Published in final edited form as:

Psychiatry Res. 2017 June 30; 264: 22–28. doi:10.1016/j.psychres.2017.03.016.

Relationship of mindful awareness to neural processing of angry faces and impact of mindfulness training: A pilot investigation

Athene K.W. Lee^{a,c}, David A. Gansler^a, Nanyin Zhang^{b,d}, Matthew W. Jerram^a, Jean A. King^b, and Carl Fulwiler^{b,*}

^aSuffolk University, Department of Psychology, Boston, MA, USA

^bThe University of Massachusetts Medical School, Department of Psychiatry, Worcester, MA, USA

^cWarren Alpert Medical School of Brown University, Department of Psychiatry and Human Behavior, Providence, RI, USA

^dThe Pennsylvania State University, Department of Biomedical Engineering, University Park, PA, USA

Abstract

Mindfulness is paying attention, non-judgmentally, to experience in the moment. Mindfulness training reduces depression and anxiety and influences neural processes in midline self-referential and lateralized somatosensory and executive networks. Although mindfulness benefits emotion regulation, less is known about its relationship to anger and the corresponding neural correlates. This study examined the relationship of mindful awareness and brain hemodynamics of angry face processing, and the impact of mindfulness training. Eighteen healthy volunteers completed an angry face processing fMRI paradigm and measurement of mindfulness and anger traits. Ten of these participants were recruited from a Mindfulness-Based Stress Reduction (MBSR) class and also completed imaging and other assessments post-training. Self-reported mindful awareness increased after MBSR, but trait anger did not change. Baseline mindful awareness was negatively related to left inferior parietal lobule activation to angry faces; trait anger was positively related to right middle frontal gyrus and bilateral angular gyrus. No significant pre-post changes in angry face processing were found, but changes in trait mindful awareness and anger were associated with sub-threshold differences in paralimbic activation. These preliminary and hypothesis-generating findings, suggest the analysis of possible impact of mindfulness training on anger may begin with individual differences in angry face processing.

Keywords

Mindfulness; Experiential Awareness; Anger; Inferior Parietal Lobule; FMRI

*Correspondence to: Psychiatry and Medicine and Medical Director, Center for Mindfulness, University of Massachusetts Medical School, 55 Lake Avenue North, Worcester, MA 01655, USA. Carl.Fulwiler@umassmed.edu (C. Fulwiler).

1. Introduction

Mindfulness is the focused, nonjudgmental awareness of experience in the present moment (Kabat-Zinn, 2003). Through emphasis on nonattachment to outcome, it brings about better health and well-being over time (Kabat-Zinn, 2003). Controlled outcome studies indicate that mindfulness training enhances physical and emotional well-being in a number of serious medical conditions (Goyal et al., 2014; Grossman et al., 2004). Mindfulness-based therapy, including Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1990), has shown efficacy in reducing negative emotional states, including that of depression and anxiety (Hofmann et al., 2010; Khoury et al., 2013), with associated hemodynamic changes in the brain (Farb et al., 2010; Goldin et al., 2009). Mindfulness practice has also been shown to reduce anger (Heppner et al., 2008; Singh et al., 2011); however, there is no known research on the association of trait mindfulness with neural processing of anger stimuli or the impact of mindfulness training on this processing.

Neuroimaging research has identified notable effects of mindfulness practice on brain structure and function (Tang et al., 2015), including greater cortical thickness (especially in the right frontal-insular regions) in meditators with decades of experience (Lazar et al., 2005), and increased activation of the right frontal-parietal-insular network among recently MBSR-trained meditators (Farb et al., 2007). Farb et al., (2010, 2013) revealed evidence for restored balance in the dynamic neural systems across which negative affect is processed when depression is reduced post-MBSR. Compared to waitlisted controls during sadness provocation, MBSR participants with depression demonstrated less activation along the cortical midline self-referential regions and left-lateralized language/conceptual centers, and more recruitment (or less deactivation) of the right-lateralized visceral and somatosensory areas (Farb et al., 2010). Similar neural mechanisms were found to operate for the negative affective state of anxiety (Goldin and Gross, 2010; Goldin et al., 2009).

