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Dispositional Mindfulness and Depressive Symptomatology: Correlations With Limbic and Self-Referential Neural Activity During Rest

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To better understand the relationship between mindfulness and depression, we studied normal young adults ($n = 27$) who completed measures of dispositional mindfulness and depressive symptomatology, which were then correlated with (a) rest: resting neural activity during passive viewing of a fixation cross, relative to a simple goal-directed task (shape-matching); and (b) reactivity: neural reactivity during viewing of negative emotional faces, relative to the same shape-matching task. Dispositional mindfulness was negatively correlated with resting activity in self-referential processing areas, whereas depressive symptomatology was positively correlated with resting activity in similar areas. In addition, dispositional mindfulness was negatively correlated with resting activity in the amygdala, bilaterally, whereas depressive symptomatology was positively correlated with activity in the right amygdala. Similarly, when viewing emotional faces, amygdala reactivity was positively correlated with depressive symptomatology and negatively correlated with dispositional mindfulness, an effect that was largely attributable to differences in resting activity. These findings indicate that mindfulness is associated with intrinsic neural activity and that changes in resting amygdala activity could be a potential mechanism by which mindfulness-based depression treatments elicit therapeutic improvement.

Keywords: mindfulness, depression, amygdala, emotion, default network

Practices that cultivate mindfulness ~~recently~~ have been incorporated into therapies for depression. These practices, which include mindfulness meditation, are designed to develop the capacity to focus attention on present moment experiences in an open and receptive manner (Brown, Ryan, & Creswell, 2007).

Enhancing mindfulness is a central component of mindfulness based cognitive therapy (MBCT; Williams, Russell, & Russell, 2008) and has been shown to prevent the relapse of major depression in patients who have experienced multiple-depression episodes (Kingston, Dooley, Bates, Lawlor, & Malone, 2007; Ma & Teasdale, 2004; Teasdale et al., 2000). Furthermore, MBCT has been shown to be more effective than maintenance antidepressant therapy in reducing residual depressive symptoms and improving quality of life (Kuyken et al., 2008). Based on the success of this approach, MBCT also has been explored as a potential treatment during the acute phase of depression, demonstrating beneficial effects in two nonrandomized trials (Eisendrath et al., 2008; Kenny & Williams, 2007).

A critical question raised by these findings concerns the mechanisms by which mindfulness-treatments impact depressive symptoms. At a neural level, major depressive disorder is associated with dysfunction in multiple-interconnected limbic and cortical structures that are thought to be part of a functional circuit governing and producing affective state (Drevets, Price, & Furey, 2008; Mayberg, 2003). One of these structures, the amygdala, is critically involved in fear-related processing and exhibits greater resting activity in patients suffering from depression. Thus, measurements of glucose metabolism or cerebral blood flow while the subject is resting in the scanner reveal higher levels of amygdala activity among depressed subjects than controls (Clark et al., 2006; Drevets et al., 1992). In addition, the magnitude of resting amygdala metabolism is positively correlated with the degree of depressive symptomatology (Abercrombie et al., 1998; Drevets et al., 2002; Drevets et al., 1992; Saxena et al., 2001). As these high levels of resting amygdala activity normalize with the remission of depression (Clark et al., 2006; Drevets et al., 1992), it appears that elevated levels of resting amygdala activity are a marker of the depressed state.

This relationship between elevated resting amygdala activity and depressive symptomatology suggests that one mechanism by which mindfulness training may reduce depression relapse and symptoms is by quelling heightened resting amygdala activity. Therefore, in this study, we examined the neural correlates of dispositional mindfulness and depressive symptomatology in a

nonclinical sample during passive sensory viewing (fixation cross) relative to a simple goal-directed control task (shape matching). The logic for this approach is that areas that are correlated with both dispositional mindfulness and depressive symptomatology are potential neural sites in which mindfulness training could be affecting depression related processes.

Neuroimaging studies of depressed patients also indicate that amygdala reactivity, as opposed to resting amygdala activity, is implicated in depression. Studies of amygdala reactivity to negative emotional stimuli have shown that the amygdala is hyperreactive during the depressed state (Sheline et al., 2009; Siegle, Thompson, Carter, Steinhauer, & Thase, 2007) and that amygdala activity normalizes with either successful pharmacotherapy (Fu et al., 2004; Sheline et al., 2001) or cognitive–behavioral therapy (Fu et al., 2008; Siegle, Carter, & Thase, 2006). Thus, it is also possible that the relationship between mindfulness and depression may be characterized by greater amygdala reactivity to threatening cues (instead of, or in addition to, resting amygdala activity), so an additional analysis explored the relationship of dispositional mindfulness and depressive symptomatology to amygdala reactivity during the viewing of threatening and fearful faces (relative to the same shape-matching control task).

In addition, we also examined neural correlates of depression and mindfulness in medial prefrontal and parietal regions, which have been shown to be involved in self-reflective processing (Lieberman, in press) and are often activated during resting states (Gusnard, Akbudak, Shulman, & Raichle, 2001). Of particular relevance for the present study, rumination on negative aspects of the self has been associated with greater risk for depression (Nolen-Hoeksema, 2000) as well as greater medial PFC activity (Ray et al., 2005). In contrast, training in mindfulness meditation, which emphasizes developing a nonjudgmental meta-awareness of the self, was associated with decreased medial PFC activity, relative to controls, in a self-referential task (Farb et al., 2007). Therefore, we hypothesized that mindfulness and depression would have contrasting effects on medial PFC during rest, with mindful individuals showing reduced activity in self-reflective neural regions at rest.

Method

Participants

Twenty-seven University of California, Los Angeles (UCLA) undergraduates (16 women) participated in the study for $20. Participants identified themselves as Asian (39%), White (29%), Latino (18%), African American (7%), or other (7%). Prospective participants were excluded through a structured telephone interview if they had serious physical or mental health problems (e.g., "Has a doctor ever told you that you have a serious physical/mental health problem?"), were receiving current treatment from a mental health professional, were using mental health-related medication (e.g., Prozac), or were pregnant/breast feeding. Participants also met the following functional MRI (fMRI)-related inclusion criteria: (a) were right-handed, (b) were not claustrophobic, and (c) had no metal in their bodies (dental fillings were allowed). All procedures were approved by the UCLA Institutional Review Board.

