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Short-term meditation modulates brain activity of insight evoked with solution cue

Xiaoqian Ding,[1] Yi-Yuan Tang,[2,3] Chen Cao,[1] Yuqin Deng,[1] Yan Wang,[1] Xiu Xin,[1] and Michael I. Posner[2]
[1]Institute of Neuroinformatics and Laboratory for Body and Mind, Dalian University of Technology, Dalian 116024, China, [2]Department of Psychology, University of Oregon, Eugene, OR 97403, USA, and [3]Department of Psychology, Texas Tech University, Lubbock, TX 79409, USA

Meditation has been shown to improve creativity in some situation. However, little is known about the brain systems underling insight into a problem when the person fails to solve the problem. Here, we examined the neural correlation using Chinese Remote Association Test, as a measure of creativity. We provide a solution following the failure of the participant to provide one. We examine how meditation in comparison with relaxation influences the reaction of the participant to a correct solution. The event-related functional magnetic resonance imaging showed greater activity, mainly distributed in the right cingulate gyrus (CG), insula, putamen, inferior frontal gyrus (IFG), and the bilateral middle frontal gyrus (MFG), the inferior parietal lobule (IPL) and the superior temporal gyrus (STG). This pattern of activation was greater following 5 h of meditation training than the same amount of relaxation. Based on prior research, we speculate on the function of this pattern of brain activity: (i) CG may be involved in detecting conflict and breaking mental set, (ii) MFG/IFG may play an important role in restructuring of the problem representation, (iii) insula, IPL and STG may be associated with error detection, problem understanding or general attentive control and (iv) putamen may be activated by 'Aha' feeling.

Keywords: insight; short-term meditation; integrative body–mind training; event-related functional magnetic resonance imaging

INTRODUCTION

The ability of insightful problem solving (IPS) plays an important role in almost all areas of our life: education, arts and the scientific domain. It is also advantageous in the economic sector, where insight can contribute to novel and meaningful solutions to various personnel, strategic and task-oriented dilemmas. Behavioral research indicates four salient features of IPS which occur in the order as: mental impasse (Isaak and Just, 1995), restructuring of problem representation (Köhler and Winter, 1925; Ash and Wiley, 2006), deeper understanding of the problem (Dominowski and Dallob, 1995) and a sudden and obvious 'Aha!' feeling about the solution (Siegler, 2000).

Because of its close relationship with IPS, meditation as a way of enhancement has been identified as a practical method (Ding *et al.*, 2011; Ostafin and Kassman, 2012). Meditation cultivates skillful attentiveness by paying attention as non-reactively as possible and thereby prevents an individual from fixating on the mental impasse (Fresco *et al.*, 2007) that hinders the search for new representation during problem solving (Ostafin and Kassman, 2012). Moreover, meditation is used as a form of introspection and allows the switch of attention to awareness of thought and perception at the present moment (Didonna, 2009). This reappraisal of thought allows a restructuring of problem representation, thus leading to a deeper understanding of the present problem (Cayoun, 2011). Consistent with the above theory, meditation significantly inspires IPS by keeping people in a mindful, alert and conscious state (Ren *et al.*, 2011). Though studies on the effects of meditation on insight have attracted great interest, the brain mechanism of the connection between meditation and IPS remains mysterious.

Our study is first designed to explore the question of whether insight provided by the problem solution is aided by prior training in meditation. To accomplish this goal, we adopted Chinese Remote Association Test (RAT; Chen *et al.*, 2011) to elicit insight and measured performance on the RAT before and after training. The RAT is a means of measuring insight without requiring knowledge specific to any field (Mednick, 1962). In RAT, a solution word is obtained by thinking of more distantly related information to form a valid compound word with each of the three test words. To examine brain activation by insight we used event-related functional magnetic resonance imaging (fMRI; Luo and Knoblich, 2007).