Like sadness and anxiety, anger is a negatively valenced emotion (Bradley and Lang, 1994) whose neural representation overlaps with the effects of MBSR. Brain areas involved in the neural representation of anger among healthy adults include the orbitofrontal cortex (OFC; Murphy et al., 2003), inferior frontal gyrus and parahippocampal gyrus (Vytal and Hamann, 2010), anterior cingulate cortex (Denson et al., 2009), and insula (Fusar-Poli et al., 2009). Stronger trait anger has been found to correlate with weaker resting-state functional connectivity between right amygdala and left OFC (Fulwiler et al., 2012). Psychopathology characterized by anger control problems has been associated to the failed reciprocal inhibition of the OFC and amygdala during anger expression (Dougherty et al., 2004; Coccaro et al., 2007). Evidence suggests that the dorsolateral prefrontal cortex (PFC), part of the networks enhanced by MBSR, plays an indirect role in anger and aggression through its top-down influence on the OFC (Gansler et al., 2011).

Trait mindfulness has been shown to be a multi-dimensional construct (Baer et al., 2004). The present study aims to investigate the association of the dimension of trait mindful awareness and trait anger in response to MBSR, by focusing on neural processing of angry face stimuli. Mindful awareness has been defined as the capacity for acting with present-centered awareness rather than on 'automatic pilot' or being lost in the past or future (Vago

and Silbersweig, 2012). Mindful awareness is thought to be crucial to the self-regulation of cognition and emotion and may be important for avoiding automatic reactions to anger and reducing the harmful mental and physical effects of this emotion (Chambers et al., 2009). First, we identified the neural correlates of trait mindful awareness during angry face processing. Second, we tested the impact of mindfulness training on the brain hemodynamics of angry face processing.

Drawing on prior research on depression and anxiety, three specific hypotheses were developed. 1) Trait mindful awareness would be positively associated with right lateralized networks for attentional/executive control and somatosensory and interoceptive processes, such as the dorsolateral PFC, insula cortex, and inferior parietal lobule, and negatively associated with cortical midline self-referential regions, such as the ventromedial PFC and posterior cingulate cortex. 2) Trait anger would display inverse relationships to activation patterns, relative to mindful awareness. 3) Activation patterns following MBSR will change towards resembling those with higher trait mindful awareness.

2. Methods

2.1. Participants and procedures

Eighteen right-handed healthy volunteers (4 women; mean age =39.28, SD =12.63; mean years of education =17.78, SD =2.67) consented to participate in this study. The sample is a snowball convenience sample, initially recruited through online posting (www.craigslist.com) and paper advertisements. Ten of these healthy participants (4 women; mean age =43.50, SD =7.86; mean years of education =17.60, SD =2.55) were recruited from orientation sessions of the MBSR program at the University of Massachusetts Medical School (UMMS) Center for Mindfulness. Those referred to MBSR for serious health conditions were excluded based on our exclusion criteria. Most cited stress as the reason for attending the classes. The remaining subjects were recruited from the community. Initial screening was conducted by phone and full screening for inclusion/exclusion criteria was conducted in person. Exclusion criteria included severe mental illnesses, neurological disorders, drug abuse, psychotropic medication use, and MRI contraindication. All 18 participants completed an fMRI protocol and psychological measures in a single session at baseline. The 10 participants recruited from the MBSR program completed the same evaluation again post-MBSR. The MBSR program consisted of eight weekly 2.5-hour sessions and an all-day session in week 6. It included training in formal meditation practices like body scan, sitting meditation, walking meditation, and mindful movement, as well as informal practices to integrate mindfulness into everyday life. Participants were encouraged to practice for 45 min at home 6 days per week. Participants who completed MBSR were not significantly different from those who did not in terms of age ($t(16)=-1.67$, $p=0.12$) or education ($t(16)=0.31$, $p=0.76$). The study was approved by the UMMS Institutional Review Board.

2.2. Measures

2.2.1. Mindfulness—The Kentucky Inventory of Mindfulness Skills (KIMS; Baer et al., 2004) is a well validated 39-item self-report measure based on a 5-point Likert scale. The

Mindful Awareness subscale refers to focusing undivided attention on the current activity and avoiding both internal and external distractions (KIMS-Awareness). The subscale has good internal consistency ($\alpha=0.83$) and test-retest reliability ($r > 0.86$) (Baer et al., 2004).

