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Editorial

Special issue on mindfulness neuroscience

Mindfulness neuroscience is a new, interdisciplinary field of mindfulness practice and neuroscientific research; it applies neuroimaging techniques, physiological measures and behavioral tests to explore the underlying mechanisms of different types, stages and states of mindfulness practice over the lifespan. Mindfulness-based meditation (MBM) or mindfulness-based intervention (MBI) has been a hot topic in psychology, neuroscience, health care and education in recent years (Chiesa and Serretti, 2010; Holzel *et al.*, 2011), and publications have been rapidly growing from only 28 in 2001 to 397 papers listed in ISI during 2011. Many studies indicate the positive effects of MBM or MBI and researchers explore the mechanisms (Lutz *et al.*, 2008; Tang and Posner, 2009; Chiesa and Serretti, 2010; Holzel *et al.*, 2011; Tang *et al.*, 2012a). However, the mechanisms of mindfulness practice are still poorly understood.

To improve the understanding of mindfulness mechanisms, we began a special issue on *mindfulness neuroscience* in *Social Cognitive and Affective Neuroscience* (*SCAN*) in the fall of 2010 and invited more than 20 leading research laboratories in this field from all over the world. In this special issue, we include 12 peer-reviewed empirical articles using neuroimaging to address neural mechanisms and clinical issues in mindfulness neuroscience. The articles in this special issue offer a sample of the cutting-edge discoveries being made at the frontier of mindfulness neuroscience.

Studies indicate that meditation training may change the resting state, but different directions of change have been reported (Tang *et al.*, 2012b). Taylor *et al.* (2013) studied the impact of meditation training on whether mindfulness practice influences functional connectivity between default mode network (DMN) regions. They collected the resting-state functional magnetic resonance imaging (fMRI) data from an experienced meditation group (with more than 1000 h of training) and a beginner group (with no prior experience, trained for 1 week before the study). Relative to beginners, experienced meditators had weaker functional connectivity between DMN regions involved in self-referential processing and emotional appraisal. In addition, meditators had increased connectivity between certain DMN regions [e.g. dorsomedial prefrontal cortex (DMPFC) and right inferior parietal lobule] compared with beginners. These findings suggest that meditation training leads to functional connectivity changes between core DMN regions possibly reflecting strengthened present-moment awareness.

Focused attention is a common mindfulness induction where practitioners focus on specific physical sensations, typically the breath. Dickenson *et al.* (2013) explores the neural mechanisms of this common mindfulness induction among novice practitioners. Healthy participants completed a brief task with both mindful attention (focused breathing) and control (unfocused attention) conditions during fMRI. Relative to the control condition, focused breathing recruited an attention network including parietal and prefrontal structures. The results suggest that the neural mechanisms of a brief mindfulness induction are related to attention processes in novices and that trait mindfulness positively moderates this activation.

One component of MBM is the development of interoceptive attention (IA) to visceral bodily sensations, facilitated through daily practices such as breath monitoring. Using fMRI, Farb *et al.* (2013) examine experience-dependent functional plasticity in accessing interoceptive representations by comparing a mindfulness-based stress reduction (MBSR) course to a wait-listed control group. Meditation predicted greater IA-related activity in anterior dysgranular insula regions, consistent with greater integration of interoceptive sensation with external context. Meditation also predicted decreased recruitment of the DMPFC during IA and altered functional connectivity between the DMPFC and the posterior insula, putative primary interoceptive cortex. Furthermore, meditation practice compliance predicted greater posterior insula and reduced visual pathway recruitment during IA. These findings suggest that interoceptive training modulates task-specific cortical recruitment, analogous to training-related plasticity observed in the external senses.

Diffusion tensor imaging and cortical thickness mapping have been used in MBIs (Lazar *et al.*, 2005; Tang *et al.*, 2010, 2012b; Holzel *et al.*, 2011; Luders *et al.*, 2011). Kang *et al.* (2013) combined these two techniques to explore the effect of a long-term Asian meditation on brain structure. Compared with controls, meditators showed significantly greater cortical thickness in the anterior regions of the brain including the medial prefrontal cortex, superior frontal cortex, temporal pole and the middle and interior temporal cortices. Significantly reduced cortical thickness was found in the posterior regions of the brain including the postcentral cortex, inferior parietal cortex, middle occipital cortex and posterior cingulate cortex. Moreover, in the region adjacent to the medial prefrontal cortex, both higher fractional anisotropy values and greater cortical thickness were observed. These findings indicate that long-term meditators have structural differences from controls in both gray and white matter.

