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Tools of the trade: theory and method in mindfulness neuroscience

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Mindfulness neuroscience is an emerging research field that investigates the underlying mechanisms of different mindfulness practices, different stages and different states of practice as well as different effects of practice over the lifespan. Mindfulness neuroscience research integrates theory and methods from eastern contemplative traditions, western psychology and neuroscience, and from neuroimaging techniques, physiological measures and behavioral tests. We here review several key theoretical and methodological challenges in the empirical study of mindfulness neuroscience and provide suggestions for overcoming these challenges.

Keywords: mindfulness neuroscience; mindfulness; meditation; neuroplasticity; gene-environment interaction

This special issue illustrates the diverse strategies for training mindfulness currently being used. These different strategies derive from ancient Hindu, Buddhist and Chinese contemplative and medical traditions as well as from modern adaptations developed mainly in the United States and Europe. These various strategies have in common the goal of being in a state of heightened but restful awareness of what is occurring within the phenomenological field that goes beyond conceptual and emotional classifications of what is characterized by increased acceptance of whatever is experienced and reduced mental judgments and ruminations. The different strategies and thought build, over time, a common brain state of mindfulness that can be beneficial to attention, emotion, performance, stress reduction and well-being.

KEY CHALLENGES IN MINDFULNESS NEUROSCIENCE RESEARCH

A number of key challenges arise when conducting mindfulness neuroscience research. Here, we highlight several core challenges and offer ways of addressing them. Because the majority of mindfulness research has utilized functional magnetic resonance imaging (fMRI) as a neuroimaging tool for measuring brain functional and structural changes. Later, we focus on the methodological issues related to fMRI.

The theoretical challenge

A major challenge in the field is the development of integrated theory to deal with what is common among mindfulness practices. Although the number of empirical publications in the field has been growing very fast (around 400 in 2011), there have been less effort to integrate the existing literature into a comprehensive theoretical framework from a conceptual, psychological and neuroscientific perspective (Baer, 2003; Baer *et al.*, 2006; Cahn and Polich, 2006; Shapiro *et al.*, 2006; Brown *et al.*, 2007; Lutz *et al.*, 2008; Tang and Posner, 2009; Chiesa and Malinowski, 2011; Tang *et al.*, 2012a; D.R. Vago and D.A. Silbersweig, submitted for publication).

Holzel *et al.* (2011) reviewed the literature and summarized four components of how mindfulness meditation may work: (i) attention regulation, (ii) body awareness, (iii) emotion regulation (including reappraisal, exposure, extinction and reconsolidation) and (iv) change in perspective on the self. The authors indicate that mindfulness practice comprises a process of enhanced self-regulation that can be differentiated into distinct but interrelated components. While these components are a start, future empirical work should identify additional components of mindfulness and establish to what extent the components involve distinct mechanisms.

The methodological challenges

Control and comparison groups

Different control and comparison groups have been used in mindfulness research, such as waiting lists, active control groups and interventions designed to match the non-specific effects of mindfulness practices, such as trainer's confidence, expectancy effects and group support (Davidson, 2010; Chiesa, 2011). Ideally, participants would be randomly assigned to condition, and the conditions would be matched with the many non-specific factors that have been found to produce beneficial change (Davidson, 2010). Random assignment allows the changes observed in mindfulness research to be reasonably attributed to the active ingredient of mindfulness practice *per se* rather than to pre-existing differences in the experimental and control groups. Therefore, moving the field will require the use of rigorous comparison conditions to which participants are randomly assigned (Tang *et al.*, 2007, 2012a; Davidson, 2010; MacLean *et al.*, 2010).

In long-term studies, an active control is not possible. In studies of long-term practitioners such as monks with many thousands of hours of practice, it is challenging to find even a matched control group (Davidson, 2010). We don't know how the monks differed before meditation practice and other factors including the environment and low stress, which differ from any 'matched' control group.

Different mindfulness techniques and different stages of practice

Different types of mindfulness practice may involve or emphasize different components (Lutz *et al.*, 2008; Tang and Posner, 2009). Within any technique of training, the stage of practice may involve

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differences in behavior, physiology and brain activity (Tang *et al.*, 2012a).

Two styles of training most commonly studied are (i) focused attention meditation, which entails the voluntary focusing of attention on a chosen object and (ii) open monitoring meditation, involving non-reactive moment-to-moment monitoring of the content of experience (Lutz *et al.*, 2008). Previous studies showed that portions of the anterior cingulate cortex (ACC), prefrontal cortex (PFC) and parietal cortex are involved at some stage in both these mindfulness techniques, but results are not always consistent (Cahn and Polich, 2006; Chiesa *et al.*, 2011; Holzel *et al.*, 2011; Tang *et al.*, 2012a). One reason for inconsistent findings is that most studies average measures from different stages of meditation together to determine mechanisms or effects, or compare them without identifying the stage involved (Travis and Shear, 2010).

Chiesa *et al.* (2011) proposed that the early phases of mindfulness training, concerned with the development of focused attention, are associated with significant improvements in selective and executive attention. The following phases, characterized by open monitoring, are mainly associated with improved vigilance and sustained attention.

Tang *et al.* (2012a) proposed three stages of meditation practice. The authors differentiate early and middle stages that involve effortful control from an advanced, more effortless stage of meditation. The stages clearly overlap, and intermediate stages, in which effort is needed for maintenance of the state, can also be observed. The early stage of achieving the meditative state appears to involve the use of attentional control and often involves in lateral PFC and parietal areas (Farb *et al.*, 2007; Siegel, 2007; Lutz *et al.*, 2008; Tang *et al.*, 2009; Posner *et al.*, 2010).