Individual Difference Measures

Depressive symptomatology was assessed using the Beck Depression Inventory (BDI, $\alpha = .88$), which was the primary measure used in studies documenting the effectiveness of MBCT (Williams et al., 2008). Dispositional mindfulness was assessed using the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003; e.g., "I find it difficult to stay focused on what's happening in the present," all items were reverse scored; $\alpha = .78$). This measure has good psychometric properties and is sensitive to the effects of mindfulness training (Brown et al., 2007; Chambers, Lo, & Allen, 2008). In addition, participants also completed other measures previously associated with amygdala activation or the MAAS, including the Spielberger Trait Anxiety Inventory ($\alpha = .91$), a 10-item measure of neuroticism, drawn from the International Personality Item Pool ($\alpha = .86$), and the Public Self-Consciousness subscale of the Self-Consciousness Scale, a 7-item measure assessing one's self-awareness as a social object ($\alpha = .70$).

Experimental Paradigm

As part of an affect labeling and processing study (Lieberman et al., 2007), participants viewed three different sets of stimuli: (1) a fixation cross, (2) shapes, and (3) faces displaying emotional expressions (see Figure 1). When viewing shapes or faces, participants performed a matching task between a target at the top of the screen and a pair of stimuli presented at the bottom of the screen. For shape matching, participants were instructed to choose the shape at the bottom of the screen that matched the target presented at the top of the screen and for face matching they chose the face from the pair at the bottom that expressed the same emotion as the target face at the top of the screen. To prevent habituation of

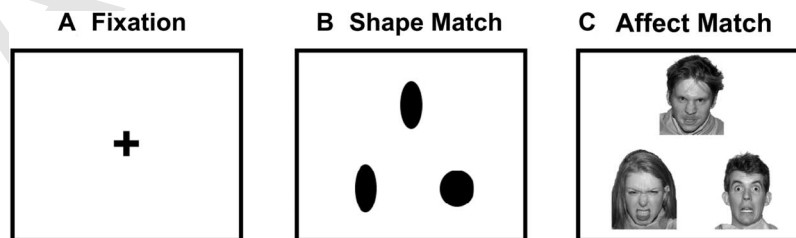*Figure 1.* The three different forms of stimuli viewed by the participants. A) Passive viewing of the fixation cross. B) Shape-match condition: from the pair of shapes at the bottom of the screen, participants chose the shape that best matched the target at the top of the screen. C) Affect-match condition: from the pair of faces at the bottom of the screen, participants chose the face that had the matching facial expression.

amygdala response to the viewing of negative emotional expressions (fear and anger), 20% of the trials in the affect matching condition used faces with a positive emotional expression (happiness or surprise). Faces were selected from a standardized set of images (Tottenham et al., 2009) and consisted of an equal number of male and female faces.

Task blocks began with a 3-s instruction cue notifying the participant to perform either the shape-matching or face-matching task, which was followed by 10 randomized trials, each 5 s in length, resulting in task blocks that were 50 s in length. In addition to these two tasks, participants completed four other tasks for which analyses were reported separately (Creswell, Way, Eisenberger, & Lieberman, 2007). The six task blocks were separated by a fixation crosshair, which remained on the screen for 10 s, and served as the baseline. The participants completed two runs; the shape-matching task and the affect-matching task occurred once in each run. The participants responded via a button box as soon as they were sure of the correct answer. The stimuli remained on the screen for the entire 5-s trial.

Data Acquisition and Analysis

AQ: 9 Data were acquired on a Siemens Allegra 3-T head-only scanner. Head movements were restrained with foam padding and surgical tape placed across each subject's forehead. For each subject, a high-resolution structural T2-weighted echo-planar imaging volume (spin-echo; repetition time = 5,000 ms; echo time = 33 ms; matrix size = 128 × 128; 36 axial slices 3 mm thick with a 1-mm skip between slices; field of view = 20 cm) was acquired coplanar with the functional scans. Two functional scans were acquired (echo-planar T2*-weighted gradient-echo, repetition time = 3,000 ms, echo time = 25 ms, flip angle = 90°, matrix size = 64 × 64, 36 axial slices 3 mm thick with a 1-mm skip between slices, field of view = 20 cm), each lasting 6 min 18 s. During each functional scan, 126 volumes were collected.

The imaging data were analyzed using statistical parametric mapping (SPM99; Wellcome Department of Cognitive Neurology, Institute of Neurology, London, England). Images for each subject were realigned to correct for head motion, normalized into a standard stereotactic space as defined by the Montreal Neurological Institute (MNI), and smoothed with an 8-mm Gaussian kernel, full width at half maximum. For each subject, task conditions were modeled as epochs. Planned comparisons were computed for each subject using the general linear model, with a canonical hemodynamic response function. The resulting contrast images were entered into second-level analyses using a random effects model to allow for inferences at the group level.

For assessment of the resting state, fixation was compared to shape matching. Typically, such comparisons of active and passive task blocks refer to the differences in activity with reference to the goal-directed task. Hence, the term *deactivations* is often used to describe these differences (Raichle et al., 2001). To facilitate the connection with resting glucose metabolism studies of depressed subjects, we refer to these differences in reference to the fixation condition and use the term *activations* (Gusnard & Raichle, 2001), though the reader should be mindful that these are relative comparisons. Direct neurophysiological recordings of activity during passive and goal-directed tasks confirm this interpretation of the neuroimaging data, as neural activity has been found to increase during passive tasks in both the medial prefrontal cortex and precuneus (Miller, Weaver, & Ojemann, 2009).

To create a mindfulness variable controlling for related individual differences measures, variables that correlated significantly or marginally significantly with the MAAS were regressed into the MAAS and the standardized residuals were saved. These standardized residual values were then entered as a regressor in a random effects whole-brain group analysis, comparing neural activity during shape matching with neural activity during passive fixation. Results are reported according to the voxel of peak activation among each identified cluster of activation. The correction for multiple comparisons in whole-brain analyses was carried out using an uncorrected p value of .005 combined with a cluster-size threshold of 20 voxels (Forman et al., 1995). To identify activation clusters that spatially overlapped in both the correlation with dispositional mindfulness as well as depressive symptomatology, the Marsbar toolbox was used (Brett, Anton, Valabregue, & Poline, 2002). Each activation cluster was defined as a region of interest and then a subtraction was performed to reveal voxels that were conjointly related to each variable. Marsbar was used to then extract the mean parameter estimates from this ROI and subsequent statistical analyses were performed in SPSS 14.0. All coordinates are reported in MNI coordinate space.

