CHAPTER 2

# Brain Mechanisms of Mindfulness Meditation

**Abstract** Many brain regions have been reported to be involved in different forms of mindfulness meditation. What is the function of each participating region? Do different forms of mindfulness meditation involve different brain networks? Do different practice stages recruit the same or distinct brain regions while practicing the same mindfulness technique? Does the brain network differ with amount of effort during practice? To answer these questions, I organize this chapter based on the latest neuroscience findings, showing that mindfulness meditation includes at least three components: enhanced attention control, improved emotion regulation, and altered self-awareness. I discuss the brain regions involved in these components respectively, mainly including anterior cingulate cortex (ACC) and adjacent prefrontal cortex, striatum, insula, and default mode network (DMN). I also propose a distinction between *state training* and *network training* to clarify the unique brain networks following mindfulness meditation.

**Keywords** Attention control · Emotion regulation · Self-awareness · Self-control · State training · Network training · Default mode network · Cognitive behavior therapy (CBT)

## Key Components of Mindfulness Meditation

In recent years, more than 500 works on mindfulness meditation have been published annually. Based on the latest neuroscience findings, mindfulness meditation includes at least three components that interact closely to



Y.-Y. Tang, *The Neuroscience of Mindfulness Meditation*,
DOI 10.1007/978-3-319-46322-3_2

constitute a process of *enhanced self-regulation* or self-control: enhanced attention control, improved emotion regulation, and altered self-awareness (Tang et al. 2015; Holzel et al. 2011).

*Attention control* refers to the persistent focus on an object or target (e.g., breath, sensation) during the mindfulness practice, and often involves alerting, orienting, and executive control attention networks. Attention controlinvolves explicit process with conscious control and effort at the early stage of mindfulness practice, but the advanced meditator can use less effort or engage in an effortless way to maintain the focus and awareness. Moreover, mindfulness practice trains a unique attention toward the present experience, and thus could mitigate negative affective experiences in a nonjudgmental and accepting way (Tang and Tang 2015a, b).

*Emotion regulation* refers to implicit and explicit strategies that can influence which emotions arise and when, how long they occur, and how these emotions are experienced and expressed. Emotion regulation is needed to handle the experiences of boredom and of negative moods during mindfulness practice. When the practitioner is skillful, positive emotions associated with subjective experience of joy and well-being emerge, which can help sustain attention and the meditative state, thereby supporting mental processes (Tang and Tang 2015b).

*Self-awareness* often refers to the awareness of "self" as the object of attention (meta-awareness). Meta-awareness is often used to describe the function of being aware of mental processing or processes of consciousness. During mindfulness meditation, we are aware of our own internal bodily state (interoception) and mental (consciousness) state in an equanimous way (Tang et al. 2015), then gradually our self and environment merge or dissolve into one inherent experience. Self-awareness through mindfulness practice can help distance the individual from his/her own thinking and thought processes, which in turn facilitates openness and acceptance of thought, emotion and sensation (Tang et al. 2015; Tang and Tang 2015b). Without meta-awareness of self, we become a part of what we experience such as sensation, emotion, and thoughts. Here, we discuss key brain regions involved in these three components respectively.

## Brain Regions Related to Attention Control During Mindfulness

Neuroimaging studies show that the brain regions involved in attention control mainly include the anterior cingulate cortex (ACC), the adjacent medial prefrontal cortex (mPFC), and the striatum/basal ganglia including the nucleus accumbens (NAc), which is also a key brain region in the reward circuit (Petersen and Posner 2012). Similarly, brain systems shown to be activated in the broad construct of self-regulation cover the same ACC, adjacent mPFC, and striatum (Posner et al. 2007). Thus, the overlap of brain regions associated with attention control and self-regulation suggests a neurobiological pathway whereby mindfulness meditation could exert its influences including at least the ACC, mPFC, and striatum (Tang et al. 2015). Importantly, when expert meditator maintains an advanced state such as Jhana using the appropriate amount of effort and attention control, an ecstatic meditation experience with extreme joy and pleasure would occur, suggesting that an optimal attention control could activate the reward system including NAc in the striatum, and the striatum (as the key region of attention control) could further strengthen self-control ability of attention. Studies have also shown more release of neurotransmitter dopamine in the striatum following meditation (Tang et al. 2015).

