–38. doi:10.1007/s10339-009-0272-0

- Barnard, L. K., & Curry, J. F. (2011). Self-compassion: Conceptualizations, correlates, & interventions. *Review of General Psychology, 15*(4), 289–303. doi:10.1037/a0025754
- Baumeister, R. F., Gailliot, M., DeWall, C. N., & Oaten, M. (2006). Self-regulation and personality: How interventions increase regulatory success, and how depletion moderates the effects of traits on behavior. *Journal of Personality, 74*(6), 1773–1802. doi:10.1111/j.1467-6494.2006.00428.x
- Beer, J. S., Heerey, E. H., Keltner, D., Scabini, D., & Knight, R. T. (2003). The regulatory function of self-conscious emotion: Insights from patients with orbitofrontal damage. *Journal of Personality and Social Psychology, 85*, 594–604.
- Beer, J. S., Lombardo, M. V., & Bhanji, J. P. (2009). Roles of medial prefrontal cortex and orbitofrontal cortex in self-evaluation. *Journal of Cognitive Neuroscience, 22*(9), 2108–2119. doi:10.1162/jocn.2009.21359
- Bertrand, O., Perrin, F. & Pernier, J. (1985). A theoretical justification of the average reference in topographic evoked potential studies. *Electroencephalography and Clinical Neurophysiology 62*(6), 462-4.
- Bishop, S. J. (2008). Trait anxiety and impoverished prefrontal control of attention. *Nature Neuroscience, 12*(1), 92–98. doi:10.1038/nn.2242
- Bledowski, C., Prvulovic, D., Hoechstetter, K., Scherg, M., Wibral, M., Goebel, R., & Linden, D. E. J. (2004). Localizing P300 generators in visual target and distractor processing: a combined event-related potential and functional magnetic resonance imaging study. *The Journal of Neuroscience, 24*(42), 9353–9360. doi:10.1523/JNEUROSCI.1897-04.2004
- Bowen, S., Witkiewitz, K., Dillworth, T. M., Chawla, N., Simpson, T. L., Ostafin, B. D., Larimer, M. E., et al. (2006). Mindfulness meditation and substance use in an incarcerated population. *Psychology of Addictive Behaviors, 20*(3), 343–347. doi:10.1037/0893-164X.20.3.343
- Brazil, I. A., de Bruijn, E. R. A., Bulten, B. H., von Borries, A. K. L., van Lankveld, J. J. D. M., Buitelaar, J. K., & Verkes, R. J. (2009). Early and late components of error monitoring in violent offenders with Ppsychopathy. *Biological Psychiatry, 65*(2), 137–143. doi:10.1016/j.biopsych.2008.08.011
- 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*(27), 11483–11488. doi:10.1073/pnas.0606552104

- Brewer, J. A., Worhunsky, P. D., Gray, J. R., Tang, Y.-Y., Weber, J., & Kober, H. (2011). Meditation experience is associated with differences in default mode network activity and connectivity. *PNAS Proceedings of the National Academy of Sciences of the United States of America*, *108*(50), 20254–20259. doi:10.1073/pnas.1112029108
- 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. doi:10.1037/0022-3514.84.4.822
- Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical foundations and evidence for its salutary effects. *Psychological Inquiry*, *18*(4), 211–237. doi:10.1080/10478400701598298
- Buchheld, N., Grossman, P., & Walach, H. (2001). Measuring mindfulness in insight meditation (Vipassana) and meditation based psychotherapy: The development of the Freiburg mindfulness inventory (FMI). *Journal for Meditation and Meditation Research*, *1*, 11–34.
- Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*(6), 215–222. doi:10.1016/S1364-6613(00)01483-2
- Bussey, T. J., Muir, J. L., Everitt, B. J., & Robbins, T. W. (1997). Triple dissociation of anterior cingulate, posterior cingulate, and medial frontal cortices on visual discrimination tasks using a touchscreen testing procedure for the rat. *Behavioral Neuroscience*, *111*(5), 920–936.
- Cahn, B. R., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin*, *132*(2), 180–211. doi:10.1037/0033-2909.132.2.180
- Cahn, B. R., & Polich, J. (2009). Meditation (Vipassana) and the P3a event-related brain potential. *International Journal of Psychophysiology*, *72*(1), 51–60. doi:10.1016/j.ijpsycho.2008.03.013
- Carmody, J., & Baer, R. A. (2008). Relationships between mindfulness practice and levels of mindfulness, medical and psychological symptoms and well-being in a mindfulness-based stress reduction program. *Journal of Behavioral Medicine*, *31*(1), 23–33. doi:10.1007/s10865-007-9130-7
- Chadwick, P., Hember, M., Mead, S., Lilley, B., & Dagnan, D. (2005). Responding mindfully to unpleasant thoughts and images: Reliability and validity of the Mindfulness Questionnaire. Unpublished manuscript, University of Southampton Royal South Hants Hospital, UK.