Results

Initial Analyses

Initial zero-order correlational analyses were performed to examine the interrelationship between the individual difference measures. Although scores on the MAAS and the BDI were not significantly related, there was a trend in the negative direction ($r = -.29$, $p = .14$), as would be expected (Brown & Ryan, 2003). Scores on the MAAS were negatively related to public self-consciousness ($r = -.51$, $p < .01$) and were marginally higher in male subjects, $t(25) = 1.79$, $p = .09$. There was no relationship between the MAAS and either neuroticism ($r = -.24$, *ns*) or the STAI ($r = -.13$, *ns*). To examine correlations between mindfulness and neural activity, we examined correlations between neural activity and (1) self-reported dispositional mindfulness and (2) a residualized dispositional mindfulness variable, in which gender and public self-consciousness were regressed into the MAAS and the standardized residuals were then used as the regressors.

The BDI had a similar magnitude of relationship ($r = -.31$, $p = .12$) with the residualized measure of mindfulness as it did with the uncorrected measure. Scores on the BDI were positively correlated with both neuroticism ($r = .61$, $p < .001$) and trait anxiety ($r = .63$, $p < .001$). There were no gender differences in reported depressive symptomatology, $t(25) = 0.40$, $p = .69$. There was a wide distribution of depressive symptomatology in this sample, ranging from 0 to 24 on the BDI, with 26% of the participants scoring at or exceeding the cutoff (10) for mild depression.

Neural Analyses

Resting state analyses (fixation vs. shape matching). In the fixation condition, relative to shape matching, there was widespread activation throughout a network of areas (Table 1; Figure 2) **T1, F2** that have been referred to as the default network (Gusnard &

Table 1
Baseline Neural Activation During Fixation Relative to Shape Matching

Region	Side	Brodmann area	MNI coordinate			t	k (voxels)
Frontal lobe							
Superior frontal gyrus	R	10	28	66	16	3.61	52
Superior frontal gyrus	L	8	−24	36	52	4.32	51
Superior frontal gyrus	L	9	−34	48	32	3.54	20
Superior frontal gyrus		8	0	46	34	3.44	95
Superior frontal gyrus	R	6	6	26	46	3.54	40
Medial frontal gyrus	L	9	−40	20	34	3.63	68
Inferior frontal gyrus	R	44	50	24	26	6.10	1,470
Inferior frontal gyrus	L	45	−58	24	18	4.30	192
Inferior frontal gyrus	R	47	40	34	−18	4.44	72
Inferior frontal gyrus	L	47	−26	52	−2	3.63	47
Precentral gyrus	L	4	−62	−4	10	3.33	26
Medial prefrontal cortex	R	32	2	50	−10	3.75	351
Temporal lobe							
Superior temporal gyrus	L	42	−50	−32	12	3.72	183
Superior temporal gyrus	R	22	62	−38	2	5.44	393
Middle temporal gyrus	L	21	−64	−42	−10	3.97	64
Middle temporal gyrus	R	21	58	−2	−24	4.49	200
Middle temporal gyrus	R	21	64	−52	6	4.91	263
Parahippocampal gyrus	R	36	36	−8	−40	6.29	3,511
Parahippocampal gyrus	L	35	−20	−28	−24	5.84	257
Fusiform gyrus	R	20	40	−18	−24	5.24	220
Parietal lobe							
Precuneus	L	7	−2	−36	48	6.48	462
Posterior cingulate	L	23	−2	−26	36	5.62	464
Inferior parietal lobule	L	39	−36	−78	40	5.03	171
Inferior parietal lobule	R	39	36	−76	46	4.49	303
Occipital lobe							
Fusiform gyrus	R	18	30	−92	−10	7.00	1,171
Fusiform gyrus	L	18	−32	−94	−12	6.33	893
Subcortical and Paralimbic							
Dorsal anterior cingulate cortex	R		2	12	24	4.15	239
Dorsal striatum	R		8	18	8	6.26	288
Amygdala	L		−22	−6	−16	4.84	320
Amygdala	R		22	0	−32	4.42	168
Ventral midbrain	R		4	−14	−18	4.94	163

Note. Significance was determined using $p < .005$ with a 20-voxel extent threshold. MNI = Montreal Neurological Institute; L = left; R = right.

Raichle, 2001). These included the four areas most commonly included in the default network (Buckner, Andrews-Hanna, & Schacter, 2008): a large midline cluster with a peak in the precuneus/posterior cingulate (−2, −36, 48), $t = 6.48$, $p < .005$, inferior parietal lobule, bilaterally (−36, −78, 40), $t = 5.03$, $p < .005$, and (36, −76, 40), $t = 4.49$, $p < .005$, dorsomedial prefrontal cortex (BA 9: 0, 46, 34), $t = 3.44$, $p < .005$, and medial prefrontal cortex

(BA10: 2, 50, 10), $t = 3.75$, $p < .005$. In addition, there was activation in medial and lateral temporal lobe areas associated with the default network (Buckner et al., 2008) including the left and right amygdala (−22, −6, −16), $t = 4.84$, $p < .005$, (22, 0, −32), $t = 4.42$, $p < .005$, the left and right parahippocampal gyrus (−20, −28, −24), $t = 5.84$, $p < .005$, (36, −8, −40), $t = 6.29$, $p < .005$, and the left (−64, −42, −10), $t = 3.97$, $p < .005$, and right (rostral:
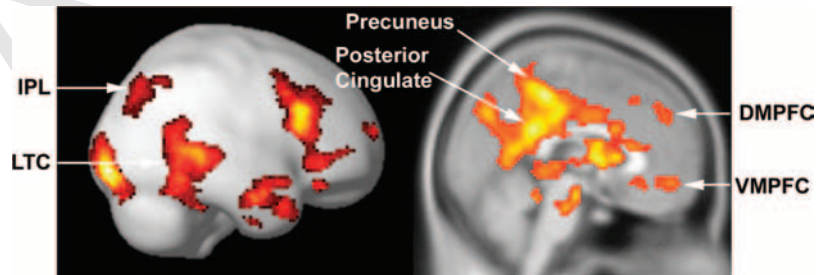

Figure 2. Activations in the fixation relative to shape-match contrast. Denoted areas are part of the default network. IPL = inferior parietal lobule; LTC = lateral temporal cortex; DMPFC = dorsomedial prefrontal cortex; VMPFC = ventromedial prefrontal cortex.