2.2.2. Anger—The *Trait Anger* (T-Anger) subscale from the State Trait Anger Expression Inventory (STAXI-2; Spielberger, 1999) measures how often angry feelings are experienced over time on a 4-point Likert scale. It has good internal consistency ($\alpha=0.87$) and adequate test-retest reliability ($r=0.70$) (Spielberger and Sydeman, 1994).

2.2.3. Emotional faces processing paradigm—An emotional faces processing paradigm was designed to perturb emotion processing systems. During fMRI, participants were instructed to identify the gender of faces, sampled from the Pictures of Facial Affect (Ekman and Friesen, 1976). Stimuli were presented in a mixed event-block design. Each 6.6-min run contained two 40-seconds blocks of each facial expression (Neutral, Angry, Fearful, Happy) totaling eight blocks. The block order was counterbalanced across four runs and remained the same across participants. Stimuli were presented in a jittered fashion within the block. The duration of face stimulus presentation was randomly varied between 1 to 2 s and the inter-stimulus interval was 5 s. Random length of stimulus presentation was utilized to reduce the chance that the participant would be able to anticipate the length of exposure and to help maintain attention to the task. Participants responded by pressing the left button for “male” and right button for “female,” as soon as the picture changed. As a manipulation check, emotion recognition was tested after fMRI in the pre-MBSR session. Participants labeled a sample of 20 faces (5 of each expression) with one of seven emotion labels (neutral, angry, fearful, happy, sad, surprised, disgusted). On average, participants were 79% accurate at emotion labeling ($SD = 11.57$).

2.3. Imaging

2.3.1. Acquisition—MRI data was acquired at the UMMS Advanced MRI Center, using a Philips Achieva 3 T scanner (Philips Medical Systems, Best, the Netherlands). Whole-brain T1-weighted images were obtained for anatomical reference ($TR=2460$ ms, $TE=3.4$ ms, $FOV=192$ mm², $matrix=256 \times 256$, $resolution=1$ mm³). Functional echo-planar images optimized for blood oxygenation level-dependent (BOLD) signal contrast were acquired during four 6.6-min runs ($TR=3000$ ms, $TE=35$ ms, $FOV=256$ mm², $matrix=128 \times 128$, $slice=28-32$, $resolution=2 \times 2 \times 3$ mm³). A resting-state functional sequence was also acquired between the structural and fMRI sequences and reported on elsewhere (Fulwiler et al., 2012).

2.3.2. Preprocessing—Brain images were preprocessed using Statistical Parametric Mapping (SPM8; Wellcome Department of Imaging Neuroscience, University College London, UK) implemented on Matlab (Mathworks Inc., Sherborn, MA, USA). Anatomical images were reoriented and aligned along the anterior commissure-posterior commissure axis. Functional images were slice-time corrected, realigned to the mean image of each run, and co-registered to the anatomical images for motion correction. Corrected functional images were then normalized to the Montreal Neurological Institute (MNI) space using the SPM echo-planar image template, sampled into unmodulated 2 mm isotropic resolution with

4th degree B-spline interpolation, and spatially smoothed with a Gaussian kernel with full width at half maximum (FWHM) of 5 mm. Motion and intensity artifact was evaluated using Artifact Detection Tools (ART; Whitfield-Gabrieli, 2009). Two subjects had one of the four runs removed due to excessive movement (> 3 mm translation or 0.1 rad rotation). Other outlier images (global signal intensity > 3 SD or motion correction values > 1 mm translation or 0.02 rad rotation) were included as nuisance covariates in subsequent analysis. The low frequency BOLD signal drift was removed by a high pass filter using a 128-second cut-off period. Serial BOLD signal autocorrelations were corrected with a first-order autoregressive model.

2.4. Statistical analysis

2.4.1. Statistical significance—Correction for multiple comparisons in whole-brain fMRI analyses was guided by Forman et al. (1995). A voxel p -level of 0.001 (uncorrected) and a cluster-size of 50 voxels were used as the threshold to ensure an overall p -level of 0.05 (FDR-corrected). All brain image statistical analyses were conducted on SPM8.