Different forms of meditation practice may involve in different brain networks or neuroplasticity. Leung *et al.* (2013) examined brain structural changes related to the practice of an emotion-oriented meditation, the loving-kindness meditation in the Theravada tradition. They found increased gray matter volume in the right angular and posterior parahippocampal gyri in those loving-kindness meditators who had practiced at least 5 years compared with novices. They argue that the right angular gyrus has a specific role in theory of mind and cognitive empathy is important for affective regulation associated with empathic response, anxiety and mood. Mascaro *et al.* (2013) reported one form of compassion meditation, the cognitively based compassion training enhances empathic accuracy. The participants received fMRI scans while completing the empathic accuracy task both before and after completion of either meditation or a health discussion control. After 8 week interventions, meditation group outperformed than control on the empathic accuracy and also had increased brain activity in the inferior frontal gyrus (IFG) and DMPFC. Moreover, changes in DMPFC and IFG activity from baseline to the post-intervention were associated with changes in empathic accuracy.

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MBIs are effective for reducing depressive symptoms. However, the psychological and neural mechanisms are still largely unknown. Paul *et al.* (2013) report on the psychological and neural mechanisms of mindfulness in reducing depression vulnerability. In two fMRI studies, they utilized a stress-induction task or a mindful breathing task and found non-reactivity scores on the five facet mindfulness questionnaire correlated negatively with rumination and negative bias following the stress induction. Non-reactivity was inversely correlated with insula activation during inhibition to negative stimuli after the mindful breathing task. Their results suggest non-reactivity to inner experience is the key facet of mindfulness that protects individuals from psychological risk for depression. Mindfulness could reduce vulnerability to depression in at least two ways: (i) by buffering against trait rumination and negative bias and (ii) by reducing automatic emotional responding via the insula.

MBSR is thought to reduce emotional reactivity and enhance emotion regulation in patients with social anxiety disorder (SAD). Goldin *et al.* (2013) examined the neural correlates of attentional emotion regulation using MBSR *vs* aerobic exercise (AE) in SAD. In a randomized controlled trial, those with SAD were randomly assigned to MBSR or a comparison AE stress reduction program. Meditation practice was associated with *decreases* in negative emotion and social anxiety symptom severity and *increases* in attention-related bilateral parietal cortex neural responses when implementing attention regulation of negative self-beliefs. Changes in attention regulation may be an important psychological factor that helps to explain how mindfulness meditation training benefits patients with anxiety disorders.

Research suggests that MBIs may be beneficial for smoking cessation and the treatment of other addictive disorders. One way that mindfulness may facilitate smoking cessation is through the reduction of craving to smoking cues. Westbrook *et al.* (2013) report the mindful attention reduces self-reported cue-induced craving in treatment-seeking smokers (12 h abstinent from smoking). Smokers were trained and instructed to view these images passively or with mindful attention while undergoing fMRI. The results indicated that mindful attention reduced self-reported craving to smoking images and reduced neural activity in a craving-related region of subgenual anterior cingulate cortex (sgACC). Moreover, a psychophysiological interaction analysis revealed that mindful attention reduced functional connectivity between sgACC and other craving-related regions compared with passively viewing smoking images. This finding indicated that mindfulness may decouple craving neurocircuitry when viewing smoking cues.

Electroencephalography (EEG)/event-related potential has been widely employed in MBI's research. Previous studies have documented the positive effects of MBIs on executive control. Temper and Inzlicht (2013) examine the meditation effect on emotional acceptance and performance monitoring. They measured error-related negativity (ERN) during a Stroop task. Meditators showed fewer errors, a larger ERN and more emotional acceptance than controls. Mediation pathway models further revealed that meditation practice relates to greater executive control and that this effect can be accounted for by heightened emotional acceptance and, to a lesser extent, increased performance monitoring as measured by ERN.

Brown *et al.* (2013) examined whether individual differences in mindfulness would modulate neural responses associated with the early processing of affective stimuli using the late positive potential (LPP) of the event-related brain potential. They found that more mindful individuals showed lower LPP responses to high arousal unpleasant images, even after controlling for trait attentional control. Conversely, two traits contrasting with mindfulness—neuroticism and negative affectivity—were associated with higher LPP responses to high arousal unpleasant images. These findings suggest that mindfulness modulates neural responses (LPP) in an early phase of affective processing and may promote healthy emotional functioning.

Cahn *et al.* (2013) reported event-related delta, theta, alpha and gamma correlates to auditory oddball processing during long-term Vipassana meditation. The EEG of Vipassana meditators was collected during 25 min of meditation and compared with an instructed period of mind wandering. For the last 4 min, a three-stimulus auditory oddball series was presented during both meditation and control periods through headphones and no task imposed. Time–frequency analyses suggest that Vipassana meditation evokes a brain state related to enhanced perceptual clarity and decreased reactivity to distraction.

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