Brain and Cognition 87 (2014) 1–6

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Short-term meditation induces changes in brain resting EEG theta networks

Shao-Wei Xue [a,b], Yi-Yuan Tang [c,e,*], Rongxiang Tang [d], Michael I. Posner [e]

[a] Institute of Neuroinformatics and Laboratory for Body and Mind, Dalian University of Technology, Dalian 116024, China
[b] Center for Cognition and Brain Disorders, Hangzhou Normal University, Hangzhou 310003, China
[c] Department of Psychology, Texas Tech University, Lubbock, TX 79409, USA
[d] Department of Psychology, University of Texas at Austin, Austin, TX 78705, USA
[e] Department of Psychology, University of Oregon, Eugene, OR 97403, USA

ARTICLE INFO

Article history:
Accepted 17 February 2014
Available online 13 March 2014

Keywords:
Brain complex networks
EEG
Integrative body–mind training
Relaxation training

ABSTRACT

Many studies have reported meditation training has beneficial effects on brain structure and function. However, very little is known about meditation-induced changes in brain complex networks. We used network analysis of electroencephalography theta activity data at rest before and after 1-week of integrative body–mind training (IBMT) and relaxation training. The results demonstrated the IBMT group (but not the relaxation group) exhibited significantly smaller average path length and larger clustering coefficient of the entire network and two midline electrode nodes (Fz and Pz) after training, indicating enhanced capacity of local specialization and global information integration in the brain. The findings provide the evidence for meditation-induced network plasticity and suggest that IBMT might be helpful for alterations in brain networks.

1. Introduction

Meditation can be conceptualized as a family of complex emotional and attentional regulatory training regimes (Lutz, Slagter, Dunne, & Davidson, 2008). In research and clinical contexts, mindfulness meditation is often defined as a practice with nonjudgmental attention to experiences in the present moment (Kabat-Zinn, 1990). However, one of the major issues in the literature is the inconsistency of operational definitions of meditation (Awasthi, 2013; Cahn & Polich, 2006; Williams & Kabat-Zinn, 2011). For example, Bishop et al. (2004) proposed an operational definition including self-regulation of attention, which would seem to be one of the key ingredients believed to be active in mindfulness. Nevertheless, mindfulness neuroscience or contemplative 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 (Tang & Posner, 2013).

Meditation has recently received increasing attention as a vehicle for understanding training-related brain plasticity. Previous studies have reported meditation relates to changes in brain structure and function such as increased regional cortical thickness (Lazar et al., 2005), grey matter densities (Luders, Toga, Lepore, & Gaser, 2009; Vestergaard-Poulsen et al., 2009), white mater connectivity (Luders, Clark, Narr, & Toga, 2011; Tang, Lu, Fan, Yang, & Posner, 2012; Tang et al., 2010), reorganization of cognitive resources (Hölzel et al., 2011; Slagter et al., 2007), and the default mode network connectivity (Brewer et al., 2011; Jang et al., 2011).

Integrative Body–Mind Training (IBMT) is one form of mindfulness meditation that originates from ancient eastern contemplative traditions, including traditional Chinese medicine, Zen, etc. IBMT shares several key components with other forms of meditation, including relaxation, mental imagery, and mindfulness. IBMT stresses no effort or less effort to control thoughts, and the achievement of a state of restful alertness that allows a high degree of awareness and balance of the body, mind, and environment (Tang, Rothbart, & Posner, 2012). A number of randomized clinical trials indicate that IBMT improves attention and self-regulation and induces neuroplasticity through interaction between the central and the autonomic nervous systems (Tang et al., 2007; Tang et al., 2009; Tang et al., 2010). For example, 4-week IBMT has been

* Corresponding author at: Department of Psychology, Texas Tech University, Lubbock, TX 79409, USA. Fax: +1 806 742 8188.
E-mail address: yiyuan.tang@ttu.edu (Y.-Y. Tang).

http://dx.doi.org/10.1016/j.bandc.2014.02.008
0278-2626/

reported to increase network efficiency of the anterior cingulate cortex (Xue, Tang, & Posner, 2011) and connectivity of the white matter surrounding the anterior cingulate cortex (Tang et al., 2010; Tang et al., 2012).

Recently, brain networks derived from functional magnetic resonance imaging (fMRI) or electroencephalography (EEG) have been consistently reported to exhibit an optimal organization pattern for information processing, such as high clustering coefficient and short path lengths (Stam, Jones, Nolte, Breakspear, & Scheltens, 2007), and high efficiency of information transfer for low wiring costs (Achard & Bullmore, 2007), suggesting the balance of functional integration and segregation (Rubinov & Sporns, 2010). Recent studies indicated differences in the network topological parameters associated with an array of factors including diseases (Seeley, Crawford, Zhou, Miller, & Greicius, 2009) and different task conditions (Bullmore & Sporns, 2009). Besides, using network science to evaluate exercise-associated brain changes is also becoming increasingly attractive (Bassett et al., 2011; Burdette et al., 2010).