2.4.2. Individual- and group-level BOLD analysis—The BOLD time series at each voxel were convolved with a canonical hemodynamic response function using an event-related approach. BOLD responses were modeled for each condition (Fixation, Neutral, Angry, Fearful, Happy). Individual contrast images were estimated for each emotion compared to neutral face. Group-level whole-brain contrast maps were calculated from individual contrast maps using a mixed-effects analysis approach. Regions with significant activation and deactivation were identified using one-sample t -tests. Only the Angry-Neutral contrast was used in subsequent hypothesis testing.

To assess changes in neural activation during processing of angry faces, whole-brain regression models of Angry-Neutral contrast were fitted for KIMS-Awareness and T-Anger at baseline ($n=18$). Regions with significant positive or negative correlation with each trait measure were identified. To evaluate changes in processing of angry faces following mindfulness training, the pre-post difference in Angry-Neutral contrast was analyzed with voxel-wise paired- t -tests ($n=10$). To test whether changes in processing were associated with changes in mindful awareness, the Angry-Neutral contrast change map for each participant was computed by subtracting the pre-MBSR contrast from the post-MBSR contrast. The mindful awareness and trait anger changes were represented by the unstandardized residuals when regressing pre-MBSR scores on post-MBSR scores for each participant (KIMS-Awareness Residual; T-Anger Residual). Whole-brain regression models of Angry-Neutral contrast change were fitted for KIMS-Awareness Residual and T-Anger Residual ($n=10$).

3. Results

3.1. Baseline and post-MBSR changes in psychological measures: paired t -tests

At baseline, the measures of mindful awareness (KIMS-Awareness; Mean =39.28, SD =12.63), and trait anger (T-Anger; Mean =17.22, SD =6.19) fell within range of published norms and showed reasonably normal distributions for examining individual differences (all $|\text{skewness}|$ and $|\text{kurtosis}| < 1.2$). Participants reported significantly greater awareness on

KIMS-Awareness post-MBSR ($t(9)=4.21$, $p < 0.01$), but no statistically significant change was found in T-Anger ($t(9)=-1.54$, $p=0.16$).

3.2. Angry face processing BOLD response at baseline

Contrast between angry and neutral face (Angry-Neutral contrast) was computed to identify regions unique to angry face processing relative to neutral (non-expressive) face processing. No suprathreshold activation or deactivation was found.

3.3. Hypothesis I: baseline correlation between trait mindful awareness and Angry-Neutral contrast

Based on a whole-brain analysis, one significant negative association was found between Angry-Neutral contrast and KIMS-Awareness at the left inferior parietal lobule (BA 40; peak voxel: $-38, -36, 52$; peak $z=4.2$; FDR-corrected cluster $p=0.04$; cluster size =60). (Fig. 1). That is, individuals with higher scores on KIMS-Awareness showed reduced activation at the inferior parietal lobule while processing Angry versus-Neutral faces.

3.4. Hypothesis II: baseline correlation between trait anger and Angry-Neutral contrast

Based on a whole-brain analysis, significant positive associations were found between Angry-Neutral contrast and T-Anger at the right middle frontal gyrus (BA 6; peak voxel: $14, 6, 52$; peak $z=4.01$; FDR-corrected cluster $p=0.03$; cluster size =68), and the bilateral angular gyrus (BA 39; left peak voxel: $-42, -72, 20$; peak $z=4.04$; FDR-corrected cluster $p=0.03$; cluster size =66) (BA 39; right peak voxel: $52, -70, 18$; peak $z=4.22$; FDR-corrected cluster $p=0.04$; cluster size =55), (Fig. 2A & B). That is individuals with higher scores on T-Anger showed greater activation at these three regions while processing Angry versus Neutral faces.

3.5. Hypothesis III. post-MBSR activation patterns will change towards a resemblance of high trait mindful awareness: paired t-test

Contrary to the hypothesis, no significant changes in Angry-Neutral contrast were identified pre-post-MBSR.

