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# THE BRAIN STRUCTURE CORRELATES OF INDIVIDUAL DIFFERENCES IN TRAIT MINDFULNESS: A VOXEL-BASED MORPHOMETRY STUDY

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**Abstract—Mindfulness is the state of being attentive to and aware of what is taking place in the present, which is beneficial for reducing stress-related symptoms and improving mental and physical health. Previous studies have demonstrated that meditation practice can improve individuals' mindfulness through modifying functions and structures of multiple brain regions, including the anterior cingulate cortex (ACC), insula, fronto-limbic network, posterior cingulate cortex (PCC), and temporal-parietal junction. However, little is known about the neuroanatomical correlates of trait mindfulness. In the current study, we used voxel-based morphometry to investigate the neural correlates of individual differences in trait mindfulness by correlating the gray matter (GM) volume of each voxel across the whole brain with trait mindfulness measured by the Mindful Attention Awareness Scale in a large sample of young adults ($N = 247$). We found that individuals who were more mindful of the present had greater GM volume in the right hippocampus/amygdala and bilateral ACC, but less GM volume in bilateral PCC and the left orbitofrontal cortex. These results suggest that trait mindfulness is associated with brain regions involved in executive attention, emotion regulation, and self-referential processing, through which mindfulness may exert its beneficial effects on psychological and physical well-being.**


**Key words: trait mindfulness, voxel-based morphometry, executive attention, emotion regulation, self-referential processing.**

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*Abbreviations:* ACC, anterior cingulate cortex; fMRI, functional magnetic resonance imaging; FFMQ, Five-Facet Mindfulness Questionnaire; GM, gray matter; MAAS, Mindful Attention Awareness Scale; MPFC, medial prefrontal cortex; OFC, orbitofrontal cortex; PCC, posterior cingulate cortex; RAPM, Raven's Advanced Progressive Matrix; SVC, small-volume correction; TPJ, temporal-parietal junction; VBM, voxel-based morphometry; WBC, whole-brain correction.

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## INTRODUCTION

Have you ever started eating a snack bar, taken a couple of bites, then noticed all you had left was an empty packet in your hand? Or, have you ever been driving somewhere and arrived at your destination only to realize you remembered nothing about your journey? Often during our daily lives, we are ''not present.'' The nonjudgmental awareness of what is taking place in the present is called mindfulness (Brown and Ryan, 2003). A large body of evidence has shown that mindfulness produces a wide range of beneficial effects, including improvements in cognitive functioning, psychological well-being, and physical health, for healthy participants as well as for those with clinical disorders such as anxiety, depression, and attention-deficit hyperactivity disorder (Tang et al., 2007; Carmody and Baer, 2008; Shapiro et al., 2008; Schmertz et al., 2009; Smalley et al., 2009; Howell et al., 2010; Killingsworth and Gilbert, 2010; Barnhofer et al., 2011; Conn, 2011).

It has been proposed that the wide range of benefits related to mindfulness are produced by an array of distinct but interacting cognitive mechanisms, namely, attention regulation, body awareness, emotion regulation, and change in perspective on the self (Hölzel et al., 2011). Neuroimaging studies provided supporting evidence for these mechanisms by demonstrating that meditation practice improves mindfulness through modifying functions and structures of multiple regions involved in these mechanisms (Hölzel et al., 2011; Ott et al., 2011). For example, experienced meditators, compared with non-meditators, showed increased activation and greater cortical thickness in the anterior cingulate cortex (ACC) (Holzel et al., 2007; Grant et al., 2010; Gard et al., 2012) and insula (Lazar et al., 2005; Farb et al., 2007, 2010), which are typically involved in executive attention (Bush et al., 2000), and body awareness (Craig, 2003) respectively. In addition, meditation training is associated with modified gray matter (GM) density in the fronto-limbic network (including multiple sites of the prefrontal cortex, amygdala, and hippocampus), which is particularly important for emotion regulation (Holzel et al., 2008, 2010; Luders et al., 2009a, 2012; Chiesa, 2010; Froeliger et al., 2012; Leung et al., 2013). Finally, the posterior cingulate cortex (PCC) and temporal-parietal junction (TPJ), which are engaged in the self-referential processing (Northoff and Bermpohl, 2004), showed modified GM density following meditation practice (Holzel et al., 2011).