Electrophysiological studies have observed altered theta activity is linked to meditation practice (Cahn & Polich, 2006; Rubia, 2009; Tang et al., 2009). Our previous study has also reported five days of IBMT induced increased EEG power in the theta frequency band at frontal midline electrodes (Tang et al., 2009). Based on these studies, we hypothesize that meditation experience is associated with changes in brain networks derived from resting-state EEG theta activity. We thus combine synchronization likelihood method, network analysis, and IBMT to test the hypothesis.

2. Methods

2.1. Participants

Forty-five healthy Chinese students (29 males, mean age, 22.9 ± 1.55 (SD) yrs, all right-handed) without any previous meditation or relaxation training experience were recruited through advertisements in Dalian University of Technology, and randomly assigned to an experimental group (IBMT, 24 subjects, mean age 22.9 ± 1.6 yrs) and a relaxation training control group (21 subjects, mean age 22.8 ± 1.5 yrs). They all provided their written informed consent. The experiment was approved by the local Institutional Review Board.

2.2. Training

Twenty-four subjects attended a group of IBMT at campus for 1-week with 30 min per session (a total of 3.5 h of training), while 21 control subjects received the same number and length of group sessions with relaxation training (Benson, Greenwood, & Klemchuk, 1975; Tang et al., 2007). No extra home practice was required (Tang et al., 2007).

Each IBMT or relaxation training (RT) session includes a presession (~5 min for training preparation), a practice session (~20 min), and a postsession (~5 min for practice feedback and Q&A), facilitated by an experienced and certified coach, demonstrating the ability to lead the group to achieve the goal of IBMT and/or RT (Tang, Yang, Leve, & Harold, 2012; Tang et al., 2007). IBMT involves body relaxation, mental imagery and mindfulness training accompanied by a soft music background. Cooperation between the body and the mind is emphasized in facilitating and achieving a meditative state. RT involves relaxing different muscle groups over the face, head, shoulders, arms, legs, chest, back, abdomen, and so on, accompanied by soft music background. With eyes closed and in a sequential pattern, one concentrates on the sensation of relaxation, such as feelings of warmth and heaviness (See the Training Methods in Tang et al. (2007), Tang, Rothbart, et al. (2012) and Tang, Yang, et al. (2012) for more details and examples on IBMT). Psychological mood states for all subjects of two groups before and after training were assessed using the Profile of Mood States (POMS) (Spinella, 2007; Tang et al., 2007).

2.3. EEG recording

Electroencephalography activity was recorded continuously using the Brain Products System (Brain Products GmbH, Munich, Germany) at the following 28 positions: FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, Oz and O2. The electrode was placed according to International 10–20 System nomenclature. The EEG signal was digitized at 500 Hz. The impedance of each electrode was below 5 kΩ. An electrode placed on the vertex (FCz) served as a reference with an analog pass band of 0.01–100 Hz.

Spontaneous EEG was recorded during 5 min of quiet rest with eyes closed before and after 1-week of training. Off-line EEG data analysis was performed with commercially available software (Vision Analyzer, Brain Products GmbH, Germany). EEG data were filtered with low-pass filters at 2 Hz and high-pass filters at 50 Hz, rereferenced to the average reference. Following the previous studies (Boersma et al., 2011; Tang et al., 2009), 30 s of artifact-free data (containing no eye blinks, slow eye movements, excess muscle activity, electrocardiogram artifacts, etc.) were selected. The EEG was down sampled to 125 Hz, resulting in time series of 4096 samples for further analysis. The theta (3–8 Hz) frequency bands were analyzed.

2.4. Network analysis

In the present study, we regarded brain networks as graph representations of brain activity acquired by resting EEG data, where the vertices represented electrodes and the edges described their functional connectivity between each pair of electrodes. After extracting the time courses for each electrode, we computed the functional connectivity by synchronization likelihood (Stam & Van Dijk, 2002). For each subject, we obtained a 28×28 weighted-edge matrix of all possible (378) pair-wise combinations of electrodes. The diagonal element was self-correlation of the corresponding node and we set all the diagonal elements to 0. Graph theoretical measures were further estimated.

The average path length of a node was used to characterize how well the ith node propagated information in the network and defined as follows:

$$L_i = \frac{1}{N-1}\sum_{i \neq j} \min\{d_{ij}\}, \qquad (1)$$

in which d_{ij} was the shortest path length between the ith node and the jth node computed as the sum of the edge lengths along this path, N represented the total number of nodes ($N = 28$). As described in a previous study (Yan et al., 2011), we can likewise define the edge's length as the reciprocal of the strength of the functional connectivity.

Clustering coefficient quantified the extent to which a node's first neighborhood was a completely-connected sub-graph, and a large clustering coefficient meant high local functional overlap of densely connected neighborhood elements. In the present study, we used its definition as follows (Onnela, Saramäki, Kertész, & Kaski, 2005):

$$C_i = \frac{1}{k_i(k_i-1)}\sum_{j,k} (w_{ij}w_{jk}w_{ki})^{1/3}, \qquad (2)$$

where k_i is the degree of node i and w_{ij} denoted the weighted edge that connected node i to node j. The clustering coefficient C of the