Usually an individual exerts great effort to meditate in the early stage of practice, and the dorsal lateral PFC and parietal cortex are often involved (Posner et al. 2015; Tang et al. 2015). In contrast, the ACC and striatum mainly participate while one uses less effort. Since meditation tends to reduce mind-wandering or/and task-unrelated thoughts that are associated with midline brain areas including mPFC and posterior cingulate cortex (PCC))/precuneus, which all belong to the default mode network (DMN), meditators who engage more effort have been shown to have stronger deactivation in DMN. This suggests that more effortful meditation requires higher mental effort with increased attention, which seems to be mediated by strong deactivation in DMN and activation in dorsal lateral PFC (Tang et al. 2015).

## Brain Regions Related to Emotion Regulation During Mindfulness

Studies have shown that the prefrontal regions of the brain, including the mPFC and ACC, are primarily responsible for the regulation of emotion through the modulation of limbic system activity, while at the same time ensuring that current strategies are consistent with the regulatory goals (Bush et al. 2000). There are different strategies for regulating one's emotions explicitly and implicitly, and each strategy involves shared and distinct neural networks (Gross 2014). Although there are subtle differences among various control strategies, the ACC, mPFC, and limbic regions are consistently involved in the regulation of emotional responses during mindfulness. Particularly, emotion regulation is needed to handle the experiences of boredom and of negative moods during mindfulness practice when the meditator struggles with the control of wandering mind. When the practitioner becomes skillful, positive emotions associated with subjective experience of joy, pleasure, and well-being emerge, which can further help sustain attention and the meditative state, thereby supporting mental processes and cognitive functioning (Tang et al. 2015).

Since one form of mindfulness meditation–IBMT involves systematic training of attention and self-control with an attitude of acceptance and openness to internal and external experiences, and has been tested in a series of randomized controlled studies, IBMT can be used as an example to demonstrate how brief training (a few hours) improves attention control (executive functions) and emotion regulation, reduces stress (cortisol), and increases ACC/mPFC activity related to better self-control abilities in healthy and patient populations. The control group was given the same amount of relaxation training that is often used as a part of CBT. Furthermore, relaxation training only includes body relaxation and mental imagery (but not mindfulness), which is an appropriate control condition of mindfulness meditation (Tang et al. 2007, 2009). Because IBMT shares key components with other forms of mindfulness meditation, we expect other mindfulness methods would show the similar effects.

In one study (Tang et al. 2007), college students were randomly assigned to an IBMT or a relaxation training group for five sessions of short-term training (20–30 min per session). The IBMT group showed significantly greater improvement of performance in executive attention control than the relaxation group, as measured by the Attention Network Test. Individuals in the IBMT condition also had lower negative affect and fatigue, and higher positive feelings on the self-report Profile of Mood States (POMS). In addition, IBMT can also decrease levels of the stress hormone cortisol and increase immune reactivity, suggesting health benefits (Tang et al. 2007). In another study, using the measurement of Positive Affect and Negative Affect Schedule (PANAS) with the same randomized design as mentioned earlier, brief IBMT showed significantly better positive mood states and lower negative mood states compared to relaxation training (Ding et al. 2014a, b). A similar study by another research team showed that in comparison with a waitlist control group, an 8-week mindfulness training program significantly reduced negative moods. These results indicated that mindfulness meditation can effectively improve self-control abilities, including attention control, emotion regulation, and stress response (Tang 2017).

*How does mindfulness enhance emotion regulation?* Evidence suggests that the present-moment awareness and nonjudgmental acceptance cultivated by mindfulness are crucial in promoting self-control, because they increase sensitivity to affective cues in the experiential field and improve response to incipient affective cues that help signal the need for control such as effective emotion regulation (Teper et al. 2013). In one of our studies, five sessions of IBMT increased brain theta activity in ACC and adjacent mPFC and emotion regulation (Tang et al. 2007, 2009). It should be noted that emotion regulation is not always deliberate, but can also operate in nonconscious or implicit levels (Koole et al. 2015). These implicit processes may allow people to decide whether or not to engage in emotion regulation, guide people in selecting suitable emotion regulation strategies, and facilitate the enactment of emotion regulation strategies (Childress et al. 2008). Over the last decade, studies have found some forms of psychopathology arise from deficits in implicit emotion regulation. For example, anxiety patients show significant deficits in the noninstructed and spontaneous regulation of emotion processing, suggesting abnormalities in emotion regulation could occur outside of awareness (Etkin et al. 2010). These results open avenues for novel and unconscious treatments, such as by targeting the mPFC/ACC (Tang et al. 2016a, b). These are in line with our recent IBMT results in which smokers improved emotion and changed their addiction behavior unconsciously through implicit processes (see Chap. 5).