58, –2, –24), t_A = 4.49, p < .005, (caudal: 64, –52, 6), t_A = 4.91, p < .005 middle temporal gyrus. The bilateral fusiform gyrus also showed greater activation (30, –92, –10), t_A = 7.00, p < .005, (−32, –94, 12), t_A = 6.33, p < .005, which is common when a passive sensory task rather than eyes-closed rest is used as the baseline (Gusnard & Raichle, 2001). In addition, the right dorsal anterior cingulate cortex (2, 12, 24), t_A = 4.15, p < .005, and the dorsal striatum (8, 18, 8), t_A = 6.26, p < .005, were activated.

In this same resting state contrast, the BDI was positively correlated with activation in the right amygdala (22, 0, –28); t_A = 3.28, p < .005, k = 40, medial prefrontal cortex (BA10/11: 4, 56, –14), t_A = 3.37, p < .005, inferior frontal gyrus (−42, 42, 6), t_A = 3.46, p < .005, and several areas in the visual cortex (Table 2; Figure 3). As anxiety related constructs have been related to amygdala activity (Etkin & Wager, 2007), the relationship of both trait anxiety and neuroticism with amygdala activity were examined. Neither variable exhibited a significant correlation with amygdala activity and when they were used as covariates in an assessment of the neural correlates of the BDI, the relationship between BDI score and right amygdala activity remained significant (26, 2, −24), t_A = 3.76, p < .005, k = 55. In terms of areas inversely correlated with BDI scores, only one cluster had a significant negative relationship and that was in the superior frontal gyrus (30, 46, 38), t_A = 3.34, p < .005, k = 47.

In this same fixation versus shape-match contrast, dispositional mindfulness was negatively correlated with activity in multiple areas (see Table 3). The global maximum was centered in the left amygdala/hippocampal transition area (−12, −12, −20), t_A = 5.22, p < .005, k = 301, and extended both rostrally and caudally from this peak. There was also a peak in the right anterior medial temporal lobe (34, 10, −26), t_A = 3.99, p < .005, k = 109, that extended caudally to encompass the rostral amygdala. In addition, the left ventrolateral prefrontal cortex (−44, 34, −10), t_A = 3.73, p < .005, k = 134, was negatively associated with dispositional mindfulness. With respect to areas considered part of the default network, dispositional mindfulness was also negatively related to precuneus activity (2, −48, 56), t_A = 3.68, p < .005, k = 101. As for the positive correlation with dispositional mindfulness, no areas exceeded the statistical threshold for significant activation.

To examine the unique relationship of mindfulness to neural activity in the fixation versus shape match contrast, the residualized dispositional mindfulness measure (controlling for gender and public self-consciousness) was used as a regressor in a random effects whole-brain analysis. The residualized dispositional mindfulness variable was negatively correlated with activity in multiple subcortical areas, including both the right (24, 2, −20), t_A = 4.09, p < .005, k = 367, and left amygdala (−20, 2, −20), t_A = 3.73, p < .005, k = 31, the hippocampus bilaterally (−28, –20, –10), t_A = 3.81, p < .005, (42, –18, –22), t_A = 3.90, p < .005, and the thalamus bilaterally (−22, –20, 14), t_A = 3.69, p < .005, (14, –6, 2), t_A = 4.64, p < .005. Cortically, there was a significant negative correlation of residualized dispositional mindfulness with midline clusters of activation in the medial prefrontal cortex (BA10: 16, 68, 12), t_A = 3.40, p < .005, and the posterior cingulate (8, –34, 48), t_A = 3.42, p < .005, as well as with several clusters in the temporal cortex and visual cortex (Table 4; Figure 3). In contrast to these negative correlations, the residualized dispositional mindfulness variable was positively related to a single cluster in the right orbitofrontal gyrus (18, 40, –14), t_A = 3.88, p < .005.

To identify areas that correlated with dispositional mindfulness as well as depressive symptomatology and thus might be involved in both processes, clusters of activation from each respective correlation map were assessed for spatial overlap. Only one area, the right amygdala, had a cluster (22, 0, −26, k = 20) possessing a significant relationship with both variables. This 20 voxel cluster was positively correlated with BDI scores and negatively correlated with the residualized dispositional mindfulness variable (see Figure 4). To determine the degree to which shared variance **F4** accounted for the relationship of depressive symptomatology and dispositional mindfulness, each variable was entered into a multiple regression with this 20 voxel right amygdala cluster as the dependent variable. Both the residualized dispositional mindfulness variable, β = −0.47, t = −3.18, p < .005, and the BDI, β = 0.43, t = 2.87, p < .01, were significantly related to activity in this cluster. Thus, each variable was uniquely associated with amygdala activity. In addition, the mean activation for this ROI was not significantly different between men and women, according to an independent samples t test, $t(25)$ = 1.1, p = .29.

Reactivity analyses (affect matching relative to shape matching). To examine the relationship of depressive symptomatology and dispositional mindfulness with amygdala reactivity, the right amygdala ROI (described above) was used to extract values from the affect matching relative to shape matching contrast (see Figure 5). **F5** Consistent with predictions, the dispositional mindfulness variable was negatively correlated with amygdala activation (r = −.53, p < .005) when viewing threatening and fearful faces, relative to shape matching. Similarly, BDI scores were positively correlated with amygdala activation in this contrast (r = .63, p < .001). Thus, the right amygdala showed the same pattern of relationship with both depressive symptomatology and the residualized dispositional mindfulness variable in the reactivity analysis as it did in the resting state analysis.

Critical for the interpretation of these results is to remember that the amygdala reactivity observed in this analysis stems from comparing affect matching with a neutral, goal-directed task, as is typically done in the field. However, according to the resting analyses, there is also greater amygdala activity when passive fixation is compared to shape matching. This gives rise to the question as to whether there is amygdala activation during affect matching that exists over and above that during resting activity. In other words, is the amygdala activity seen in the affect match versus shape match contrast more attributable to amygdala activation over and above passive fixation or is it more attributable to the deactivation from passive fixation during shape matching? To disentangle these alternative interpretations, amygdala response to the viewing of emotional faces was compared to the passive viewing of the fixation cross (as opposed to shape matching). As in the previous contrast, the same right amygdala ROI defined in the fixation versus shape-matching contrast was used to extract parameter estimates. There was no significant relationship between the residualized dispositional mindfulness measure and amygdala activation (r = –.26, p = .18) in this affect match versus fixation contrast (see Figure 6). Thus, when amygdala reactivity is assessed **F6** relative to a passive rather than goal-directed task, the relationship with the dispositional mindfulness measure is no longer significant. This indicates that for those either high or low in dispositional mindfulness there were relatively similar degrees of amygdala activation when viewing emotional faces relative to passive