3.6. Post-hoc exploratory analyses. Correlation between post-MBSR changes in Angry-Neutral contrast, trait mindful awareness, and trait anger

Changes in KIMS-Awareness were found to have one significant negative association with post-MBSR-changes in Angry-Neutral contrast at the left thalamus (peak voxel: $-16, -14, -4$; peak $z=4.19$; FDR-corrected cluster $p=0.01$; cluster size =59). (Fig. 3). That is, individuals with greater increase in KIMS Awareness post-MBSR showed less changes in Angry-Neutral contrast at the left thalamus. Changes in T-anger showed one significant positive association with post-MBSR changes in Angry-Neutral contrast at the right parahippocampal gyrus (BA 28; peak voxel: $22, -20, -20$; peak $z=4.85$; FDR-corrected cluster $p=0.00$; cluster size =75). (Fig. 4). Specifically, individuals with greater reduction in T-Anger post MBSR showed increased contrast at the right parahippocampal gyrus while viewing Angry versus Neutral faces.

4. Discussion

4.1. Principal findings

The principal study findings were that baseline (pre-MBSR) levels of trait mindful awareness were negatively associated to left parietal lobe activation to viewing of angry faces, and that baseline (pre-MBSR) levels of trait anger were positively associated to right middle frontal gyrus and bilateral angular gyrus activation to viewing of angry faces. Additionally, greater changes in trait mindful awareness after mindfulness training (post-MBSR) were negatively associated with post-MBSR activation differences in left thalamus to angry-face processing, while greater changes in trait anger post-MBSR were positively associated with greater post-MBSR activation differences in right hippocampal gyrus to angry-face processing. These findings occurred in the context of a statistically significant increase in trait mindful awareness post-MBSR. In that context, participants did not report a corresponding statistically significant decrease in trait anger post-MBSR. This MBSR study joins another which did not identify supra-threshold pre-post MBSR changes brain-wise, but which did identify associations of psychological state variables to the pre-post contrast (Hölzel et al., 2010).

The neural correlates of viewing angry faces with trait mindful awareness and anger at baseline were dissimilar in valence and region, a pattern that would continue post-MBSR. Consistent with the constructs of nonattachment to outcome and nonjudgmental awareness, trait mindful awareness was negatively associated with the degree of hemodynamic response in the left parietal lobe during angry face viewing. Trait anger, on the other hand, was positively associated with degree of hemodynamic response in the right frontal and bi-parietal cortices during angry face viewing. Trait anger likely involves psychological processes that are the inverse of mindfulness, namely, a significant degree of attachment to outcome and judgmental forms of awareness. The inverse nature of these processes is consistent with their respective negative and positive association to brain hemodynamics.

The difference in valence of association of mindful awareness, anger, and brain hemodynamics of viewing angry faces persisted to the analysis of changes in brain hemodynamics of face processing post-MBSR. The location of both of these associations was paralimbic, in the thalamus and parahippocampal gyrus for trait mindful awareness and anger, respectively; however, the mindful awareness-thalamus association was negative while the parahippocampal-anger association was positive. Although these were not supra-threshold pre-post MBSR changes in angry face processing, changes in the degree of trait mindful awareness and anger were associated with sub-threshold differences in paralimbic activation post-MBSR. Post-MBSR mindful awareness increased significantly at the group level and the increased scores were associated with reduced left thalamus activation to angry face viewing. Within the framework of mindfulness-based interventions, the thalamus is thought to be involved in the non-conscious aspect of the enactive experiential self (Vago and Silbersweig, 2012). The mean change in trait anger was not statistically significant post-MBSR, but the greater the reduction in trait anger, the greater the increase in right parahippocampal gyral activation to angry face viewing post-MBSR. In relation to a framework of mindfulness-based interventions the hippocampus and parahippocampal gyrus

are thought to be part of the narrative-self network, and, increases in hippocampal density post-MBSR have been interpreted to represent greater efficiency of memory networks and may contribute to the effects of mindfulness on emotion regulation (Holzel et al., 2011; Vago and Silbersweig, 2012). This connection implies that a future productive line of research would be to explore the relation of MBSR reductions in anger and memory efficiency capacity.