To reveal the brain mechanisms of IBMT, college students were randomly assigned to IBMT or relaxation groups and underwent brain-imaging assessments before, during, and after five sessions of training. Neuroimaging data demonstrated that IBMT group showed stronger subgenual and adjacent ventral ACC activity compared to relaxation control. Based on previous research, this brain area is involved in emotion regulation and attention control. Since this area is also linked to autonomic nervous system (ANS), we thus measured the indexes of ANS activity such as heart rate variability, and found better parasympathetic regulation following brief IBMT (see Chap. 3 for details) (Tang et al. 2009). These results are consistent with IBMT's techniques in which IBMT stresses no effort or less effort to control thoughts explicitly, but instead emphasizes the achievement of a state of restful alertness naturally that allows a high degree of awareness and balance of the body, mind, and environment. Moreover, the meditation state is facilitated through body-mind training and trainer-group dynamics, harmony, and resonance led by a qualified IBMT coach or trainer (Tang et al. 2012a, b, c).

It should be noted that in addition to ACC/mPFC, which commonly is involved in attention and emotion regulation following brief IBMT, other brain areas such as dorsal lateral PFC and amygdala also participate in the top-down and bottom-up control networks. Some studies have detected these brain regions in different forms of mindfulness meditation, but we do not know exactly whether this observed phenomenon is due to different techniques or other factors such as effort or regulation strategies (Tang et al. 2015).

If five sessions of short-term IBMT improves attention and emotion regulation supported by the ACC activity, what will happen following longer IBMT practice? We expected that longer IBMT practice could induce structural change related to ACC and brain changes correlate with emotion regulation. Previous results using MRI diffusion tensor imaging have shown that training results in changes in white matter efficiency as measured by fractional anisotropy (FA), an index of integrity and connectivity of white matter. We randomly assigned undergraduates to an IBMT or relaxation group and acquired brain images from each participant at rest using diffusion tensor imaging for analysis of white matter changes before and after training. Results showed that around 10 h of IBMT (20 sessions within 4 weeks) increased FA in the corona radiata (Tang et al. 2010), an important white matter tract connecting the ACC to other structures, consistent with our hypothesis (see Fig. 2.1).

To measure the time-course of white matter change from 5 h (10 sessions within two weeks) to 10 h of training, we found, in comparison to relaxation training, 5 h of IBMT was only associated with axonal changes,

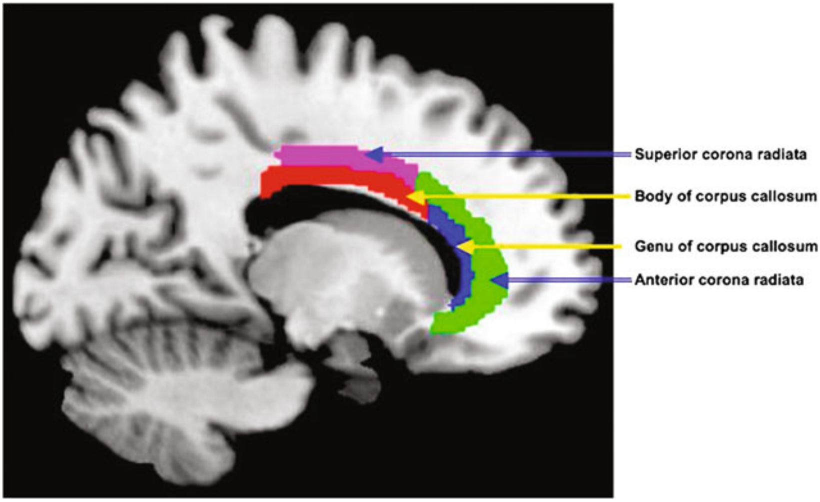


**Fig. 2.1** Significant white matter changes following IBMT

but 10 h of IBMT increased both myelin and axonal changes, indicating improved efficiency of white matter involves increased myelin as well as other axonal changes. Moreover, in the study of 5 h of IBMT, there was a significant correlation between emotion regulation and axonal changes, indicating the training-induced change in emotion was correlated with the ACC structural changes (Tang et al. 2012a, b, c). If the aforementioned behavior change is supported by brain structural changes, does behavior change last longer? Our series of studies show that longer IBMT practice can lead to greater benefits, including better attention control in executive attention and sustained attention, emotion regulation, lower basal stress as measured by cortisol levels, and better immune function as measured by lower level of basal sIgA (Fan et al. 2010, 2013), suggesting a dose-dependent fashion following IBMT. Furthermore, IBMT also helps change addiction behaviors and habits see Chaps. 5 and 7).