- Chambers, R., Gullone, E., & Allen, N. B. (2009). Mindful emotion regulation: An integrative review. *Clinical Psychology Review*, 29(6), 560–572. doi:10.1016/j.cpr.2009.06.005
- Chambers, R., Lo, B., & Allen, N. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy and Research*, 32(3), 303–322. doi:10.1007/s10608-007-9119-0
- Chan, D., & Woollacott, M. (2007). Effects of level of meditation experience on attentional focus: Is the efficiency of executive or orientation networks improved? *The Journal of Alternative and Complementary Medicine*, 13(6), 651–658. doi:10.1089/acm.2007.7022
- Chiesa, A., Calati, R., & Serretti, A. (2011). Does mindfulness training improve cognitive abilities? A systematic review of neuropsychological findings. *Clinical Psychology Review*, 31(3), 449–464. doi:10.1016/j.cpr.2010.11.003
- Chiesa, A., & Serretti, A. (2009). Mindfulness-based stress reduction for stress management in healthy people: A review and meta-analysis. *The Journal of Alternative and Complementary Medicine*, 15(5), 593–600. doi:10.1089/acm.2008.0495
- Corbetta, M., Akbudak, E., Conturo, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., Linenweber, M. R., et al. (1998). A common network of functional areas for attention and eye movements. *Neuron*, 21(4), 761–773. doi:10.1016/S0896-6273(00)80593-0
- Davies, P. L., Segalowitz, S. J., Dywan, J., & Pailing, P. E. (2001). Error-negativity and positivity as they relate to other ERP indices of attentional control and stimulus processing. *Biological Psychology*, 56(3), 191–206. doi:10.1016/S0301-0511(01)00080-1
- Dehaene, S., Posner, M. I. & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science* 5, 303-5.
- Di Russo, F., Martínez, A., & Hillyard, S. A. (2003). Source analysis of event-related cortical activity during visuo-spatial attention. *Cerebral Cortex*, 13(5), 486–499. doi:10.1093/cercor/13.5.486
- Eriksen, B., & Eriksen, C. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Attention, Perception, & Psychophysics*, 16(1), 143–149. doi:10.3758/BF03203267

- Evans, S., Ferrando, S., Findler, M., Stowell, C., Smart, C., & Haglin, D. (2008). Mindfulness-based cognitive therapy for generalized anxiety disorder. *Journal of Anxiety Disorders*, 22(4), 716–721. doi:10.1016/j.janxdis.2007.07.005
- Evans, D. E., & Rothbart, M. K. (2007). Developing a model for adult temperament. *Journal of Research in Personality*, 41(4), 868–888. doi:10.1016/j.jrp.2006.11.002
- Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology*, 78(6), 447–455.
- Farb, N. A. S., Segal, Z. V., Mayberg, H., Bean, J., McKeon, D., Fatima, Z., & Anderson, A. K. (2007). Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference. *Social Cognitive and Affective Neuroscience*, 2(4), 313–322. doi:10.1093/scan/nsm030
- Farb, N. A. S., Anderson, A. K., Mayberg, H., Bean, J., McKeon, D., & Segal, Z. V. (2010). Minding one's emotions: mindfulness training alters the neural expression of sadness. *Emotion*, 10(1), 25–33. doi:10.1037/a0017151
- Fitzgerald, K. D., Welsh, R. C., Gehring, W. J., Abelson, J. L., Himle, J. A., Liberzon, I., & Taylor, S. F. (2005). Error-related hyperactivity of the anterior cingulate cortex in obsessive-compulsive disorder. *Biological Psychiatry*, 57(3), 287–294. doi:10.1016/j.biopsych.2004.10.038
- Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science*, 4, 385-390.
- Gehring, W. J., Himle, J., & Nisenson, L. G. (2000). Action monitoring dysfunction in obsessive-compulsive disorder. *Psychological Science*, 11, 1-6.
- Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science*, 295(5563), 2279–2282. doi:10.1126/science.1066893
- Germer, C.K. (2009). *The Mindful Path to Self-Compassion: Freeing Yourself from Destructive Thoughts and Emotions* (1st ed.). The Guilford Press.
- Gilbert, P. & Irons, C. (2005). Focused therapies and compassionate mind training for shame and self-attacking. In P. Gilbert (Ed.), *Compassion: Conceptualizations, research, and use in psychotherapy* (pp. 263-325). London: Routledge.
- Goddard, P. H. (1989). Reduced age-related declines of P300 latencies in elderly practicing transcendental meditation. *Psychophysiology*, 26, S29.