Insight requires a restructuring of the problem situation that is relatively rare and hard to elicit in the laboratory. One way of dealing with this problem is to catalyze such restructuring using solution cue (Luo and Niki, 2003; Luo *et al.*, 2004; Mai *et al.*, 2004; Luo and Knoblich, 2007). During fMRI scanning, the participant is given sufficient time to ponder over a Chinese RAT problem. If a participant fails to solve the problem independently, there is a high probability that s/he experiences an impasse and is mentally stuck on an inappropriate representation of the problem (Luo and Knoblich, 2007). Then, the restructuring of problem representation is triggered by the standard solution uncovered. This allows one to obtain multiple insight events and the accurate onset time, which are required for event-related fMRI designs.

In this study, integrative body–mind training (IBMT), which is adopted from traditional Chinese medicine and incorporates the key components of meditation training, is utilized as a meditation intervention. Instead of effort to control thoughts, IBMT stresses a balance and optimization between mind and body that facilitate to arrive at a meditative state (Niedenthal, 2007; Tang *et al.*, 2007, 2009, 2010), and maintain this state to resolve mental conflicts (Tang and Posner, 2009). On the other hand, relaxation training (RT) involves the relaxing of different muscle groups over the head to abdomen and forces one to concentrate on the feelings of warmth and heaviness. This progressive muscle training helps a participant achieve physical (body) and mental (mind) relaxation and calmness (Tang *et al.*, 2007, 2009, 2010). As both RT and IBMT emphasize on achieving their desired states through regulating the body and the mind, RT matches IBMT in the training and thus we choose RT as an active control condition. During RT, thinking about control operations could interfere with training effects (Tang *et al.*, 2007; Tang and Posner, 2009), leading to different

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Correspondence should be addressed to Yi-Yuan Tang, Department of Psychology, Texas Tech University, Lubbock, TX 79409, USA. E-mail: yiyuan.tang@ttu.edu

results between the IBMT and the RT groups. To achieve the meditation state, 5 days of IBMT differed from RT chiefly in facilitating emotional and cognitive processing (Tang *et al.*, 2007) and greater activity in cingulate gyrus (CG) and insula (Tang *et al.*, 2009). This design also allowed us to randomly assign our participants to either a meditation group (IBMT) or a RT control group (RT). Each group received 2 weeks of training with 5 h in total. Differences in fMRI on these 'insight' trials were used to measure differences in brain activation between the IBMT and RT groups.

We have following hypotheses:

First, a component process of insight is to break a mental impasse, and the participants need to detect and resolve a cognitive conflict (Druyan, 2001). CG is responsible for conflict detection (Carter *et al.*, 2000; MacDonald *et al.*, 2000; Botvinick *et al.*, 2004). However, CG is also sensitive to IBMT (Tang *et al.*, 2009), which was proposed to maintain the meditation state by reducing conflict with other states because of its role in attention and self-regulation (Van Veen and Carter, 2002; Farb *et al.*, 2007; Tang *et al.*, 2007; Johansen-Berg *et al.*, 2008; Wager *et al.*, 2008). Therefore, we predict that CG is involved in IBMT compared with RT during the insight moment.

Second, the solution uncovered process-evoked insight relates closely to error feedback. According to a previous error-feedback study, insula cortex activity is associated with error awareness, which is useful for post-error adjustment (Klein *et al.*, 2007). Correspondingly, the insula, an area associated with the introspective processes and breath awareness, is also sensitive to meditation (Lazar *et al.*, 2005). Moreover, introspection plays important roles during IPS, such as error detection (realizing that one's initial representation is inappropriate), problem understanding (realizing the crucial step toward the solution) or general attentive control. Therefore, we predict that the insula and some other introspection-related neural substrates, such as the bilateral inferior parietal lobules (IPLs) and the superior temporal gyrus (STG) (Gallagher *et al.*, 2000; Saxe and Kanwisher, 2003; German *et al.*, 2004) may be involved in IBMT compared with RT during insight moment, because of the high introspection of meditation: more objective assessment of a meditator's own internal states and mental contents (Kabat-Zinn, 1994; Goenka, 2000; Lutz *et al.*, 2008; Sze *et al.*, 2010).

METHODS

Participants

Thirty-two healthy right-handed undergraduates at Dalian University of Technology were recruited. They did not have any meditation or RT experience and were randomly assigned to an IBMT group or an RT group (16:16). The IBMT group (aged 21 ± 1.3 years; 12 males) completed the whole IBMT 30 min per day for 10 days (5 h in total). The RT group (aged 21 ± 1.9 years; 11 males) was given the same amount and length of muscle RT. The study was approved by the University's Institutional Review Board, and informed consent was obtained from each participant.