Table 2
Areas Positively Correlated With Beck Depression Inventory Score

Region	Side	Brodmann area	MNI coordinate			t	k (voxels)
Frontal lobe							
Inferior frontal gyrus	L	46	−42	42	6	3.46	65
Medial prefrontal cortex	R	10	4	56	−14	3.37	33
Parietal lobe							
Superior parietal lobule	R	7	24	−72	56	3.07	21
Occipital lobe							
Fusiform gyrus	R	19	26	−84	−16	3.92	131
Fusiform gyrus	R	37	46	−56	−18	3.91	129
Cuneus	R	18	20	−94	12	3.41	53
Subcortical							
Amygdala	R		22	0	−28	3.28	40

Note. Significance was determined using $p < .005$ with a 20-voxel extent threshold. MNI = Montreal Neurological Institute; L = left; R = right.

viewing of a fixation cross. In other words, when the measure of resting activity is subtracted from the measure of reactivity, there is not a relationship between the residualized dispositional mindfulness variable and amygdala activity, indicating that the association between dispositional mindfulness and amygdala reactivity is largely attributable to the differences in resting activity. More specifically, because there were no mindfulness related differences in amygdala activation when affect matching was compared to passive fixation, but there were robust differences when affect matching was compared to shape matching, the relationship of mindfulness to amygdala activation in the affect matching versus shape matching contrast would appear to be explained by the difference in amygdala activity between fixation and shape matching.

With respect to depressive symptomatology, there was a positive correlation between BDI scores and amygdala activation ($r = .44$, $p = .02$) in the affect matching versus fixation contrast (see Figure 6). This suggests that the association of depressive symptomatology with amygdala activity in the affect matching versus shape-matching contrast was a reflection of both greater amygdala response to the viewing of emotional faces as well as greater deactivation during shape matching, relative to fixation. However, the effect in the latter condition was more robust.

Discussion

During passive sensory viewing relative to cognitive engagement in a simple goal-directed task, dispositional mindfulness and depressive symptomatology exhibited opposite, overlapping relationships with activity in only one area of the brain, the right amygdala. This association of greater depressive symptomatology with greater relative baseline amygdala activity is consistent with resting glucose metabolism and cerebral blood flow studies of depressed patients showing that amygdala activity is correlated with depression severity (Abercrombie et al., 1998; Clark et al., 2006; Drevets et al., 1992) and suggests that the association of dispositional mindfulness with levels of amygdala activation in this contrast may have clinical relevance.

In addition to these resting state differences, greater depressive symptomatology was associated with greater amygdala reactivity to the viewing of emotional faces. Conversely, dispositional mindfulness was associated with reduced amygdala reactivity to the viewing of emotional faces. This association of dispositional mindfulness and depressive symptomatology with differences in reactivity appeared to be largely driven by differences in the resting state, underscoring the psychological importance of intrinsic neural activity. Hence, studying the relationship between mindfulness and resting neural activity is likely to be a valuable approach for understanding the mechanisms by which mindfulness has salutary effects.

Resting State Activity

The focus on the resting state in this study stems from recent research indicating that unconstrained, passive sensory processing exhibits reliable and predictable deactivations that become appar-

Figure 3. Correlations of depression and mindfulness with self-referential regions during rest (fixation vs. shape match). Positive correlations with Beck Depression Inventory score in the ventromedial prefrontal cortex (A: 4, 56, –14) and negative correlations with dispositional mindfulness in the medial prefrontal cortex (B: 16, 68, 12) and the posterior cingulate (C: 8, –34, 48).

Table 3
Areas Negatively Correlated With Dispositional Mindfulness

Region	Side	Brodmann area	MNI coordinate			*t*	*k* (voxels)
Frontal lobe							
Inferior frontal gyrus	L	47	−44	34	−10	3.73	134
Inferior frontal gyrus	L	44	−58	6	6	3.59	35
Precentral gyrus	L	6	−50	0	50	3.59	23
Temporal lobe							
Anterior medial temporal lobe	R	38	34	10	−26	3.99	109
Medial temporal gyrus	R	21	50	−4	−26	3.83	112
Superior temporal gyrus	L	22	−54	−6	−16	3.65	68
Superior temporal gyrus	R	22	66	−44	2	3.50	38
Occipital and parietal lobe							
Cuneus	R	31	26	−66	22	4.13	79
Precuneus	R	7	2	−48	56	3.68	101
Parietal operculum	L	41	−38	−18	24	3.69	35
Lingual gyrus	R	18	26	−60	8	3.92	102
Fusiform gyrus	R	19	24	−56	−12	3.38	49
Fusiform gyrus	R	19	18	−80	−14	3.05	29
Subcortical and paralimbic							
Amygdala/anterior ~~HPC~~	L		−12	−12	−20	5.22	301
Caudate	R		10	12	12	4.47	60
Hippocampus	L		−26	−20	−12	3.99	79
Hippocampus	L	35	−14	−32	−2	3.80	91
Thalamus	L		−8	−10	14	3.80	29
Globus pallidus	R		12	−4	0	3.30	29
Globus pallidus	L		−16	2	2	3.28	23

Note. Significance was determined using $p < .005$ with a 20-voxel extent threshold. MNI = Montreal Neurological Institute; HPC = ; L = left; R = right.

ent when contrasted with a wide variety of cognitive tasks (Gusnard & Raichle, 2001). The constellation of interconnected areas identified using such methods are typically referred to as the default network and generally include the precuneus/posterior cingulate, dorsal and ventral medial prefrontal cortices, and lateral posterior cortices as well as medial temporal lobe areas such as the amygdala and hippocampus (Buckner et al., 2008; Gusnard & Raichle, 2001; Shulman et al., 1997). In this study, each of these areas were identified in the fixation versus shape-match contrast (see Table 1), supporting the validity of our methods for delineating a resting state.

Despite the full expanse of the default network exhibiting relative activation in this contrast, only medial portions of it were associated with either depressive symptomatology or dispositional mindfulness. Although the amygdala was the sole area for which the significantly correlated clusters spatially overlapped, portions of the medial prefrontal cortex positively correlated with depressive symptomatology and negatively correlated with residualized dispositional mindfulness (see Figure 3).

Tasks that require self-reflection, such as the assessment of the self-descriptiveness of traits (Kelley et al., 2002) or making judgments about one's feelings (Ochsner et al., 2004), reliably activate medial prefrontal cortex and frequently the posterior cingulate, as well (Lieberman, 2007). As Beck, Rush, Shaw, and Emery (1979) identified negative attitudes toward the self (e.g., "I am a failure") as a primary driver of depression-inducing and depression-maintaining cognitions, the BDI is designed to measure these self-relevant cognitions. Hence, the positive correlation of the BDI with medial prefrontal activation at rest is consistent with individuals who are higher in depressive symptomatology engaging in

greater self-relevant processing when not engaging in a goal-directed task.