4.2. Limitations and conclusions

This is the first imaging study to examine MBSR-induced changes in the neural processing of angry face stimuli, which in preliminary and hypothesis-generating fashion, indicate the value of further work in this area. We used a healthy group with a normal range of trait anger and dispositional mindfulness; therefore, it is possible that higher trait anger scores more typical of those of clinical populations would be more likely to display statistically significant reductions. We also used a passive angry face processing paradigm, which may have evoked more automatic responses to the facial emotion with attention being drawn to non-emotional aspects of the face. More explicit emotional interpretation demands might have permitted more study of the effects of MBSR on top-down processing mechanisms. Brain hemodynamic response to angry faces is also influenced by gender and traits other than anger (Carre et al., 2012), a factor which could also have limited the measurement paradigm sensitivity to MBSR-induced changes. Persistent mindfulness practice beyond the course of 8-week MBSR may be necessary to induce more robust effects on trait anger and alterations in brain reactivity, or, perhaps mindfulness skills need to be explicitly linked to anger regulation skills for greater effect. Nevertheless, we were able to demonstrate the utility of this paradigm to reveal correlations between changes in mindful awareness, trait anger, and changes in brain reactivity to emotional perturbation by angry faces.

The occurrence of type I and II errors are a concern in pilot and smaller scale investigations, and the cluster correction and regression approach used here are associated with particular concern for type 1 error when making inferences in fMRI (Eklund et al., 2016). Nevertheless, our findings that changes in dispositional mindful awareness and anger were associated with altered reactivity to angry faces is important, because it provides preliminary evidence that one way mindful awareness may help regulate anger is by altering the reactivity mechanism. Future studies may use this passive emotional perturbation by angry face paradigm, and more in-depth (e.g., appraisal) paradigms, to evaluate the effect of MBSR on individuals with clinically significant anger problems, to test if an altered reactivity mechanism could apply to a clinical sample and translates to behavioral changes such as reduced angry outbursts.

Acknowledgments

The authors thank Dr. Wei Huang for technical assistance as well as advice and discussions on this study, and the staff and teachers of the Center for Mindfulness at the University of Massachusetts Medical School (UMMS) for their assistance with recruitment. The project described was conducted at the UMMS Advanced MR Imaging Center with support from Dr. Shaokuan Zheng. This work was supported by the National Institute of Health (NIH) [1R01MH067096-02 and 5R01DA021846-02 to J.A.K., R34AT006963 to C.F. and J.A.K., and R01MH098003 and R01NS085200 to N.Z.]; and by an award from the UMMS Department of Radiology. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH or the UMMS Center for Mindfulness, Department of Radiology, or Advanced MR Imaging Center.