- Goldin, P. R., & Gross, J. J. (2010). Effects of mindfulness-based stress reduction (MBSR) on emotion regulation in social anxiety disorder. *Emotion, 10*(1), 83–91. doi:10.1037/a0018441
- Goldin, P., Ramel, W., & Gross, J. (2009). Mindfulness meditation training and self-referential processing in social anxiety disorder: Behavioral and neural effects. *Journal of Cognitive Psychotherapy, 23*(3), 242–257. doi:10.1891/0889-8391.23.3.242
- Green, J. J., & McDonald, J. J. (2008). Electrical neuroimaging reveals timing of attentional control activity in human brain. *PLoS Biol, 6*(4), e81. doi:10.1371/journal.pbio.0060081
- Gross, J. J. (2002). Emotion regulation: affective, cognitive, and social consequences. *Psychophysiology, 39*(3), 281–291. doi:10.1017/S0048577201393198
- Grossman, Paul, Tiefenthaler-Gilmer, U., Raysz, A., & Kesper, U. (2007). Mindfulness training as an intervention for fibromyalgia: Evidence of postintervention and 3-year follow-up benefits in well-being. *Psychotherapy and Psychosomatics, 76*(4), 226–233. doi:10.1159/000101501
- Gruber, W. R., Klimesch, W., Sauseng, P., & Doppelmayr, M. (2005). Alpha phase synchronization predicts P1 and N1 latency and amplitude size. *Cerebral Cortex, 15*(4), 371–377. doi:10.1093/cercor/bhh139
- Gu, R., Ge, Y., Jiang, Y., & Luo, Y. (2010). Anxiety and outcome evaluation: The good, the bad and the ambiguous. *Biological Psychology, 85*(2), 200–206. doi:10.1016/j.biopsycho.2010.07.001
- Hajcak, G., McDonald, N., & Simons, R.F. (2004). Error-related psychophysiology and negative affect. *Brain and Cognition, 56*, 189-197.
- Hajcak, G., McDonald, N., & Simons, R.F. (2003). Anxiety and error-related brain activity. *Biological Psychology, 64*, 77-90.
- Halgren, E., Marinkovic, K., & Chauvel, P. (1998). Generators of the late cognitive potentials in auditory and visual oddball tasks. *Electroencephalography and Clinical Neurophysiology, 106*(2), 156–164. doi:10.1016/S0013-4694(97)00119-3
- Hasenkamp, W., Wilson-Mendenhall, C. D., Duncan, E., & Barsalou, L. W. (2012). Mind wandering and attention during focused meditation: a fine-grained temporal analysis of fluctuating cognitive states. *NeuroImage, 59*(1), 750–760. doi:10.1016/j.neuroimage.2011.07.008

- Hayes, A. M., & Feldman, G. (2004). Clarifying the construct of mindfulness in the context of emotion regulation and the process of change in therapy. *Clinical Psychology: Science and Practice*, *11*(3), 255–262. doi:10.1093/clipsy.bph080
- Herrmann, M. J., Römmler, J., Ehlis, A.-C., Heidrich, A., & Fallgatter, A. J. (2004). Source localization (LORETA) of the error-related-negativity (ERN/Ne) and positivity (Pe). *Cognitive Brain Research*, *20*(2), 294–299. doi:10.1016/j.cogbrainres.2004.02.013
- Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *353*(1373), 1257–1270.
- Hofmann, S. G., Sawyer, A. T., Witt, A. A., & Oh, D. (2010). The effect of mindfulness-based therapy on anxiety and depression: A meta-analytic review. *Journal of Consulting and Clinical Psychology*, *78*(2), 169–183. doi:10.1037/a0018555
- Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*(4), 679–709. doi:10.1037/0033-295X.109.4.679
- Hölzel, B. K., Lazar, S. W., Gard, T., Schuman-Olivier, Z., Vago, D. R., & Ott, U. (2011). How does mindfulness meditation work? Proposing mechanisms of action from a conceptual and neural perspective. *Perspectives on Psychological Science*, *6*(6), 537–559. doi:10.1177/1745691611419671
- Hölzel, B. K., Ott, U., Gard, T., Hempel, H., Weygandt, M., Morgen, K., & Vaitl, D. (2007). Investigation of mindfulness meditation practitioners with voxel-based morphometry. *Social Cognitive and Affective Neuroscience*, *3*(1), 55–61. doi:10.1093/scan/nsm038
- Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research: Neuroimaging*, *191*(1), 36–43. doi:10.1016/j.psychresns.2010.08.006
- Ives-Deliperi, V. L., Solms, M., & Meintjes, E. M. (2011). The neural substrates of mindfulness: An fMRI investigation. *Social Neuroscience*, *6*(3), 231–242. doi:10.1080/17470919.2010.513495
- Jain, S., Shapiro, S. L., Swanick, S., Roesch, S. C., Mills, P. J., Bell, I., & Schwartz, G. E. R. (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: A Publication of the Society of Behavioral Medicine*, *33*(1), 11–21. doi:10.1207/s15324796abm3301_2