Insight paradigm

fMRI was used to test distinct neural mechanisms between short-term meditation training and RT during IPS. Given Mednick's (1962) association theory and Weisberg's (1995) multi-facet assumption of creative problem, a set of compound remote association problems were adapted from the Chinese RAT (Chen *et al.*, 2011). Figure 1 illustrates the sequence for each trial (Mai *et al.*, 2004). The participants saw three problem words (疗 防 统) and attempted to think of a single solution word (治) that can form a familiar Chinese phrase with each of the three words (治疗 防治 统治). We used solvers' reports to sort out the insight moment (Mai *et al.*, 2004) based on the participants responses discussed below. The stimuli and questions were implemented and presented using E-Prime 1.0 (Psychology Software Tools, USA).

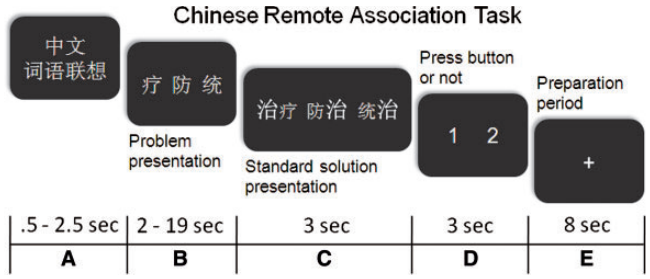

Fig. 1 Sequence of events for each trial. (**A**) The Chinese RAT prompt was presented for 0.5 s, and then persisted for a variable amount of time (0–2 s) until a cue from the scanner indicated the beginning of a new whole-brain acquisition. (**B**) A three-word problem appeared on the screen and persisted until the participant indicated (with a button press) that s/he had solved the problem, or until the 19 s time limit elapsed. Thus, event timing and condition were completely dependent on the participant's responses. (**C**) Following the button press or time limit, the standard solution to the previous problem appeared on the screen and then (**D**) the participant was prompted to press a button or not: (1) number one button, the solution participant thought of was identical to the standard solution; (2) number two button, the solution participant thought of was different from the standard one but s/he believed the standard solution was more reasonable, or did not think of the solution by herself/himself and believed the standard solution matched the problem. The participant did not need to press any button if s/he could not understand the meaning of the standard solution, or did not think the standard solution matched the problem. If participant could understand the meaning of the standard solution, they were required to press the button as accurately and quickly as possible once the standard solution appeared. Only those trials in which the solutions were judged as (2) mentioned above were included in the fMRI analysis, because it was regarded as including an insight process. (**E**) A central fixation cross that lasted for 8 s was presented, signaling the onset of the preparation interval and allowing BOLD signal to return to the baseline (Ogawa *et al.*, 1992). After the fixation cross, the next problem was presented.

The presentation of the standard solution could confirm whether or not a participant solved the previous three-word problem correctly. However, if a participant solved incorrectly but believed the standard solution was more reasonable, or s/he could not solve the three-word problem and believed the standard solution matched the problem, the presentation of solution (solution uncovered events) should result in an insight. Given that it takes around 2 s for most participants to fully understand the meaning of a solution cue (Mai *et al.*, 2004; Luo and Knoblich, 2007), the insight event during fMRI scanning was selected and analyzed with a time window of 6–11 s after the presentation of standard solution to isolate the corresponding hemodynamic response (Jung-Beeman *et al.*, 2004). Insight problems and standard solutions, and responding to them required a strict sequence of events (reading words, understanding the solution and decision), but the sequences were identical for IBMT and RT, so differences in fMRI signals resulted from the degree to which distinct cognitive processes and neural systems led to insight between the two groups. Therefore, differences between the two groups in insight events were estimated using the average signal of each participant.