In the intermediate (middle) stage of meditation, the participant exerts an appropriate effort to deal with distractions and the wandering mind, and this process involves diverse brain networks depending on the strategies. In the advanced stage of training, little or no effort is needed, meditation is maintained by activity in the ventral ACC, left insula and striatum, accompanied by high parasympathetic activity (Tang *et al.*, 2012a). In this stage, there is a reduction of activity in the lateral PFC and parietal cortex (Tang and Posner, 2009; Tang *et al.*, 2009; Posner *et al.*, 2010; Holzel *et al.*, 2011).

Short-term and long-term training

Short-term and long-term mindfulness meditation training seems to induce different brain responses and neuroplasticity. Early studies of meditation recruited long-term practitioners (Lutz *et al*, 2004; Brefczynski-Lewis, *et al.*, 2007), while more recent research focuses on short-term training effects (Tang *et al.*, 2007, 2009; Erisman and Roemer, 2010; Zeidan *et al.*, 2010; Leiberg *et al.*, 2011). Short-term training studies allow for better control and may answer important question in the field, such as the changes in brain systems with various levels of training.

One important issue is whether mindfulness training alters the default network obtained from resting-state fMRI. The meditation state clearly differs from the resting state, particularly in the early stages, in that it involves effort. However, it is not yet clear whether the resting state changes as a result of meditation training (Tang *et al.*, 2012a). Several studies indicate that meditation training may alter the resting state, but different directions of change have been reported: two studies found increased resting state activity (Travis *et al.*, 2010; Jang *et al.*, 2011), whereas two others showed reduced resting state activity (Berkovich-Ohana *et al.*, 2011; Brewer *et al.*, 2011). Plausible explanations for these conflicting results include the following: (i) the differences are due to the form of meditation used in the studies, (ii) differences between studies arise because the participants are in different stages of meditation involving varying amounts of effort or (iii) differences may be due to varying numbers of persons achieving the meditation state during testing following the training. Further investigations providing specific details as to how mindfulness is differently conceptualized and practiced in each study will be needed to resolve these inconsistencies.

Our previous studies used one form of mindfulness training [integrative body–mind training (IBMT)] as a vehicle for understanding how training influences neuroplasticity observed by functional activation, functional connectivity of white matter, electroencephalography (EEG) coherence, gray matter volume and other measures. Our studies have found changes in all of these measures after various amounts of training (Tang *et al.*, 2007, 2009, 2010, 2012b). However, we do not yet know the order in which they emerge or the behavioral consequences observed with each brain change.

We believe IBMT might induce over a relatively short duration of training (weeks to months) all of these changes and thus may serve as a vehicle for basic understanding of their functional significance. For example, further research may allow us to learn the sequence of these various forms of brain plasticity related to the behavioral, developmental and physiological changes in attention, cognition and emotion.

SOME FUTURE DIRECTION

New techniques decoding the mental states

Investigating different types, different stages and different states of mindfulness practice requires new advanced tools and methods. For example, simultaneous multilevel recording including fMRI-physiological coupling could provide rich information to explore the underlying mechanisms of practice (Lane and Wager, 2009).

Studies of meditation have often used EEG to give the trainee information concerning the brain waves they are producing. This method has been used to aid training. Real-time fMRI allows the experimenter to collect and feedback aspects of the brain activity to the person to induce learning. Real-time fMRI has been applied in cognitive neuroscience to pain, motor control and emotion regulation. This dynamic recording and feedback technique may provide a specific platform to train the subject effectively or decode the mental states more accurately (LaConte, 2011; Zotev *et al.*, 2011).

Individual differences

Not all people show the same level of change due to mindfulness training. However, little is known about what temperamental, personality or genetic differences contributing to these differential training effects. Studies of effects of training in other domains have suggested that a number of genetic polymorphisms may interact with experience to influence the success of training (von IJendoorn *et al.*, 2011). Because of evidence that mindfulness meditation can influence the activation and connection of the ACC, PFC and other brain regions, it might be useful to examine polymorphisms in dopamine genes for their likely influence on the success of practice (Posner *et al.*, 2007). In addition, individual differences in personality, lifestyle, trainers and group dynamics during training are likely to have significant influence on training effects, but this influence is poorly understood. It may be that as in other fields the study of temperament and personality differences by questionnaires serves as an important level of analysis to predict success in mindfulness training (Rothbart, 2011). One study showed that different temperament and personality traits might be associated with different EEG patterns and heart rate variability in Zen meditators (Takahashi *et al.*, 2005).

CONCLUSIONS

The study of the mindfulness neuroscience is still in its infancy. The research reviewed here demonstrates that mindfulness practice is indeed a powerful modulator of structural and functional brain plasticity. The precise components and time course of mindfulness-mediated changes are beginning to be delineated. The key ingredients of the mindfulness practice for triggering specific aspects of brain–mind–body changes are yet to be determined. However, research in mindfulness neuroscience has the potential to address the important questions in the human neuroscience and development. Future studies could demonstrate the potential of certain mindfulness practice as a tool to remediate a variety of debilitating diseases as well as to maximize human potential in development or to lessen the burden of cognitive decline associated with aging.

We are grateful to have this opportunity to edit this special issue on mindfulness neuroscience. In this article, we share what we have learned from the process of the special issue. Our article is meant not as a complete summary of the mindfulness research but to motivate further scientific discussion. We sincerely hope this issue contributes to the development of the field of mindfulness research.

SUPPLEMENTARY DATA

Supplementary Data are available at *SCAN* online.

Conflict of Interest

None declared.

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