- Jensen, C. G., Vangkilde, S., Frokjaer, V., & Hasselbalch, S. G. (2012). Mindfulness training affects attention—Or is it attentional effort? *Journal of Experimental Psychology: General*, *141*(1), 106–123. doi:10.1037/a0024931
- Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(2), 109–119. doi:10.3758/CABN.7.2.109
- Jha, Amishi P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. *Emotion*, *10*(1), 54–64. doi:10.1037/a0018438
- Jimenez, S. S., Niles, B. L., & Park, C. L. (2010). A mindfulness model of affect regulation and depressive symptoms: Positive emotions, mood regulation expectancies, and self-acceptance as regulatory mechanisms. *Personality and Individual Differences*, *49*(6), 645–650. doi:10.1016/j.paid.2010.05.041
- Josefsson, T., & Broberg, A. (2011). Meditators and non-meditators on sustained and executive attentional performance. *Mental Health, Religion & Culture*, *14*(3), 291–309. doi:10.1080/13674670903578621
- Josipovic, Z., Dinstein, I., Weber, J., & Heeger, D. J. (2012). Influence of meditation on anti-correlated networks in the brain. *Frontiers in Human Neuroscience*, *5*, 183. doi:10.3389/fnhum.2011.00183
- Kabat-Zinn, J. (1990). *Full Catastrophe Living: Using the Wisdom of Your Body and Mind to Face Stress, Pain, and Illness*. New York, NY: Delta Books.
- Kabat-Zinn, J., Wheeler, E., Light, T., Skillings, A., Scharf, M. J., Cropley, T. G., Hosmer, D., et al. (1998). Influence of a mindfulness meditation-based stress reduction intervention on rates of skin clearing in patients with moderate to severe psoriasis undergoing phototherapy (UVB) and photochemotherapy (PUVA). *Psychosomatic Medicine*, *60*(5), 625–632.
- Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science*, *5*(1), 43–57. doi:10.1177/1745691609356784
- Kingston, T., Dooley, B., Bates, A., Lawlor, E., & Malone, K. (2007). Mindfulness-based cognitive therapy for residual depressive symptoms. *Psychology and Psychotherapy: Theory, Research and Practice*, *80*(2), 193–203. doi:10.1348/147608306X116016
- Klimesch, W. (1997). EEG-alpha rhythms and memory processes. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *26*(1-3), 319–340.

- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*, 29(2–3), 169–195. doi:10.1016/S0165-0173(98)00056-3
- Kubota, Y., Sato, W., Toichi, M., Murai, T., Okada, T., Hayashi, A., & Sengoku, A. (2001). Frontal midline theta rhythm is correlated with cardiac autonomic activities during the performance of an attention demanding meditation procedure. *Cognitive Brain Research*, 11(2), 281–287.
- Kuyken, W., Byford, S., Taylor, R. S., Watkins, E., Holden, E., White, K., . . . Teasdale, J.D. (2008). Mindfulness-based cognitive therapy to prevent relapse in recurrent depression. *Journal of Consulting and Clinical Psychology*, 76(6), 966–978. doi:10.1037/a0013786
- Lagopoulos, J., Xu, J., Rasmussen, I., Vik, A., Malhi, G. S., Eliassen, C. F., . . . Ellingsen, O. (2009). Increased theta and alpha EEG activity during nondirective meditation. *The Journal of Alternative and Complementary Medicine*, 15(11), 1187–1192. doi:10.1089/acm.2009.0113
- Lazar, S. W., Bush, G., Gollub, R. L., Fricchione, G. L., Khalsa, G., & Benson, H. (2000). Functional brain mapping of the relaxation response and meditation. *Neuroreport*, 11(7), 1581–1585.
- Leahy, R. L., & Holland, S. J. (2000). *Treatment Plans and Interventions for Depression and Anxiety Disorders*. New York, NY: Guilford.
- Leary, M. R., Tate, E. B., Adams, C. E., Batts Allen, A., & Hancock, J. (2007). Self-compassion and reactions to unpleasant self-relevant events: The implications of treating oneself kindly. *Journal of Personality and Social Psychology*, 92(5), 887–904. doi:10.1037/0022-3514.92.5.887
- Linden, D. E. J. (2005). The P300: Where in the brain is it produced and what does it tell us? *The Neuroscientist*, 11(6), 563–576. doi:10.1177/1073858405280524
- Lisman, J. (2010). Working memory: The importance of theta and gamma oscillations. *Current Biology*, 20(11), R490–R492. doi:10.1016/j.cub.2010.04.011
- Lucas, M. (2012). *Rewire Your Brain For Love: Creating Vibrant Relationships Using the Science of Mindfulness*. Carlsbad, CA: Hay House.
- Luders, E., Clark, K., Narr, K. L., & Toga, A. W. (2011). Enhanced brain connectivity in long-term meditation practitioners. *NeuroImage*, 57(4), 1308–1316. doi:10.1016/j.neuroimage.2011.05.075