Dispositional mindfulness was negatively correlated with resting activation in closely related medial prefrontal and parietal self-referential areas (see Figure 3). The lower levels of resting activation in those high in mindfulness might indicate that they are less likely to engage in self-focused processing at rest. Potentially, these lower levels of activation within neural areas processing self-relevant information may indicate that the attachment of thoughts and feelings to the self is less robust in those high in mindfulness. If so, this would be consistent with a core skill trained in MBCT (Segal, Williams, & Teasdale, 2002), which is to develop a metacognitive awareness that allows patients to change their relationship with their depression promoting cognitions. More speculatively, in so far as intrinsic neural activity across time and situations represents a "self" (Gusnard & Raichle, 2001), the reduced levels of such neural activity in those high in mindfulness may also be related to the concept of "no-self" in Eastern contemplative traditions or "dying to self" in Western contemplative traditions.

Amygdala Activity and the Resting State

A critical issue in the depression literature has been the relationship between studies showing heightened intrinsic resting amygdala activity in depression (usually PET glucose metabolism studies) and studies showing depressed patients have heightened amygdala reactivity, as assessed by comparing emotional stimuli to neutral stimuli (Whalen, Shin, Somerville, McLean, & Kim, 2002). The data presented herein underscore the importance of the baseline condition in

Table 4

Areas Negatively Correlated With Dispositional Mindfulness Residualized for Gender and Public Self-Consciousness

Region	Side	Brodmann area	MNI coordinate			t	k (voxels)
Frontal lobe							
Superior frontal gyrus	R	10	16	68	12	3.40	23
Middle frontal gyrus	L	46	−40	40	16	3.27	30
Inferior frontal gyrus	L	44	−58	8	6	4.38	32
Orbitofrontal gyrus	R	11	22	26	−20	3.76	64
Temporal lobe							
Temporal pole	R	38	54	10	−26	5.12	143
Middle temporal gyrus	L	21	−48	−4	−24	4.25	155
Parahippocampal gyrus	L	34	−12	−12	−22	3.56	28
Anterior transverse temporal area	L	41	−38	−22	24	3.64	83
Parahippocampal gyrus	L	27	−16	−34	−4	3.92	37
Occipital lobe							
Superior occipital gyrus	L	19	−12	−86	38	3.35	38
Middle occipital gyrus	L	19	−26	−82	20	3.66	206
Cuneus	R	31	24	−62	10	3.54	51
Cuneus	R	31	28	−64	22	3.5	122
Cuneus	L	17	−8	−76	16	3.41	23
Lingual gyrus	R	18	16	−98	−10	3.69	161
Lingual gyrus	L	17	−8	−92	16	3.47	133
Lingual gyrus	L	18	−6	−76	0	3.40	56
Fusiform gyrus	R	37	24	−62	−22	3.58	148
Fusiform gyrus	L	37	−28	−64	−22	3.56	113
Fusiform gyrus	R	18	34	−90	−14	3.39	45
Subcortical and paralimbic							
Amygdala/anterior ~~HPC~~	R		24	2	−20	4.09	367
Amygdala	L		−20	2	−20	3.73	31
Posterior cingulate	R	23	8	−34	48	3.42	73
Caudate body	L		−18	−10	28	4.59	209
Hippocampal formation	L		42	−18	−22	3.90	20
Hippocampal formation	L		−28	−20	−10	3.81	30
Thalamus	R		14	−6	2	4.64	120
Thalamus	L		−22	−20	14	3.69	42
Cerebellum			0	−48	−4	3.71	63

Note. Significance was determined using $p < .005$ with a 20-voxel extent threshold. MNI = Montreal Neurological Institute; HPC = ; L = left; R = right.

interpreting results of such studies. Typically, it is assumed that when contrasting evocative emotional stimuli to neutral stimuli, the greater amygdala activation is due to activation by the evocative stimuli rather than deactivation to the neutral stimuli. Consistent with this model, amygdala activation had a robust positive correlation with depressive symptomatology in the affect match versus shape match contrast as well as a robust negative correlation with dispositional mindfulness. However, when passive viewing of the fixation cross was used as the baseline for the viewing of emotional faces, there was no relationship between amygdala activation and dispositional mindfulness and only a weak relationship with depressive symptomatology. In light of the robust relationship of these psychological variables with amygdala activation in the fixation relative to shape matching contrast, these data suggest that the differences seen in the affect-match versus shape-match contrast are not primarily a result of differences in reactivity to emotional stimuli, but rather a reflection of differences in deactivation from resting baseline during shape matching.

Because blood oxygen level dependent fMRI analyses are dependent on relative comparisons between two tasks, it is not possible to determine whether dispositional mindfulness and depressive symptomatology are more closely associated with differences in amygdala activity during passive fixation or shape matching. Our interpretation is that lower dispositional mindfulness (and higher depressive symptomatology) is associated with greater resting amygdala activity during the passive fixation condition and comparable levels of amygdala activity during shape matching. This would be consistent with PET studies that have found a positive correlation between resting amygdala glucose metabolism and depression severity (Abercrombie et al., 1998; Drevets et al., 2002; Drevets et al., 1992; Saxena et al., 2001). It would also be consistent with two recent fMRI studies that measured absolute levels of amygdala activity and found that carriers of a risk allele for depression had higher levels of amygdala blood flow at rest (Canli et al., 2006; Rao et al., 2007). However, with the methodology used in the present study, it cannot be conclusively determined that mindfulness differences ~~was not related~~ in amygdala activity during shape matching. Ultimately, methodological approaches (e.g., perfusion MRI) that do not use a relative comparison will be necessary to conclusively address this question.