fMRI data acquisition

Data were collected using an Intera 3.0 T MRI scanner (Philips Medical Systems, Best, the Netherlands) with a standard head coil. Head movement was restricted using foam padding around the head. T2*-weighted functional images were acquired parallel to the anterior commissure/posterior commissure line using a single-shot gradient echo-planar imaging sequence [repetition time (TR) = 2 s, echo time (TE) = 30 ms, flip angle (FA) = 80°, field of view = 230 mm, matrix size = 64 × 64]. Two sessions were obtained with 296 functional volumes in each session and 36 interleaved axial slices (4 mm thick) in each volume covering the entire brain. After fMRI, an inversion recovery-prepared T1-weighted structural volume was acquired in the same slice location and orientation as the functional images using a fast spin-echo sequence with TR/TE = 7/3.20 ms, FA = 8° and slice thickness = 1 mm in a high-resolution scan (1 × 1 × 1 mm).

fMRI data analysis

fMRI data for each participant were preprocessed and analyzed using Statistical Parametric Mapping (SPM8, Wellcome Department of Imaging Neuroscience, London, UK). Slice timing was corrected using sinc interpolation and resampling with the middle (18th) slice as a reference point. All functional volumes were realigned to the first volume to correct between-scan motion. Each structural volume was co-registered to the mean functional image and segmented to extract a gray matter image. The segmented structural volume was then spatially normalized to a gray matter image of the Montreal Neurological Institute (MNI) template and resliced to a voxel size of 2 × 2 × 2 mm. The realigned functional volumes were brought into a standardized MNI space by using the derived spatial transformation. Finally, the functional volumes were smoothed with an 8 mm full-width at half-maximum isotropic Gaussian kernel to compensate for residual between-subject variability after spatial normalization and to permit application of Gaussian random field theory for the corrected statistical inference (Friston *et al.*, 1994). To remove low-frequency drift in the blood oxygen level-dependent (BOLD) signal, the data were high-pass filtered using an upper cut-off period of 128 s. No global scaling was performed.

Condition effects at each voxel were estimated according to a general linear model for the main whole-brain analyses. The model included: (i) the observed intensity time series that represent the dependent variable, (ii) covariates that model the session-specific effects (i.e. the six head movement parameters), later treated as confounds and (iii) regressor functions that are constructed by convolving condition-specific boxcar functions with a synthetic hemodynamic response function. We were interested in insight condition. The regressor functions were constructed to model insight condition and compared using T contrasts for each participant. The between-group differences were compared using t-test. The resulting T maps were then transformed to the unit normal Z-distribution to create a statistical parametric map for each contrast. A task-related response was considered significant when it exceeded an false discovery rate (FDR)-corrected threshold of $P < 0.05$ and consisted of at least 10 contiguous voxels. In addition, we indicate in table, peaks that survived FDR correction ($P < 0.05$) (Genovese *et al.*, 2002). We also considered to balance between Type 1 and Type 2 errors in statistical analysis (Lieberman and Cunningham, 2009).

fMRI signal change analysis: to assess the difference of neural activity during insight event between the two groups, several insight-related regions of interest (ROIs) were defined by selecting all voxels within a sphere of 5 mm radius around the coordinates of activation peaks provided by the above analysis (Jung-Beeman *et al.*, 2004).

Procedures

The experimental sessions included pre-session, training session and post-session.

(i) Pre-session: Participants performed the insight task in the scanner.
(ii) Training session: The practice sessions are intended to help each participant improve meditation or relaxation experience. The participant concentrates on achieving a balanced state between body and mind guided by a qualified coach and a compact disk. RT involves the relaxing of different muscle groups guided by a qualified coach and the compact disk. The participant concentrates on the sensation of relaxation, such as the feelings of warmth and heaviness. The IBMT group completed the whole IBMT for 10 days (30 min per day), whereas the RT group was given the same amount and length of RT (Tang *et al.*, 2007, 2010).
(iii) Post-session: After the IBMT or RT practice, participants performed the insight task in the scanner again. The insight paradigm and the difficulty of Chinese RAT problems were the same type as in the pre-session, but Chinese RAT problems were different from the pre-session to filter out familiarity.