- Lutz, A., Slagter, H. A., Rawlings, N. B., Francis, A. D., Greischar, L. L., & Davidson, R. J. (2009). Mental training enhances attentional stability: Neural and behavioral evidence. *Journal of Neuroscience*, *29*(42), 13418–13427. doi:10.1523/JNEUROSCI.1614-09.2009
- 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. doi:10.1016/j.tics.2008.01.005
- Lutz, A., Slagter, H. A., Rawlings, N. B., Francis, A. D., Greischar, L. L., & Davidson, R. J. (2009). Mental training enhances attentional stability: neural and behavioral evidence. *The Journal of Neuroscience*, *29*(42), 13418–13427. doi:10.1523/JNEUROSCI.1614-09.2009
- Luu, P., Collins, P. & Tucker, D. (2000). Mood, personality, and self-monitoring: negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology: General*, *129*(1), 43-60.
- Luu, P., Tucker, D. M., Derryberry, D., Reed, M. & Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. *Psychological Science*, *14*(1), 47-53
- Luu, P., Tucker, D. M., & Makeig, S. (2004). Frontal midline theta and the error-related negativity: neurophysiological mechanisms of action regulation. *Clinical Neurophysiology*, *115*(8), 1821–1835. doi:10.1016/j.clinph.2004.03.031
- Luu, P., Geyer, A., Fidopiastis, C., Campbell, G., Wheeler, T., Cohn, J., & Tucker, D. M. (2010). Reentrant processing in intuitive perception. *PLoS ONE*, *5*(3), e9523. doi:10.1371/journal.pone.0009523
- Lykins, E. L. B., & Baer, R. A. (2009). Psychological functioning in a sample of long-term practitioners of mindfulness meditation. *Journal of Cognitive Psychotherapy*, *23*(3), 226–241. doi:10.1891/0889-8391.23.3.22
- Lynch, JC, Mountcastle, VB, Talbot, WH, & Yin, TCT (1977). Parietal lobe mechanisms for directed visual attention. *Journal of Neurophysiology*, *40*, 362-389.
- MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., . . . Saron, C.D. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science*, *21*(6), 829–839. doi:10.1177/0956797610371339
- Maier, M., Steinhauser, M., & Hübner, R. (2008). Is the error-related negativity amplitude related to error detectability? Evidence from effects of different error types. *Journal of Cognitive Neuroscience*, *20*(12), 2263–2273. doi:10.1162/jocn.2008.20159

- Makeig, S., Westerfield, M., Jung, T.-P., Enghoff, S., Townsend, J., Courchesne, E., & Sejnowski, T. J. (2002). Dynamic brain sources of visual evoked responses. *Science*, *295*(5555), 690–694. doi:10.1126/science.1066168
- Mangun, G. R., Buonocore, M. H., Girelli, M., & Jha, A. P. (1998). ERP and fMRI measures of visual spatial selective attention. *Human Brain Mapping*, *6*(5-6), 383–389. doi:10.1002/(SICI)1097-0193(1998)6:5/6<383::AID-HBM10>3.0.CO;2-Z
- Martínez, A., Anllo-Vento, L., Sereno, M. I., Frank, L. R., Buxton, R. B., Dubowitz, D. J., . . . Hillyard, S.A. (1999). Involvement of striate and extrastriate visual cortical areas in spatial attention. *Nature Neuroscience*, *2*(4), 364–369. doi:10.1038/7274
- Martinez, A., Ramanathan, D. S., Foxe, J. J., Javitt, D. C., & Hillyard, S. A. (2007). The role of spatial attention in the selection of real and illusory objects. *The Journal of Neuroscience*, *27*(30), 7963–7973. doi:10.1523/JNEUROSCI.0031-07.2007
- Masicampo, E. J., & Baumeister, R. F. (2007). Relating mindfulness and self-regulatory processes. *Psychological Inquiry*, *18*(4), 255–258. doi:10.1080/10478400701598363
- Mathewson, K. J., Dywan, J., & Segalowitz, S. J. (2005). Brain bases of error-related ERPs as influenced by age and task. *Biological Psychology*, *70*(2), 88–104. doi:10.1016/j.biopsycho.2004.12.005
- Michalak, J., Heidenreich, T., Meibert, P., & Schulte, D. (2008). Mindfulness predicts relapse/recurrence in major depressive disorder after mindfulness-based cognitive therapy. *The Journal of Nervous and Mental Disease*, *196*(8), 630–633. doi:10.1097/NMD.0b013e31817d0546
- Mishra, J., & Hillyard, S. A. (2009). Endogenous attention selection during binocular rivalry at early stages of visual processing. *Vision Research*, *49*(10), 1073–1080. doi:10.1016/j.visres.2008.02.018
- Moore, A., Gruber, T., Derose, J., & Malinowski, P. (2012). Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control. *Frontiers in Human Neuroscience*, *6*, 18. doi:10.3389/fnhum.2012.00018
- Moore, A., & Malinowski, P. (2009). Meditation, mindfulness and cognitive flexibility. *Consciousness and Cognition*, *18*(1), 176–186. doi:10.1016/j.concog.2008.12.008
- Moore, P. (2008). Introducing mindfulness to clinical psychologists in training: An experiential course of brief exercises. *Journal of Clinical Psychology in Medical Settings*, *15*(4), 331–337. doi:10.1007/s10880-008-9134-7
- Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, *229*(4715), 782–784. doi:10.1126/science.4023713