Amygdala Activity and Attention: Functional Implications

An important question raised by the present findings concerns the potential functional effects of higher resting amygdala activity as well as why it is associated with both mindfulness and depression. One potential explanation may lie in the amygdala's involvement in modulating moment-to-moment vigilance (Davis &
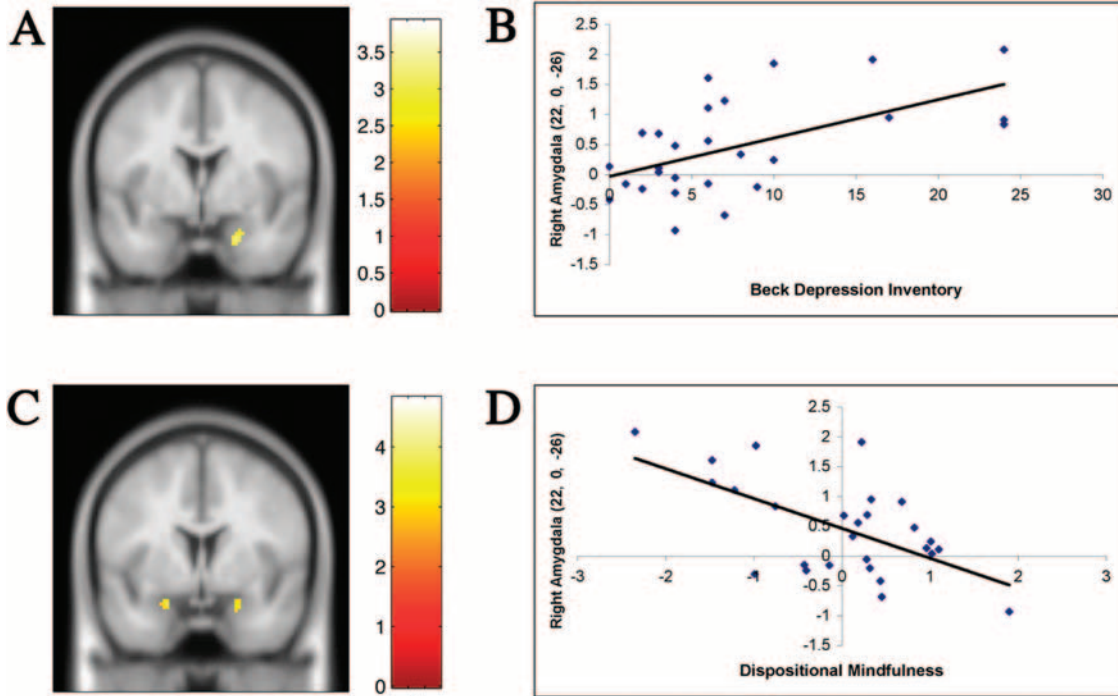
COLOR

Figure 4. Left panel: coronal sections showing the activations in the fixation relative to shape-match contrast for the positive correlation with depressive symptomatology (A) and the negative correlation with the dispositional mindfulness variable (C). In the right panel, scatterplots depict the correlation of the mean parameter estimates for the 20 voxel right amygdala cluster (22, 0, −26) with depressive symptomatology (B: $r = .57$, $p < .005$) and residualized dispositional mindfulness (D: r = −.60, $p < .005$).

Whalen, 2001). The amygdala is richly interconnected with nearly the entire cortical mantle (Amaral, Price, Pitkanen, & Carmichael, 1992) and can use these connections to direct attention to the processing of emotionally relevant stimuli. Accordingly, amygdala lesions prevent this facilitation of attention to aversive emotional stimuli (Anderson & Phelps, 2001) as well as the normal heightening of activation in the face responsive regions of the visual cortex during the viewing of fearful faces (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). Consistent with this role for the amygdala in orienting and narrowing attentional focus, activation of the amygdala in normal subjects by nonemotional stimuli

can induce a state of hypervigilance that biases subsequent processing toward negative stimuli (Herry et al., 2007). It would seem then that the higher levels of baseline amygdala activity seen in the present study might be associated with depressive symptomatology, in part because of a biasing effect on both internal and external information processing that emphasizes the negative, contributing to the feelings of worthlessness and failure characteristic of depression. Conversely, according to this model, lower levels of baseline amygdala activity may be associated with a less biased and broader attentional stance. This would be consistent with the negative correlation of dispositional mindfulness scores with
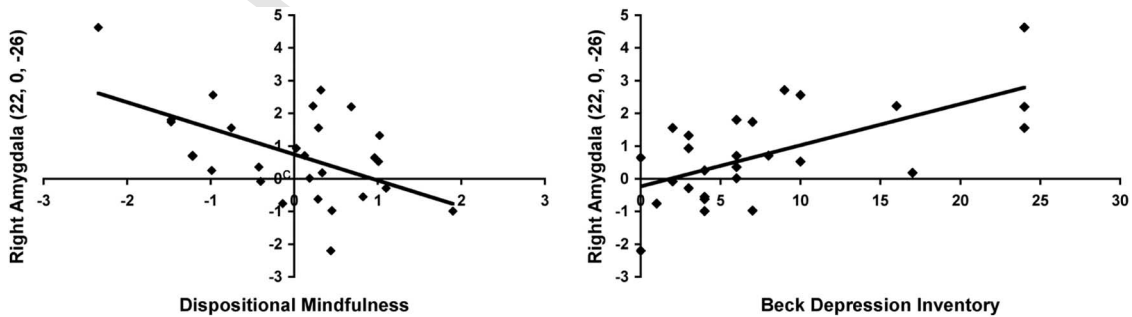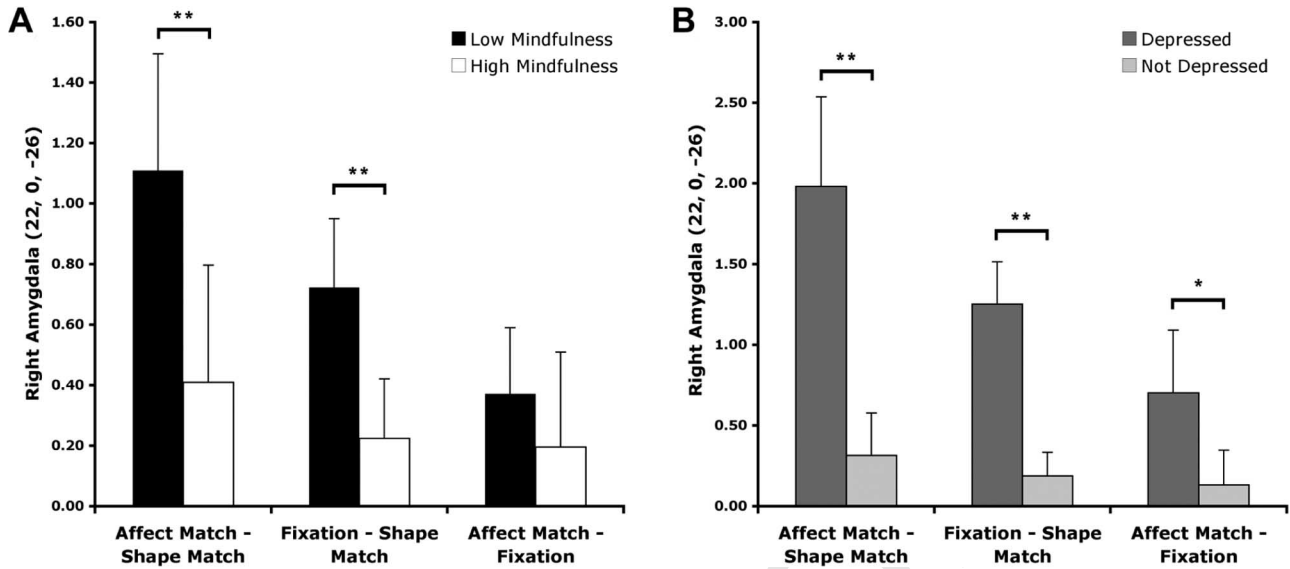
Figure 5. Amygdala reactivity. Scatterplots of the relationship between activity in the right amygdala and either dispositional mindfulness (A: $r = −.53$, $p < .005$) or depressive symptomatology (B: $r = .63$, $p < .005$) when viewing negative emotional faces, relative to shape matching.