The key region of self-control, the ACC, has been associated with many disorders, such as mood disorders, substance abuse, PTSD, and schizophrenia. The ability to strengthen ACC activity and connectivity through mindfulness training could provide a means for improving self-control and perhaps reducing or preventing various mental disorders.

In Chap. 7, I will provide several examples that will demonstrate the potential applications in the health field.

## Brain Regions Related to Self-Awareness During Mindfulness

The self lies at the core of our mental life. Recent studies suggest that self-related processing often involves midline cortical structure, including DMN, which shows a high degree of spontaneous activity at rest (Northoff and Bermpohl 2004; Northoff and Panksepp 2008). Moreover, self-related activity, mindfulness meditation, and spontaneous DMN activity overlap partially in midline brain regions. As described earlier, during mindfulness meditation, we are continuously aware of whatever thoughts, sensations, and emotions entering our consciousness or/and monitoring the nature of awareness itself in an equanimous way to cultivate the meta-awareness of self (Tang et al. 2015). However, we encounter a paradox: on one hand we detach ourselves from our own self and its perception, cognition, and emotion during meditation; on the other hand, it is the self that meditates. In a nutshell, the paradox is that we detach from our self while, at the same time, relying on it to meditate. *How can we resolve that paradox?*

We suggest that different aspects of selves correspond to different stages of meditation (see Fig. 2.3). Cognitive self refers to the self involving our beliefs, thoughts, and concepts, which are often related to the wandering mind; the bodily-emotional self links to visceral, intuitive, and introceptive processing of self while wandering mind reduces. These two forms of self are associated with narrative and evaluative self-processing. The third form of self—the phenomenal-experiential self—refers to the self in one's present awareness. Meditation aims to detach oneself from the cognitive self (first stage) and bodily-emotional self (second stage); if one focuses too much on these selves, it can lead to distress and negative emotions. Detachment from both cognitive and bodily-emotional selves allows one to reveal and lay bare the most basic and fundamental self: the phenomenal-experiential (third stage). This allows one to return to one's own experience, including its temporal dynamics and attunement to the environment. Hence, meditation elevates the phenomenal-experiential self by making the detachment from the cognitive and bodily-emotional selves possible. Once one can distinguish the different forms of self, it becomes clear that detachment and elevation of self are no longer paradoxical, but rather become complementary and central aspects of meditation in its different stages.

A latest review of imaging studies in mindfulness meditation indicated that self-awareness involves ACC, DMN, and insula. Mindfulness practice alters the self-processing mode so that a previous narrative and evaluative form of self-processing is replaced by greater awareness (meta-awareness). This shift in self-awareness is one of the major active mechanisms of the beneficial effects induced by mindfulness meditation (Tang et al. 2015). Meditation seems to reduce activity in cortical midline structures including DMN, with more reduction in the posterior part, the PCC/precuneus, than in the anterior part, the mPFC, but increases perigenual ACC activity. Studies also indicate changes in the DMN and in control networks are associated with self-processing and top-down executive control, respectively, following mindfulness meditation. Different stages of meditation (early, middle, and advanced) appear to modulate the dynamic balance between anterior and posterior midline networks involved in different aspects of self: cognitive self, bodily-emotional self, and phenomenal-experiential self. These changes in cortical midline structures may reflect the self-plasticity following meditation practice. Given that meditation improves self-control ability, it has potential in the treatment of psychiatric disorders with self-disturbances.

As shown in Fig. 2.2, brain regions involved in the systematic training of attention and self-regulation during mindfulness meditation enhance attention control, improve emotion regulation, and alter self-awareness. Here we mainly focus on the brain regions of the ACC, PFC, striatum, insula, and DMN, which contribute to the behavior changes following mindfulness meditation.