- Moser, J. S., Schroder, H. S., Heeter, C., Moran, T. P., & Lee, Y.-H. (2011). Mind your errors: Evidence for a neural mechanism linking growth mind-set to adaptive posterror adjustments. *Psychological Science*, *22*(12), 1484–1489. doi:10.1177/0956797611419520
- Neely, M., Schallert, D., Mohammed, S., Roberts, R., & Chen, Y. J. (2009). Self-kindness when facing stress: The role of self-compassion, goal regulation, and support in college students' well-being. *Motivation and Emotion*, *33*(1), 88–97. doi:10.1007/s11031-008-9119-8
- Neff, K. D. (2003a). The development and validation of a scale to measure self-compassion. *Self and Identity*, *2*(3), 223–250. doi:10.1080/15298860309027
- Neff, K. D. (2003b). Self-compassion: An alternative conceptualization of a healthy attitude toward oneself. *Self and Identity*, *2*(2), 85–101. doi:10.1080/15298860309032
- Neff, K. D., Kirkpatrick, K. L., & Rude, S. S. (2007). Self-compassion and adaptive psychological functioning. *Journal of Research in Personality*, *41*(1), 139–154. doi:10.1016/j.jrp.2006.03.004
- Newberg, Andrew B., Wintering, N., Waldman, M. R., Amen, D., Khalsa, D. S., & Alavi, A. (2010). Cerebral blood flow differences between long-term meditators and non-meditators. *Consciousness and Cognition: An International Journal*, *19*(4), 899–905. doi:10.1016/j.concog.2010.05.003
- Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P. H., & Kok, A. (2003). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology*, *38*(5), 752–760. doi:10.1111/1469-8986.3850752
- Northoff, G., Heinzl, A., de Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain--a meta-analysis of imaging studies on the self. *NeuroImage*, *31*(1), 440–457. doi:10.1016/j.neuroimage.2005.12.002
- Novitskiy, N., Ramautar, J. R., Vanderperren, K., De Vos, M., Mennes, M., Mijovic, B., . . . Wagemans, J. (2011). The BOLD correlates of the visual P1 and N1 in single-trial analysis of simultaneous EEG-fMRI recordings during a spatial detection task. *NeuroImage*, *54*(2), 824–835. doi:10.1016/j.neuroimage.2010.09.041
- O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Kelly, S. P., Hester, R., Garavan, H., . . . Foxe, J. J. (2007). The role of cingulate cortex in the detection of errors with and without awareness: a high-density electrical mapping study. *European Journal of Neuroscience*, *25*(8), 2571–2579. doi:10.1111/j.1460-9568.2007.05477.x

- Onton, J., Delorme, A., & Makeig, S. (2005). Frontal midline EEG dynamics during working memory. *NeuroImage*, *27*(2), 341–356. doi:10.1016/j.neuroimage.2005.04.014
- Orzech, K. M., Shapiro, S. L., Brown, K. W., & McKay, M. (2009). Intensive mindfulness training-related changes in cognitive and emotional experience. *The Journal of Positive Psychology*, *4*(3), 212–222. doi:10.1080/17439760902819394
- Overbeek, T. J. M., Nieuwenhuis, S., & Ridderinkhof, K. R. (2005). Dissociable components of error processing: On the functional significance of the Pe vis-à-vis the ERN/Ne. *Journal of Psychophysiology*, *19*(4), 319–329. doi:10.1027/0269-8803.19.4.319
- Pailing, P.I. & Segalowitz, S.J. (2004). The effects of uncertainty in error monitoring on associated ERPs. *Brain and Cognition*, *56*, 215-233
- Palva, S., & Palva, J. M. (2007). New vistas for α -frequency band oscillations. *Trends in Neurosciences*, *30*(4), 150–158. doi:10.1016/j.tins.2007.02.001
- Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. *Methods and Findings in Experimental and Clinical Pharmacology*, *24 Suppl D*, 5–12.
- Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128–2148. doi:10.1016/j.clinph.2007.04.019
- Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex*, *14*(6), 619–633. doi:10.1093/cercor/bhh023
- Pourtois, G., Schettino, A., & Vuilleumier, P. (in press). Brain mechanisms for emotional influences on perception and attention: What is magic and what is not. *Biological Psychology*. doi:10.1016/j.biopsycho.2012.02.007
- Raes, F., Pommier, E., Neff, K. D., & Van Gucht, D. (2010). Construction and factorial validation of a short form of the self-compassion scale. *Clinical Psychology & Psychotherapy*, *18*(3), 250–255. doi:10.1002/cpp.702
- Raffone, A., & Srinivasan, N. (2010). The exploration of meditation in the neuroscience of attention and consciousness. *Cognitive Processing*, *11*(1), 1–7. doi:10.1007/s10339-009-0354-z
- Richard Clark, C., Veltmeyer, M. D., Hamilton, R. J., Simms, E., Paul, R., Hermens, D., & Gordon, E. (2004). Spontaneous alpha peak frequency predicts working memory performance across the age span. *International Journal of Psychophysiology*, *53*(1), 1–9. doi:10.1016/j.ijpsycho.2003.12.011