Figure 6. Right amygdala activation (22, 0, –26) to viewing affective faces, shapes, and fixation stimuli as a function of dispositional mindfulness (A) or depressive symptomatology (B). Denoted on the graphs are the mean parameter estimates ($\pm$ *SEM*) for the ROI across the respective contrasts. Although the data were analyzed as correlations to take full advantage of the distributions, they are graphed here as discrete variables to facilitate visual interpretation. The residualized mindfulness variable was split at the median, while Beck Depression Inventory scores were divided into those that exceeded the threshold for mild depression ($n = 7$) and those who scored below this threshold ($n = 20$). Panel A reveals that a large portion of the apparent amygdala reactivity differences associated with residualized dispositional mindfulness (leftmost bars) can be attributed to resting state differences rather than actual reactivity. Panel B suggests that the relation of depressive symptoms to apparent amygdala reactivity can be attributed both to actual reactivity and resting state differences. $^{*} p < .05.$ $^{**} p < .005.$

amygdala activity, as high scores on this measure reflect a greater proclivity to engage in an open and receptive attentional style (Jha, Krompinger, & Baime, 2007), which may reflect less amygdaloid drive upon exteroceptive (and interoceptive) information processing.

Clinical Implications

As meditation training elicits increases in MAAS scores that are closely coupled with decreases in BDI scores (Chambers et al., 2008), the present finding of a linear relationship between dispositional mindfulness and baseline amygdala activity suggest a potential neural mechanism by which mindfulness in general, and MBCT, in particular, may reduce depressed mood and depression relapse. Bremner et al. (1997) showed that heightened resting amygdala activity was predictive of pharmacologically induced depression relapse. Thus, in so far as the between-subjects correlational data presented here applies to the within-subject changes following mindfulness training, increases in mindful awareness may lead to corresponding decreases in baseline amygdala activity. Thus, increases in mindfulness could lower baseline amygdala activity below the threshold for triggering depression relapse or depressed mood. As the findings presented here are correlational, experimental studies with mindfulness training interventions are needed to causally implicate resting state amygdala activity in the mindfulness-depression link. Nonetheless, the present findings provide an initial indication that incremental increases in mindful

awareness may lead to corresponding decreases in resting state amygdala activity and emphasize the utility of examining baseline amygdala activity.

Methodological Considerations

Although the dispositional mindfulness measure was associated with the amygdala bilaterally, the correlation with BDI was limited to the right amygdala. This association of the right amygdala with depressive symptomatology is consistent with some clinical studies (Abercrombie et al., 1998; Clark et al., 2006) although others have found that activity in the left amygdala is more closely associated to depressive state (Drevets et al., 2002; Drevets et al., 1992). This discordance is not limited to resting studies, as activational studies have found depressive state associated with the left amygdala (Fu et al., 2004), the right amygdala (Fu et al., 2008), or both the right and left amygdala (Sheline et al., 2001).

One potential factor contributing to these laterality differences that has not been extensively studied in the context of depression is sex differences. The lateralized effects of sex on amygdala function have been most persuasively documented in studies of emotionally enhanced memory, in which the left amygdala is more closely associated with memory for arousing material in males and the right amygdala is more closely associated with such memory in females (Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004; Canli, Desmond, Zhao, & Gabrieli, 2002). Functional connectivity analyses in the resting state indicated that this difference in mem-

ory may arise from sex-related differential connectivity patterns of the right and left amygdala (Kilpatrick, Zald, Pardo, & Cahill, 2006). However, we did not find any sex differences in activity in the right amygdala ROI, which is consistent with a recent meta-analysis of 148 emotional processing studies (Sergerie, Chochol, & Armony, 2008). Thus, it appears that the right lateralized amygdala correlation with mood state is not simply a function of there being a greater number of women in this sample.

In light of the role of the amygdala in anxiety and anxiety disorders (Etkin & Wager, 2007), it is important to consider the degree to which the effects reported here are driven by anxiety related factors or are specific for mindfulness and depressive symptomatology. Trait anxiety itself was not associated with baseline amygdala activity. Statistically controlling for its effects on the relationship between amygdala activity and mindfulness or depressive symptomatology had negligible effects, which is consistent with this measure being more strongly associated with amygdala reactivity to subliminal (Etkin et al., 2004) or unattended fearful faces (Bishop, Duncan, & Lawrence, 2004; Dickie & Armony, 2008). In addition, neuroticism, a trait measure of the proclivity to experience negative affect, was not associated with baseline amygdala activity and when included as a covariate did not appreciably change the results, which is consistent with studies that examined the relationship between neuroticism and resting glucose metabolism (Deckersbach et al., 2006; Kim, Hwang, Park, & Kim, 2008). Thus, dispositional mindfulness, as well as depressive symptomatology, were uniquely related to baseline amygdala activity in this sample.

Conclusions

In summary, dispositional mindfulness and depressive symptomatology show opposite relationships with resting activity in the right amygdala, indicating that this may be a potential mechanism linking mindfulness-based treatments with reductions in depressed mood and relapse risk. That resting state activity differences largely explained the differences in emotional reactivity underscores the importance of understanding intrinsic activity within the brain. Perhaps it is fitting that mindfulness, a practice focused on observant contemplation rather than action, is associated with neural activity when an individual is just "being" rather than "doing."

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