## Different Stages and Brain Networks

Mindfulness meditation can be roughly divided into three different stages of practice—early, middle (intermediate), and advanced—that involve different amounts of effort (see Fig. 2.3).

In the early stage of meditation, one uses lots of effort to control and combat the wandering mind (and its thoughts), and tries to get into the meditative state (termed as *effortful doing*). During this stage, the dorsal lateral PFC and parietal cortex are often involved. The middle stage of meditation still requires effort into the meditative state, but one learns how to recruit both mind and body into the desired state with less effort.

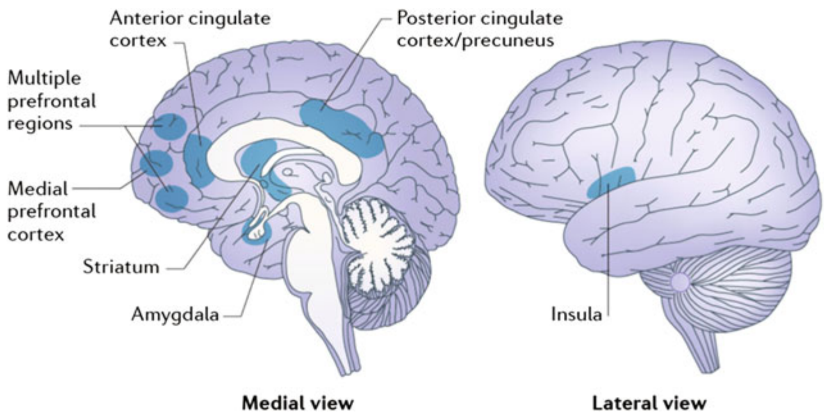


**Fig. 2.2** Brain regions involved in mindfulness meditation. Schematic view of the brain regions consistently involved in attention control (ACC, PFC, and striatum), emotion regulation (multiple prefrontal regions, limbic regions, and striatum), and self-awareness (ACC, insula, mPFC, and PCC/precuneus)

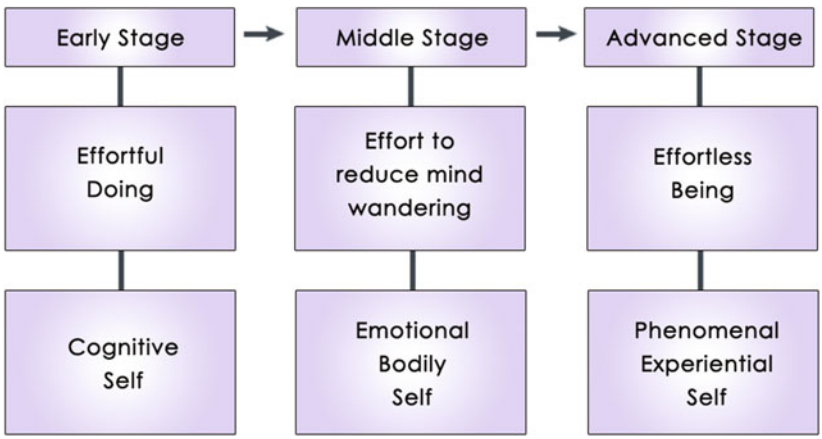


**Fig. 2.3** Self, effort, and three stages of meditation

Therefore, ACC, different parts of PFC and striatum are mainly engaged. Although the mind and its various thought contents still wander, it does not bother the meditator any more; thus the meditator experiences more positive mood, relaxation, and calmness. The advanced stage of meditation often involves the flow of meditative state with less effort or even effortlessness, in which self and environment merge or dissolve and become one inherent experience (termed as *effortless being*). The brain networks of ACC and striatum are mainly involved at this stage (Tang et al. 2015; Tang and Posner 2009, 2014; Tang 2017). It should be noted that this chapter does not discuss the state beyond the advanced stage of meditation as described in Buddhism and other contemplative traditions.

In the same vein, different mindfulness meditation methods may involve different brain networks. For example, focused attention meditation mainly involves effort-based concentration on breath or sensation, and at the same time inhibits nontarget stimuli or distraction. This mental process mainly requires the lateral PFC and parietal cortex. However, with long-term practice, skillful meditators can exert less effort (effortless) to maintain the concentration meditative state. Studies have shown the reduced brain activity in lateral PFC associated with this advanced state. In contrast, open-monitoring meditation requires continuous observation and monitoring with less effort and gradually catches the arising of mental events. This process often involves the ACC and striatum networks and induces their functional and structural changes following short- and long-term practice (Tang et al. 2015).