- Ridderinkhof, K. R., Ramautar, J. R., & Wijnen, J. G. (2009). To PE or not to PE: A P3-like ERP component reflecting the processing of response errors. *Psychophysiology*, *46*(3), 531–538. doi:10.1111/j.1469-8986.2009.00790.x
- Ridderinkhof, K. R., van den Wildenberg, W. P. M., Segalowitz, S. J., & Carter, C. S. (2004). Neurocognitive mechanisms of cognitive control: The role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. *Brain and Cognition*, *56*(2), 129–140. doi:16/j.bandc.2004.09.016
- Rosenzweig, S., Reibel, D. K., Greeson, J. M., Brainard, G. C., & Hojat, M. (2003). Mindfulness-based stress reduction lowers psychological distress in medical students. *Teaching and Learning in Medicine*, *15*(2), 88–92. doi:10.1207/S15328015TLM1502_03
- Sahdra, B. K., MacLean, K. A., Ferrer, E., Shaver, P. R., Rosenberg, E. L., Jacobs, T. L., . . . Saron, C.D. (2011). Enhanced response inhibition during intensive meditation training predicts improvements in self-reported adaptive socioemotional functioning. *Emotion*, *11*(2), 299–312. doi:10.1037/a0022764
- Sarang, S. P., & Telles, S. (2006). Changes in p300 following two yoga-based relaxation techniques. *The International Journal of Neuroscience*, *116*(12), 1419–1430. doi:10.1080/00207450500514193
- Sauseng, P., Griesmayr, B., Freunberger, R., & Klimesch, W. (2010). Control mechanisms in working memory: A possible function of EEG theta oscillations. *Neuroscience & Biobehavioral Reviews*, *34*(7), 1015–1022. doi:10.1016/j.neubiorev.2009.12.006
- Scheeringa, R., Bastiaansen, M. C. M., Petersson, K. M., Oostenveld, R., Norris, D. G., & Hagoort, P. (2008). Frontal theta EEG activity correlates negatively with the default mode network in resting state. *International Journal of Psychophysiology*, *67*(3), 242–251. doi:10.1016/j.ijpsycho.2007.05.017
- Schnyer, D. M., Nicholls, L., & Verfaellie, M. (2005). The role of VMPC in metamemorial judgments of content retrievability. *Journal of Cognitive Neuroscience*, *17*, 832–846.
- Semple, R. (2010). Does mindfulness meditation enhance attention? A randomized controlled trial. *Mindfulness*, *1*(2), 121–130. doi:10.1007/s12671-010-0017-2
- Shapiro, S. L., Astin, J. A., Bishop, S. R., & Cordova, M. (2005). Mindfulness-based stress reduction for health care professionals: Results from a randomized trial. *International Journal of Stress Management*, *12*(2), 164–176. doi:10.1037/1072-5245.12.2.164

- Shapiro, S. L., Brown, K. W., & Biegel, G. M. (2007). Teaching self-care to caregivers: Effects of mindfulness-based stress reduction on the mental health of therapists in training. *Training and Education in Professional Psychology, 1*(2), 105–115. doi:10.1037/1931-3918.1.2.105
- Shapiro, S. L., Carlson, L. E., Astin, J. A., & Freedman, B. (2006). Mechanisms of mindfulness. *Journal of Clinical Psychology, 62*(3), 373–386. doi:10.1002/jclp.20237
- Shapiro, S. L., Oman, D., Thoresen, C. E., Plante, T. G., & Flinders, T. (2008). Cultivating mindfulness: effects on well-being. *Journal of Clinical Psychology, 64*(7), 840–862. doi:10.1002/jclp.20491
- Siegel, R. D. (2009). *The Mindfulness Solution: Everyday Practices for Everyday Problems*. New York, NY: Guilford Press.
- Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., & Davidson, R. J. (2007). Mental training affects distribution of limited brain resources. *PLoS Biology, 5*(6). doi:10.1371/journal.pbio.0050138
- Specia, M., Carlson, L. E., Goodey, E., & Angen, M. (2000). A randomized, wait-list controlled clinical trial: The effect of a mindfulness meditation-based stress reduction program on mood and symptoms of stress in cancer outpatients. *Psychosomatic Medicine, 62*(5), 613–622.
- Steinhauser, M., & Yeung, N. (2010). Decision processes in human performance monitoring. *The Journal of Neuroscience, 30*(46), 15643–15653. doi:10.1523/JNEUROSCI.1899-10.2010
- Summerfield, C., & Mangels, J. A. (2005). Coherent theta-band EEG activity predicts item-context binding during encoding. *NeuroImage, 24*(3), 692–703. doi:10.1016/j.neuroimage.2004.09.012
- Talsma, D., & Woldorff, M. G. (2005). Selective attention and multisensory integration: Multiple phases of effects on the evoked brain activity. *Journal of Cognitive Neuroscience, 17*(7), 1098–1114. doi:10.1162/0898929054475172
- 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: Official Journal of the International Organization of Psychophysiology, 55*(2), 199–207. doi:10.1016/j.ijpsycho.2004.07.004