RESULTS

Behavioral results

We measured 40 Chinese RAT problems during the pre- and post-session. Before training, the participants (including the IBMT group and the RT group) pressed the button of '1' correct for 47.3% of their solutions, and '2' incorrect for 42.5% of their solutions, with 10.2% of non-response. The correct rate of this study is similar to a previous study (Subramaniam *et al.*, 2009), indicating that the difficulty level of this study is appropriate.

To explore differences in problem solving ability among the IBMT and RT groups, we compared the number of successfully solved items (correct score) in the pre- or post-session between the two groups separately. The total number of items was 40 in the both session.

Before training, between-group t-tests showed that the average correct score of Chinese RAT in IBMT group (mean = 18.563, s.d. = 5.955) and RT group (mean = 19.313, s.d. = 4.159) did not differ [$t(30) = 0.413$; $P > 0.05$] indicating that the two groups did not differ in problem-solving ability. A group (IBMT *vs* RT) × training session (before *vs* after) repeated-measures analysis of variance (ANOVA) for the correct score yielded an interaction [$F(1,30) = 11.343$; $P < 0.01$]. After training, the t-test indicated that the IBMT group (mean = 24.563, s.d. = 4.351) had significantly higher correct score [$t(30) = 2.757$; $P < 0.05$] in comparison with the RT group (mean = 20.188, s.d. = 4.622), indicating that short-term IBMT can yield a better creative problems solving performance than RT.

Imaging results

During fMRI scanning, we selected and analyzed the solution uncovered condition, in which a participant solved incorrectly but believed the standard solution was more reasonable, or s/he could not solve the three-word problem and believed the standard solution matched the problem. This condition should result in a restructuring of problem representation and a deep understanding of the problem.

The results showed that before training, no significantly different activations were observed between the two groups, suggesting that the randomization made the two groups comparable. After 5 h of training, the two types of training led to different activations. In comparison of the two groups (activation in trials in IBMT minus that in RT), significantly greater activation was found in the right CG, insula, putamen, as well as in the right inferior frontal gyrus (IFG), and the bilateral middle frontal gyrus (MFG), IPL and STG ($P < 0.05$, FDR corrected). In contrast, the RT group did not show significantly greater activation than the IBMT group even at $P < 0.001$, uncorrected. See Figure 2 and Table 1 for details.

The fMRI signal changes of ROIs (see Table 1 for coordinates) were directly contrasted to make explicit the between-group difference during insight. The average signal change across these ROI regions was calculated for 5 s following the presentation of the standard

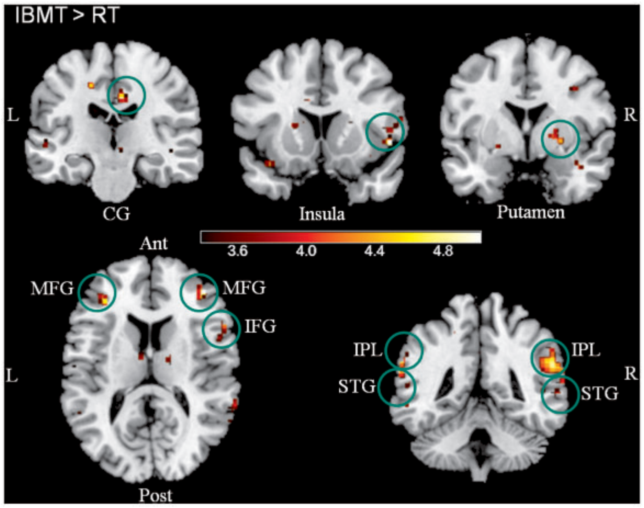

Fig. 2 Comparison maps of BOLD signal change in IBMT compared with RT at the solution uncovered moment after training. The maps were overlaid on the averaged normalized structural image, $t(30) = 3.713$, $P < 0.05$, FDR corrected. The first row shows (left to right) three coronal images, and the second row shows (left to right) a sagittal image and a coronal image (with the left hemisphere on the left of sagittal and coronal images) centered on clusters of significant size (contiguous voxel size threshold >10; no clusters of significant size showed the reverse pattern). Results show 10 clusters: the right CG, the right insula, the right putamen, the left MFG, the right MFG, the right IFG, the left IPL, the left STG, the right IPL and the right STG. Ant, anterior; post, posterior; L, left; R, right.