## State Training and Network Training

Mental training often refers to the practices that alter the brain/mind in a way that improves cognition, as well as performance in domains beyond those involved in the training. There are many forms of mental training similar to mindfulness meditation: computerized cognitive programs such as attention training, working memory training (WMT), and video games. To clarify the unique brain mechanisms following mindfulness meditation, we compare two brain-training strategies for improving performance: *state training* and *network training* (Tang and Posner 2009, 2014). Network training, such as a computerized cognitive program, involves practice of a specific cognitive task (e.g., attention, working memory) and thus exercises its specific brain network. *State training*, such as mindfulness meditation, uses practice to develop a brain state that may influence the operations of many networks. State training involves networks, but it is not designed to train networks using a specific cognitive task (Tang and Posner 2009, 2014; Tang et al. 2012a, b, c). Given the widespread interest and dramatic increases in many publications in WMT and mindfulness training, I will use WMT as an example of network training and mindfulness as an example of state training to reveal different brain mechanisms involved in these two training regimens.

Working memory involves the ability to maintain and manipulate information in one's mind while ignoring irrelevant distractions and intruding thoughts. WMT refers to training that exercises temporary storage of a small number of items either recently presented or retrieved from memory. Adaptive WMT requires maintenance of mental effort over the course of training. In general, studies after several weeks of WMT have shown that lateral frontal and parietal cortex are involved. However, we do not know whether increased brain activity is derived from greater overall task difficulty, more attention or effort needed to perform the task, or other factors (Tang and Posner 2014). As mentioned earlier, in the early stages of mindfulness, achieving the meditation state appears to involve the use of more attention control and mental effort; thus, areas of the lateral prefrontal and parietal cortex after training could be more active than before training. This may reflect the higher level of effort often found when participants struggle to obtain the meditation state in the early stage and thus provide greater overlap with what happens during adaptive WMT. However, in the advanced stages of mindfulness, prefrontal–parietal activity is often reduced or eliminated, but ACC and striatum (and insula) activity remains (Tang and Posner 2014; Tang and Tang 2015b). Moreover, mindfulness changes the frontal midline, including the ACC and its connections to the striatum and parasympathetic activity through ANS associated with self-control. These ANS and central nervous system (CNS) changes appear to differ from those in WMT, but insufficient effort has been devoted to a direct comparison of the two training methods.

In summary, among behavioral and brain imaging studies (e.g., functional and structural MRI), especially those based on longitudinal, randomized, and controlled designs with active control groups, mindfulness meditation as a state training regimen improves self-control abilities, including attention control (executive functions), emotion regulation, and self-awareness in healthy and patient populations. The ACC, PFC, striatum, insula, and DMN seem to show consistent changes associated with mindfulness meditation (Tang et al. 2015). Of course, mindfulness not only involves the CNS (brain) but also the ANS (body). In the next chapter, we will explore the physiology mechanisms of mindfulness meditation.

## References


Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Science, 4,* 215–222.

Childress, A. R., et al. (2008). Prelude to passion: Limbic activation by "unseen" drug and sexual cues. *PLoS ONE, 3,* e1506.

Ding, X., Tang, Y. Y., Tang, R., & Posner, M. I. (2014a). Improving creativity performance by short-term meditation. *Behavioral and Brain Functions, 10,* 9.

Ding, X., Tang, Y. Y., Deng, Y., Tang, R., & Posner, M. I. (2014b). Mood and personality predict improvement in creativity due to meditation training. *Learning and Individual Differences, 37,* 217–221.

Etkin, A., Prater, K. E., Hoeft, F., Menon, V., & Schatzberg, A. F. (2010). Failure of anterior cingulate activation and connectivity with the amygdala during implicit regulation of emotional processing in generalized anxiety disorder. *American Journal of Psychiatry, 167,* 545–554.

Fan, Y., Tang, Y. Y., Ma, Y., & Posner, M. I. (2010). Mucosal immunity modulated by integrative meditation in a dose dependent fashion. *Journal of Alternative and Complementary Medicine, 16*(2), 151–155.

Fan, Y., Tang, Y. Y., & Posner, M. I. (2013). Cortisol level modulated by integrative meditation in a dose-dependent fashion. *Stress Health, 30*, 65–70.