- Tang, Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., . . . Posner, M. I. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences*, *104*(43), 17152–17156. doi:10.1073/pnas.0707678104
- Tang, Y.-Y., Lu, Q., Geng, X., Stein, E. A., Yang, Y., & Posner, M. I. (2010). Short-term meditation induces white matter changes in the anterior cingulate. *Proceedings of the National Academy of Sciences*. doi:10.1073/pnas.1011043107
- Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2008). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality*, *72*(2), 271–324. doi:10.1111/j.0022-3506.2004.00263.x
- Taylor, S. F., Stern, E. R., & Gehring, W. J. (2007). Neural systems for error monitoring: Recent findings and theoretical perspectives. *The Neuroscientist*, *13*, 162–172.
- Taylor, V. A., Grant, J., Daneault, V., Scavone, G., Breton, E., Roffe-Vidal, S., . . . Beauregard, M. (2011). Impact of mindfulness on the neural responses to emotional pictures in experienced and beginner meditators. *NeuroImage*, *57*(4), 1524–1533. doi:10.1016/j.neuroimage.2011.06.001
- 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), 615–623. doi:10.1037/0022-006X.68.4.615
- Tenke, C. E., & Kayser, J. (2001). A convenient method for detecting electrolyte bridges in multichannel electroencephalogram and event-related potential recordings. *Clinical Neurophysiology*, *112*(3), 545–550. doi:10.1016/S1388-2457(00)00553-8
- Tucker, D. M. (1993). Spatial sampling of head electrical fields: the geodesic sensor net. *Electroencephalography and Clinical Neurophysiology* *87*(3), 154–63.
- Valentine, E. R., & Sweet, P.G. (1999). Meditation and attention: A comparison of the effects of concentrative and mindfulness meditation on sustained attention. *Mental Health, Religion & Culture*, *2*(1), 59–70. doi:10.1080/13674679908406332
- van den Hurk, P. A. M., Giommi, F., Gielen, S. C., Speckens, A. E. M., & Barendregt, H. P. (2009). Greater efficiency in attentional processing related to mindfulness meditation. *The Quarterly Journal of Experimental Psychology*, *63*(6), 1168–1180. doi:10.1080/17470210903249365
- van Leeuwen, S., Müller, N. G., & Melloni, L. (2009). Age effects on attentional blink performance in meditation. *Consciousness and Cognition*, *18*(3), 593–599. doi:10.1016/j.concog.2009.05.001

- van Vugt, M. K., & Jha, A. P. (2011). Investigating the impact of mindfulness meditation training on working memory: A mathematical modeling approach. *Cognitive, Affective & Behavioral Neuroscience, 11*(3), 344–353. doi:10.3758/s13415-011-0048-8
- van Meel, S. C., Heslenfeld, D. J., Oosterlaan, J., Luman, M., & Sergeant, J. A. (2011). ERPs associated with monitoring and evaluation of monetary reward and punishment in children with ADHD. *Journal of Child Psychology and Psychiatry, 52*(9), 942–953. doi:10.1111/j.1469-7610.2010.02352.x
- van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiology & Behavior, 77*(4–5), 477–482. doi:10.1016/S0031-9384(02)00930-7
- Wadlinger, H. A., & Isaacowitz, D. M. (2011). Fixing our focus: Training attention to regulate emotion. *Personality and Social Psychology Review, 15*(1), 75–102. doi:10.1177/1088868310365565
- Watson, D. & Clark, L. A. (1994). *The PANAS-X: Manual for the Positive and Negative Affect Schedule-Expanded Form*. Unpublished manuscript. University of Iowa, Iowa City.
- Williams, M., Teasdale, J., Segal, Z., & Kabat-Zinn, J. (2007). *The Mindful Way through Depression: Freeing Yourself from Chronic Unhappiness*. New York, NY: The Guilford Press.
- Yu, X., Fumoto, M., Nakatani, Y., Sekiyama, T., Kikuchi, H., Seki, Y., . . . Arita, H. (2011). Activation of the anterior prefrontal cortex and serotonergic system is associated with improvements in mood and EEG changes induced by Zen meditation practice in novices. *International Journal of Psychophysiology, 80*(2), 103–111. doi:10.1016/j.ijpsycho.2011.02.004
- Zeidan, F., Johnson, S. K., Diamond, B. J., David, Z., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: Evidence of brief mental training. *Consciousness and Cognition, 19*(2), 597–605. doi:10.1016/j.concog.2010.03.014