Table 1 Activation peaks during insight event (IBMT > RT)

Region	MNI coordinates						
	L/R	BA	*x*	*y*	*z*	Voxels	*Z*-value
CG	R	24	5	−20	38	65	5.13
Insula	R		49	14	−2	8	4.95
Putamen	R		26	0	−2	15	4.40
MFG	L	10/46	−34	44	24	112	5.90
	R	10/46	40	45	13	22	5.27
IFG	R	44/45	56	18	17	32	5.42
IPL	L	40	−62	−42	25	16	3.91
	R	40	58	−42	26	132	5.52
STG	L	22	−64	−44	20	20	5.00
	R	22	64	−46	11	29	3.46

All areas were thresholded at $P < 0.05$ with FDR correction for multiple comparisons and with 10 contiguous voxels at least. L, left hemisphere; R, right hemisphere.

solution, if participants solved three-word problem incorrectly but experienced an insight.

Before training, no significant between-group difference of average percent signal change was found in all ROIs ($P > 0.05$). ANOVA revealed a group (IBMT *vs* RT) × training session (before *vs* after) effect of average percent signal change on the right CG [$F(1,30) = 9.197$; $P < 0.01$], right insula [$F(1,30) = 17.385$; $P < 0.01$], right putamen [$F(1,30) = 10.534$; $P < 0.01$], left IPL [$F(1,30) = 6.965$; $P < 0.05$] and left STG [$F(1,30) = 12.635$; $P < 0.01$].

After training, *t*-test indicated significant between-group differences (all $P < 0.01$) in the right CG [$t(30) = 3.791$], right insula [$t(30) = 4.519$], right putamen [$t(30) = 3.708$], left IPL [$t(30) = 3.891$] and left STG [$t(30) = 3.988$]. After training, the IBMT group had increased signals in these areas, indicating neural activity increased during insight event. In contrast, the RT group had decreased signals in these areas, indicating neural activity decreased during insight event (Figure 3).

DISCUSSION

Our results show that after 5 h of training, participants engaged in meditation solved more Chinese RAT problems compared with participants in the control group (relaxation), thereby providing direct evidence for the role of meditation in promoting problem-solving ability. This is generally in line with previous research on the role of meditation (Ren *et al.*, 2011).

The task in our study is quite different from the nature of language recognition task. Language recognition means that the subjects first learn a large number of items, and then they are asked to identify the learned items. In the testing phase, the items include not only the learned ones but also the unlearned ones, so adequate abilities of encoding, storage and extracting are required to complete the language recognition task (Mandler, 1980; Luo *et al.*, 2001; Finnigan *et al.*, 2002; Wang *et al.*, 2005). But in our current study, the insight paradigm with the one-by-one testing pattern required the subject to solve a problem within a limited time. When presented with the correct answer, retrieval is required to identify whether or not the standard solution is the same as the one that s/he had developed before seeing the answer. We assume, when there was a failure followed by an answer acknowledged to be correct, the participant had achieved a new representation (Köhler and Winter, 1925; Weisberg, 1995; Davidson, 2003; Ash and Wiley, 2006) and thus had restructured the relationship between question and solution (Köhler and Winter, 1925; Ash and Wiley, 2006). In this sense our method provides one kind of insight which may or may not be different from that obtained through a sudden self realization of the correct answer.

Our study investigated the neural correlations between meditation and the form of insight we have described above. It showed that IBMT in comparison with RT increased activity mainly distributed in the right CG, insula, putamen, and the bilateral frontal, parietal and temporal regions. These activations may reflect that after 5 h training, the IBMT group was more involved in restructuring the problem.

Previous research proves that IBMT generates unique patterns of brain activities. Five days of IBMT increases brain activity in CG (Tang *et al.*, 2009) to maintain the meditation state by reducing conflict with other states (Carter *et al.*, 2000; MacDonald *et al.*, 2000; Botvinick *et al.*, 2004; Tang *et al.*, 2007). As CG is associated with cognitive control (Kounios *et al.*, 2006; Liston *et al.*, 2006) and plays an important role in breaking mental set for insight (Qiu *et al.*, 2008), together with the previous findings, our results that IBMT heightens activity in CG might help detect conflict and break mental set at the solution uncovered moment.