Gross, J. J. (2014). *Handbook of emotion regulation* (2nd ed.). Guildford Press.

Holzel, B. K., Lazar, S. W., Gard, T., Schuman-Olivier, Z., Vago, D. R., and Ott, U. (2011). How does mindfulness meditation work? Proposing mechanisms of action from a conceptual and neural perspective. *Perspectives on Psychological Science, 6,* 537–559.

Koole, S. L., Webb, T. L., & Sheeran, P. L. (2015). Implicit emotion regulation: Feeling better without knowing why. *Current Opinion in Psychology, 3,* 6–10.

Northoff, G., & Bermpohl, F. (2004). Cortical midline structures and the self. *Trends in Cognitive Science, 8*(3), 102–107.

Northoff, G., & Panksepp, J. (2008). The trans-species concept of self and the subcortical-cortical midline system. *Trends in Cognitive Science, 12*(7), 259–264.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35,* 73–89.

Posner, M. I., Rothbart, M. K., Sheese, B. E., & Tang, Y. Y. (2007). The anterior cingulate gyrus and the mechanism of self-regulation. *Cognitive, Affective, and Behavioral Neuroscience, 7,* 391–395.

Posner, M. I., Rothbart, M. K., & Tang, Y. Y. (2015). Enhancing attention through training. *Current Opinion in Behavioral Sciences, 4,* 1–5.

Tang, Y. Y., & Posner, M. I. (2009). Attention training and attention state training. *Trends in Cognitive Sciences, 13*(5), 222–227.

Tang, Y. Y., & Posner, M. I. (2014). Training brain networks and states. *Trends in Cognitive Sciences, 18*(7), 345–350.

Tang, Y. Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., et al. (2007). Short term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences, USA, 104*(43), 17152–17156.

Tang, Y. Y., Ma, Y., Fan, Y., Feng, H., Wang, J., Feng, S., et al. (2009). Central and autonomic nervous system interaction is altered by short term meditation. *Proceedings of the National Academy of Sciences, USA, 106*(22), 8865–8870.

Tang, Y. Y., Lu, Q., Geng, X., Stein, E. A., Yang, Y., & Posner, M. I. (2010). Short-term meditation induces white matter changes in the anterior cingulate. *Proceedings of the National Academy of Sciences, USA, 107*(35), 15649–15652.

Tang, Y. Y., Lu, Q., Fan, M., Yang, Y., & Posner, M. I. (2012a). Mechanisms of white matter changes induced by meditation. *Proceedings of the National Academy of Sciences, USA, 109*(26), 10570–10574.

Tang, Y. Y., Rothbart, M. K., & Posner, M. I. (2012b). Neural correlates of establishing, maintaining and switching brain states. *Trends in Cognitive Sciences, 16*(6), 330–337.

Tang, Y. Y., Yang, L., Leve, L. D., & Harold, G. T. (2012c). Improving executive function and its neurobiological mechanisms through a mindfulness-based intervention: Advances within the field of developmental neuroscience. *Child Development Perspectives, 6*(4), 361–366.

Tang, Y. Y., Holzel, B. K., & Posner, M. I. (2015). The neuroscience of mindfulness meditation. *Nature Reviews Neuroscience, 16*(4), 213–225.

Tang, Y. Y., & Tang, R. (2015a). Rethinking the future directions of mindfulness field. *Psychological Inquiry, 26*(4), 368–372.

Tang, Y. Y., Tang, R. (2015b). Mindfulness: Mechanism and application. In Arthur W. Toga (Ed.), *Brain Mapping: An Encyclopedic Reference* (Vol. 3, pp. 59–64). Academic Press: Elsevier.

Tang, Y. Y., Holzel, B. K., & Posner, M. I. (2016a). Traits and states in mindfulness meditation. *Nature Reviews Neuroscience, 17*(1), 59.

Tang, Y. Y., Tang, R., & Posner, M. I. (2016b). Mindfulness meditation improves emotion regulation and reduces drug abuse. *Drug and Alcohol Dependence, 163,* S13–S18.

Tang, Y. Y. (2017). *Brain based learning and education: Principles and application.* Elsevier.

Teper, R., Segal, Z. V., & Inzlicht, M. (2013). Inside the mindful mind: how mindfulness enhances emotion regulation through improvements in executive control. *Current Directions in Psychological Science, 22,* 449–454.