References

- Baer RA, Smith GT, Allen KB. Assessment of mindfulness by self-report the Kentucky inventory of mindfulness skills. *Assessment*. 2004; 11(3):191–206. [PubMed: 15358875]
- Bradley MM, Lang PJ. Measuring emotion: the self-assessment manikin and the semantic differential. *J Behav Ther Exp Psychiatry*. 1994; 25(1):49–59. [PubMed: 7962581]
- Carre JM, Fisher PM, Manuck SB, Hariri AR. Interaction between trait anxiety and trait anger predict amygdala reactivity to angry facial expressions in men but not women. *Social, Cogn Affect Neurosci*. 2012; 7:213–221.
- Chambers R, Gullone E, Allen NB. Mindful emotion regulation: an integrative review. *Clin Psychol Rev*. 2009; 29(6):560–572. [PubMed: 19632752]
- Coccaro EF, McCloskey MS, Fitzgerald DA, Phan KL. Amygdala and orbitofrontal reactivity to social threat in individuals with impulsive aggression. *Biol Psychiatry*. 2007; 62(2):168–178. [PubMed: 17210136]
- Denson TF, Pedersen WC, Ronquillo J, Nandy AS. The angry brain: neural correlates of anger, angry rumination, and aggressive personality. *J Cogn Neurosci*. 2009; 21(4):734–744. [PubMed: 18578600]
- Dougherty DD, Rauch SL, Deckersbach T, Marci C, Loh R, Shin LM, et al. Ventromedial prefrontal cortex and amygdala dysfunction during an anger induction positron emission tomography study in patients with major depressive disorder with anger attacks. *Arch General Psychiatry*. 2004; 61(8):795–804.
- Eklund A, Nichols TE, Knutsson H. Cluster failure: why fMRI inferences for spatial extent have inflated false-positive rates. *Proc Natl Acad Sci*. 2016; 113(28):7900–7905. [PubMed: 27357684]
- Ekman, P., Friesen, WV. *Pictures of Facial Affect*. Consulting Psychologists Press; Palo Alto, CA: 1976.
- Farb NAS, Anderson AK, Mayberg H, Bean J, McKeon D, Segal ZV. Minding one's emotions: mindfulness training alters the neural expression of sadness. *Emotion*. 2010; 10(1):25. [PubMed: 20141299]
- Farb NA, Segal ZV, Anderson AK. Mindfulness meditation training alters cortical representations of interoceptive attention. *Social Cogn Affect Neurosci*. 2013; 8(1):15–26.
- Farb NAS, Segal ZV, Mayberg H, Bean J, McKeon D, Zainab F, et al. Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference. *Social Cogn Affect Neurosci*. 2007; 2:313–322.
- Forman SD, Cohen JD, Fitzgerald M, Eddy WF, Mintun MA, Noll DC. Improved assessment of significant activation in functional magnetic resonance imaging (fMRI): use of a cluster-size threshold. *Magn Reson Med*. 1995; 33:636–647. [PubMed: 7596267]
- Fulwiler CE, King JA, Zhang N. Amygdala–orbitofrontal resting-state functional connectivity is associated with trait anger. *Neuroreport*. 2012; 23(10):606–610. [PubMed: 22617448]
- Fusar-Poli P, Placentino A, Carletti F, Landi P, Allen P, Surguladze S, et al. Functional atlas of emotional faces processing: a voxel-based meta-analysis of 105 functional magnetic resonance imaging studies. *J Psychiatry Neurosci*. 2009; 34(6):418–432. [PubMed: 19949718]
- Gansler DA, Lee AKW, Emerton BC, D'Amato C, Bhadelia R, Jerram M, et al. Prefrontal regional correlates of self-control in male psychiatric patients. *Psychiatry Res: Neuroimaging*. 2011; 191:16–23. [PubMed: 21145213]
- Goldin PR, Gross JJ. Effects of mindfulness-based stress reduction (MBSR) on emotion regulation in social anxiety disorder. *Emotion*. 2010; 10(1):83. [PubMed: 20141305]
- Goldin P, Ramel W, Gross J. Mindfulness meditation training and self-referential processing in social anxiety disorder: behavioral and neural effects. *J Cogn Psychother*. 2009; 23(3):242–257. [PubMed: 25568592]
- Goyal M, Singh S, Sibinga EMS, Gould NF, Rowland-Seymour A, Sharma R, et al. Meditation programs for psychological stress and well-being: a systematic review and meta-analysis. *J Am Med Assoc: Intern Med*. 2014; 174(3):357–368.
- Grossman P, Niemann L, Schmidt S, Walach H. Mindfulness-based stress reduction and health benefits. *J Psychosom Res*. 2004; 57:35–43. [PubMed: 15256293]