Moreover, previous neuroimaging studies demonstrate significant positive relationships of creative ability with MFG and IFG (Jung *et al.*, 2009; Takeuchi *et al.*, 2010a, b). Furthermore, a previous fMRI study on IPS shows that MFG and IFG are involved in formation of problem re-representation (Qiu *et al.*, 2009). Our results may be well consistent with previous studies. For instance, MFG is thought to execute goal-directed association (Smith and Jonides, 1998, 1999; Wager and Smith, 2003). The greater activation of the bilateral MFGs in the IBMT group than in the RT group at the insight moment may reflect that after CG breaks the incorrect mental 'fixation', the IBMT participants are better at switching their attention from the initial and superficial problem representation to the final and correct one. In addition, the right IFG is typically implicated in 'go/no go' tasks to inhibit a prepotent response (Aron *et al.*, 2004a). The greater activation of the right IFG in the IBMT group than in the RT group at the insight moment may indicate that IBMT participants better suppress the initial and pre-potent way of thinking, and accept the final and correct one for restructuring of the problem representation.

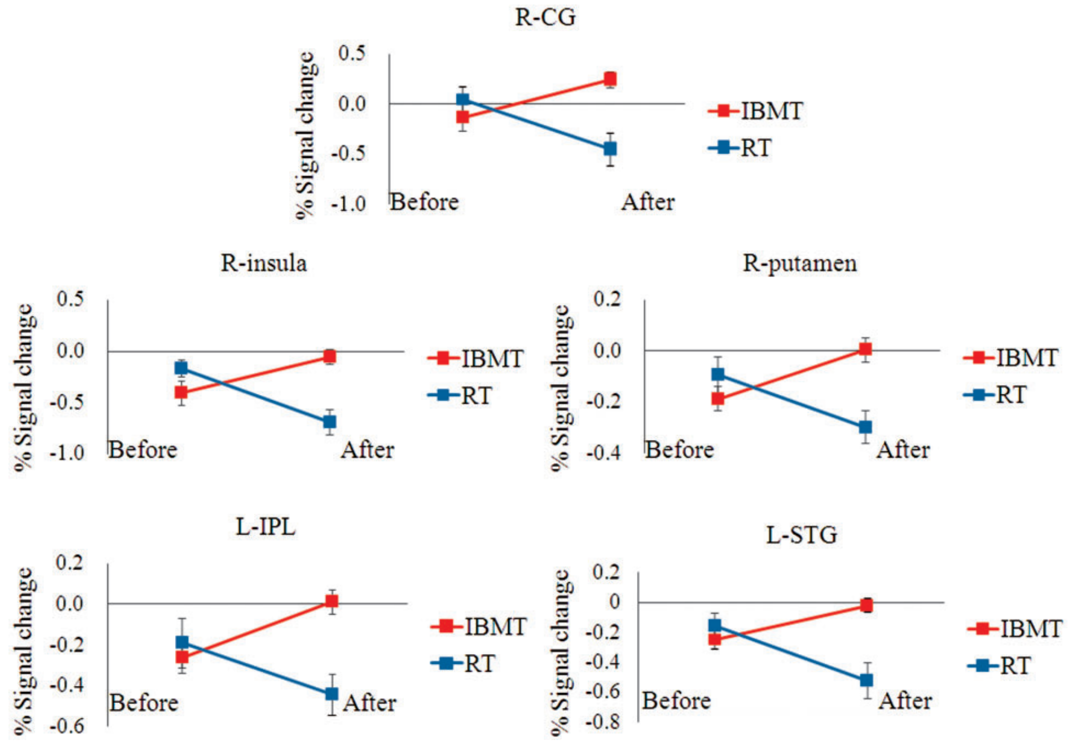

Fig. 3 Comparison of average percent signal change of ROIs (right CG, right insula, right putamen, left STG and left IPL) between the IBMT group (red) and the RT group (blue) before training and after training. Error bars show the standard error of the mean at each time point.