Although previous literature mostly focused on mindfulness fostered by meditation training, a growing number of studies have defined mindfulness as a dispositional trait and investigated the individual differences in trait mindfulness. Yet, there is only limited research assessing the neural basis of trait mindfulness, indicating involvement of the regions corresponding to those obtained in meditation training. For example, several functional magnetic resonance imaging (fMRI) studies have shown that higher trait mindfulness is associated with reduced activation in the amygdala and increased activation in the medial prefrontal cortex (MPFC), orbitofrontal cortex (OFC), ACC, and TPJ (Creswell et al., 2007; Modinos et al., 2010; Ives-Deliperi et al., 2011; Brown et al., 2013; Dickenson et al., 2013), and trait mindfulness is negatively correlated with resting-state activity in the PCC (Way et al., 2010). To date, only two recent studies have examined the relationship between brain structure and trait mindfulness (Murakami et al., 2012; Taren et al., 2013). One study measured the trait mindfulness by the Five-Facet Mindfulness Questionnaire (FFMQ) in a small sample of participants ($N = 19$), and observed a positive correlation between one of the five facets on the FFMQ (the describing facet measuring a tendency to label observed experiences with words) and GM volume in the amygdala and insula (Murakami et al., 2012). The other study examined neuroanatomical correlates of trait mindfulness, measured by the Mindful Attention Awareness Scale (MAAS, Brown and Ryan, 2003), by focusing on pre-selected ROIs in the limbic system, and found that trait mindfulness was associated with volumes in the amygdala and hippocampus (Taren et al., 2013). Therefore, the relationship between trait mindfulness and brain structure has never been examined across the whole brain in a large sample of participants.

In our study, we used voxel-based morphometry (VBM) to investigate the neuroanatomical correlates of mindfulness by examining the association between GM volume and individual differences in trait mindfulness across the whole brain in a large sample of participants ($N = 247$). We used the MAAS to assess mindfulness as a dispositional trait, which is defined as the general tendency to be attentive to and aware of present-moment experiences in everyday life (Brown and Ryan, 2003). The MAAS has been widely used to assess individual differences in trait mindfulness in previous studies (e.g., Barnes et al., 2007; Creswell et al., 2007; Carmody et al., 2008; Niemiec et al., 2010). We hypothesized that individual differences in trait mindfulness would be associated with GM volume within multiple brain regions reported in previous studies to be implicated in meditation practice and correlate with trait mindfulness, namely the ACC, insula, MPFC, OFC, amygdala, hippocampus, PCC, and TPJ (Hölzel et al., 2011; Ott et al., 2011).

## EXPERIMENTAL PROCEDURE

### Participants

Two hundred and forty-seven college students (131 females; 19–25 years of age, Mean = 21.7, SD = 1.0) voluntarily participated in this study. Participants with self-reported history of neurological or psychiatric disorders were excluded. The Institutional Review Board (IRB) of the Beijing Normal University approved the behavioral and MRI protocols. All participants gave informed written consent prior to the experiment.

### Assessment of mindfulness

Mindfulness was assessed with the MAAS (Brown and Ryan, 2003), which is a well-established self-report questionnaire measuring a general tendency to be attentive to and aware of present-moment experiences in everyday life. The MAAS contains 15 items with a single factor, and exemplar items are ‘‘I find it difficult to stay focused on what's happening in the present'' and ‘‘I find myself preoccupied with the future or the past.'' Participants rated each item based on their daily experiences on a 6-point Likert scale ranging from ‘‘Never'' to ‘‘All the time.'' The mean score across 15 items, which ranges from 1 (mind-wandering) to 6 (mindful), is used as an index for participants' trait mindfulness. Previous studies have demonstrated that this scale not only has good internal consistency and test–retest reliability but also shows a strong positive correlation with psychological well-being (including positive affect, life satisfaction, and self-actualization) and a negative correlation with social anxiety and physical symptoms (Brown and Ryan, 2003). Outliers were defined as being three standard deviations (SD) below or above the population mean on the MAAS score. One male participant (0.4% of the sample) was excluded from further analyses because his MAAS score was three SD below the mean.

### Assessment of general intelligence

We used the Raven's Advanced Progressive Matrix (RAPM, Raven et al., 1998) to measure participants' general intelligence (Takeuchi et al., 2010a, 2011). This scale contains 36 nonverbal items. For each item, the participant is required to select the missing piece of a $3 \times 3$ matrix from one of eight alternatives (Takeuchi et al., 2010b). The score of this psychometric test, which is used as an index of individual intelligence, is equal to the number of correct answers given by participants within a 30-min period (Takeuchi et al., 2010a).

### MRI data acquisition

Structural MRI scan was performed on a Siemens 3T Trio scanner (MAGENTOM Trio with a Tim system) with a 12-channel phased-array head coil at the BNU Imaging Center for Brain Research, Beijing, China. A 3D magnetization prepared rapid gradient echo (MP-RAGE) T1-weighted sequence (repetition time/echo time/inversion time = 2530/3.39/1100 ms, flip angle = 7 degrees, FOV = $256 \times 256$ mm) was used to acquire whole-brain structural images. One hundred and twenty-eight contiguous sagittal slices were acquired with $1 \times 1$-mm in-plane resolution and 1.33-mm slice thickness for whole-brain coverage.