- Heppner WL, Kernis MH, Lakey CE, Campbell WK, Goldman BM, Davis PJ, et al. Mindfulness as a means of reducing aggressive behavior: dispositional and situational evidence. *Aggress Behav.* 2008; 34(5):486–496. [PubMed: 18464229]
- Hofmann SG, Sawyer AT, Witt AA, Oh D. The effect of mindfulness-based therapy on anxiety and depression: a meta-analytic review. *J Consult Clin Psychol.* 2010; 78(2):169. [PubMed: 20350028]
- Hölzel BK, Carmody J, Evans KC, Hoge EA, Dusek JA, Morgan L, et al. Stress reduction correlates with structural changes in the amygdala. *Social, Cogn Affect Neurosci.* 2010; 5:11–17.
- Holzel BK, Carmody J, Vangel M, Congleton C, Yerramsetti SM, Gard T, et al. Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Res Neuroimaging.* 2011; 191(1):36–43. [PubMed: 21071182]
- Kabat-Zinn, J. *Pain, and Illness.* Delta; New York: 1990. *Full Catastrophe Living: Using the Wisdom of Your Mind and Body to Face Stress.*
- Kabat-Zinn J. Mindfulness-based interventions in context: past, present, and future clinical psychology. *Sci Pract.* 2003; 10(2):144–156.
- Khoury B, Lecomte T, Fortin G, Masse M, Therien P, Bouchard, et al. Mindfulness-based therapy: a comprehensive meta-analysis. *Clin Psychol Rev.* 2013; 33:763–771. [PubMed: 23796855]
- Lazar SW, Kerr CE, Wasserman RH, Gray JR, Greve DN, Treadway, et al. Meditation experience is associated with increased cortical thickness. *Neuroreport.* 2005; 16(17):1893–1897. [PubMed: 16272874]
- Murphy FC, Nimmo-Smith IAN, Lawrence AD. Functional neuroanatomy of emotions: a meta-analysis. *Cogn, Affect, Behav Neurosci.* 2003; 3(3):207–233. [PubMed: 14672157]
- Singh NN, Lancioni GE, Winton AS, Singh J, Singh AN, Singh AD. Peer with intellectual disabilities as a mindfulness-based anger and aggression management therapist. *Res Dev Disabil.* 2011; 32(6):2690–2696. [PubMed: 21741206]
- Spielberger, C. *State-Trait Anger Expression Inventory-2: Professional Manual.* Psychological Assessment Resources Inc; Odessa, FL: 1999.
- Spielberger, CD., Sydeman, SJ. *State-Trait Anxiety Inventory and State-Trait Anger Expression Inventory.* In: Maurish, MD., editor. *The Use of Psychological Testing for Treatment Planning and Outcome Assessment.* Lawrence Erlbaum Associates Inc; Hillsdale, NJ: 1994. p. 292-321.
- Tang YY, Hölzel BK, Posner MI. The neuroscience of mindfulness meditation. *Nat Rev: Neurosci.* 2015; 16:213–225. [PubMed: 25783612]
- Vago DR, Silbersweig DA. Self-awareness, self-regulation, and self-transcendence (S-art): a framework for understanding the neurobiological mechanisms of mindfulness. *Front Human Neurosci.* 2012; 6(1):1–30.
- Vytal K, Hamann S. Neuroimaging support for discrete neural correlates of basic emotions: a voxel-based meta-analysis. *J Cogn Neurosci.* 2010; 22(12):2864–2885. [PubMed: 19929758]
- Whitfield-Gabrieli, S. *Artifact Detection Tools.* 2009. Retrieved on November 1, 2013, from <http://web.mit.edu/swg/software.htm>

Fig. 1. Negative correlation between baseline KIMS-Awareness and Angry-Neutral contrast at the left inferior parietal lobule. Image shows the t-values map overlaid on a T1 template with the color blob representing the significant cluster. Scatter plot shows the mean Angry-Neutral contrast signal changes of the significant cluster against baseline KIMS-Awareness scores.

A: Bilateral angular gyrus *B: Right middle frontal gyrus* **Fig. 2.**

Positive correlation between baseline T-Anger and Angry-Neutral contrast at the bilateral angular gyrus (A) and right middle frontal gyrus (B). Images show the t-values map overlaid on a T1 template with the color blobs representing the significant clusters. Scatter plots show the mean Angry-Neutral contrast signal changes of the significant clusters against baseline T-Anger scores.

Fig. 3. Negative correlation between KIMS-Awareness residual and Angry-Neutral contrast change post-MBSR at the left thalamus. Image shows the t-values map overlaid on a T1 template with the color blob representing the significant cluster. Scatter plot shows the mean Angry-Neutral contrast pre-post signal changes of the significant cluster against KIMS-Awareness residual scores post-MBSR.

Fig. 4. Positive correlation between T-Anger residual and Angry-Neutral contrast change post-MBSR at the right parahippocampal gyrus. Image shows the t-values map overlaid on a T1 template with the color blob representing the significant cluster. Scatter plot shows the mean Angry-Neutral contrast pre-post signal changes of the significant cluster against T-Anger residual scores post-MBSR.