Furthermore, consistent with the hypothesis, our results reveal that the insula is usually linked to perception, self-awareness and cognitive functioning (Farrer and Frith, 2002; Karnath *et al.*, 2005; Olausson *et al.*, 2005; Ogino *et al.*, 2007; Tsakiris *et al.*, 2007; Von Leupoldt *et al.*, 2008; Baliki *et al.*, 2009; Craig, 2009), and that some other introspection-related neural substrates, such as the bilateral IPLs and STG (Gallagher *et al.*, 2000; Saxe and Kanwisher, 2003; German *et al.*, 2004) are activated in IBMT compared with RT at the insight moment. A probable reason for this observation is that introspection (the ability to regulate thoughts or emotions) plays important roles during IPS, such as error detection (realizing that one's initial representation is inappropriate), problem understanding (realizing the crucial step toward the solution) or general attentive control. However, the meditation experience heightens introspection (Fleming *et al.*, 2012), because of the highly introspective nature of such practices: more objective assessment of a meditator's own internal states and mental contents (Kabat-Zinn, 1994; Goenka, 2000; Lutz *et al.*, 2008; Sze *et al.*, 2010). Thus, the greater activation observed in the introspection-related neural substrates in the IBMT group at the insight moment may be explained that the IBMT participants possess the sensitivity for more awareness of their failure (observing the discontinuity between the initial way of thinking and the final correct solution), regulation of their emotional states and switching their attention to the problem-solving task.

At last, if a solver suddenly switches attention from the dominant but incorrect representation to the correct one, s/he often experiences a unique insight feeling, called the 'Aha!' moment (Siegler, 2000). The 'Aha!' experience has a positive affective component, which is related to the dopaminergic neurons that innervate portions of the putamen (Fuente-Fernández *et al.*, 2002). Given that meditation often involves the putamen linked to the reward experience (Takeuchi *et al.*, 2010b) and formation of habits (Aron *et al.*, 2004b) to maintain meditative state (Tang and Posner, 2009; Posner *et al.*, 2010; Tang *et al.*, 2012), the possible reason for the greater activity of putamen in the IBMT group than in the RT group at the insight moment may be that meditators are more sensitive to the positive 'Aha!' experience (Aftanas and Golocheikine, 2001).

The IBMT group had higher neural activation than RT in right CG, right insula, left IPL and STG and right putamen after training. The different activation patterns between IBMT and RT using fMRI signal change analysis may indicate different regulatory strategies in producing the reorganization following the correct answer. The reason for the low-level brain activation in the RT group may be contributed to its regulatory strategies, which requires voluntary control in progressive relaxation of the muscles of the body, sending feedback to influence the mind (Bernstein and Borkovec, 1973). With these regulatory strategies, so much effort is used to control and maintain the relaxation state that participants may lack brain resources to perform the insight task (Dosenbach *et al.*, 2008; Tang *et al.*, 2009; Tang and Posner, 2009).

In summary, comparison between the two groups before training revealed no differences, but the meditation group after short-term (5 h) training showed significantly higher activation in the right CG, bilateral MFGs, right IFG, right insula, bilateral IPL and STG and right putamen. These brain areas of increased activation indicate the impact of short-term meditation training on a host of insight-associated cognitive processes (Kounios *et al.*, 2008), including the highly integrated processes such as conflict detection, breaking mental set, restructuring problem representation, error detection and the experience of 'Aha!' in a moment. Our findings may coincide with previous studies on the effects of initial learning or short-term practice on complex cognitive tasks that prefrontal and parietal regions related to the support of a control processing system cognitive control become more active (Raichle *et al.*, 1994; Petersen *et al.*, 1998; Kelly and Garavan, 2005). Interestingly, the fact that long-term practice leads to generalized reduction of brain activity on complex cognitive tasks, is thought to be related to two core predictions of increasing neural efficiency and decreasing the load on the cognitive control mechanisms (Chein and Schneider, 2005; Kelly and Garavan, 2005). Further research may allow us to explore how long-term (over years to months) meditation relates to the behavioral and neural activity changes of insight.

Our study also raised new question how the neural activation found following being provided with a correct answer relates to the insight found during problem solution when a person suddenly finds the correct solution. Both of these methods provide a perspective on restructuring a problem. Whether insight is unique to self-discovery remains to be established.

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