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Review

Mindfulness meditation improves emotion regulation and reduces drug abuse

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ABSTRACT

Background: The core clinical symptoms of addiction include an enhanced incentive for drug taking (craving), impaired self-control (impulsivity and compulsivity), emotional dysregulation (negative mood) and increased stress reactivity. Symptoms related to impaired self-control involve reduced activity in anterior cingulate cortex (ACC), adjacent prefrontal cortex (mPFC) and other brain areas. Behavioral training such as mindfulness meditation can increase the function of control networks including those leading to improved emotion regulation and thus may be a promising approach for the treatment of addiction.
Methods: In a series of randomized controlled trials (RCTs), we tested whether increased ACC/mPFC activity is related to better self-control abilities in executive functions, emotion regulation and stress response in healthy and addicted populations. After a brief mindfulness training (Integrative Body-Mind Training, IBMT), we used the Positive and Negative Affect Schedule (PANAS) and Profile of Mood States (POMS) to measure emotion regulation, salivary cortisol for the stress response and fMRI for brain functional and DTI structural changes. Relaxation training was used to serve as an active control.
Results: In both smokers and nonsmokers, improved self-control abilities in emotion regulation and stress reduction were found after training and these changes were related to increased ACC/mPFC activity following training. Compared with nonsmokers, smokers showed reduced ACC/mPFC activity in the self-control network before training, and these deficits were ameliorated after training.
Conclusions: These results indicate that promoting emotion regulation and improving ACC/mPFC brain activity can help for addiction prevention and treatment.

Contents

1. Background

Emotion regulation refers to strategies that can influence which emotions arise and when, how long they occur, and how these emotions are experienced and expressed (Gross, 2014). A range of

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implicit and explicit emotion regulation processes has been proposed (Gross, 2014). Research indicates that the anterior cingulate cortex (ACC) is involved in both cognitive control and emotional regulation. Neuroimaging studies show that the ventral part of ACC and its adjacent medial prefrontal cortex (mPFC) are mainly associated with emotional regulation (Bush et al., 2000; Posner et al., 2007; Rudebeck et al., 2008).

In current clinical and research contexts, mindfulness meditation is often described as non-judgmental attention or regulation to the present experiences (Hart, 1987; Kabat-Zinn, 1990). Improvements in emotion regulation associated with mindfulness meditation have been investigated through self-report, physiology and neuroimaging methods (Tang and Posner, 2014). Mindfulness-based emotion regulation may involve a mix of the implicit and explicit processes (Tang et al., 2015a). Studies indicate increased positive emotion and decreased negative emotion (Holzel et al., 2011; Jain et al., 2007; Tang et al., 2007; Robins et al., 2012; Ding et al., 2014).

The core clinical symptoms of addiction include an enhanced incentive for drug taking (craving), impaired self-control (impulsivity and compulsivity), emotional dysregulation (negative mood) and increased stress reactivity. Symptoms related to impaired self-control involve reduced activity in ACC and adjacent mPFC. One mechanism for addiction has been shown to involve a deficit in a self-control network involving ACC and mPFC. Thus, improving ACC/mPFC activity may improve emotion regulation and thus better addiction prevention and treatment (Goldstein and Volkow, 2011; Tang et al., 2007, 2013, 2015b). A large body of literature suggests that behavioral training such as mindfulness meditation can improve self-control through better emotion regulation and may thus be a promising approach for the treatment of addiction (Holzel et al., 2011; Tang et al., 2015b).

In this article, we will focus on one of the key factors in drug abuse-emotional dysregulation and explore its underlying brain mechanisms. Our goal is to show how improved emotion regulation could help addiction prevention and treatment. We take one form of mindfulness meditation-integrative body–mind training (IBMT) as an example to demonstrate how brief IBMT improves emotion regulation, reduces stress (cortisol) and increases ACC/mPFC activity related to better self-control abilities in healthy and addicted population.

IBMT involves systematic training of attention and self-control with an attitude of acceptance and openness to internal and external experiences (Tang et al., 2007, 2009, 2015a). IBMT has been tested in several randomized controlled trials (RCTs) that indicate a very rapid change in the central and autonomic nervous systems including reduced stress hormone, improved positive mood states and induced brain functional and structural changes (Tang et al., 2007, 2009, 2015a). The control group was given a relaxation training that is often used as a part of cognitive behavioral therapy. Because IBMT shares key components with other forms of mindfulness meditation, we expect other mindfulness methods will show the similar effects in addiction prevention and treatment through improved self-control ability (Tang et al., 2012a, 2015b; Bowen et al., 2014).

2. Emotion regulation and mindfulness meditation

In order to discuss this relationship, it is necessary to first examine the neural correlates of emotion regulation. Studies have shown that the bilateral prefrontal regions of the brain including mPFC/ACC (medial prefrontal cortex/anterior cingulate cortex) are primarily responsible for the regulation of emotion through modulating limbic system activity, and at the same time, making sure current strategies meet the regulatory goals (Etkin et al., 2011; Kim and Hamann, 2007). There are different strategies when it comes to regulating one's emotion, and each strategy involves shared and distinct neural networks. In a study that compared cognitive reappraisal and emotion-expression suppression techniques, participants were found to have an increased activity in cognitive control PFC regions and decreased amygdala and insula responses when employing reappraisal strategy, suggesting the down-regulation of amygdala and insula reactivity to negative emotional stimuli; whereas the suppression strategy not only activated the PFC, but also engaged visual-sensory multimodal association (posterior occipito-temporal lobes) and visual-spatial (precuneus and occipital areas) processing (Goldin et al., 2008). Although there are subtle differences among various control strategies, the ACC/mPFC regions are consistently involved in the regulation and inhibition of emotion responses (Bush et al., 2000; Tang et al., 2015a).

Negative emotion often implicates the need for effective emotion control. Impulsivity is recognized as a risk factor for many problems, including the initiation of drug use and drug abuse vulnerability. Growing evidence indicates that emotional dysregulation and impulsivity interact in important ways that can inform strategies to prevent and treat drug abuse. For example, emotional dysregulation can engender impulsive behaviors during adolescence and young adulthood, and mood-based rash action is both predictive of addiction, as well as predictive of treatment outcomes. Thus, improving emotion regulation is important to the prevention and treatment of addictions (Tang et al., 2015b).

In one study, Chinese college students were randomly assigned to an IBMT ($N = 40$) or a relaxation training group ($N = 40$) for 5 days of short-term training (20 min per day). The IBMT group showed significantly greater improvement of performance in executive control as measured by the Attention Network Test (Fan et al., 2002) than did the relaxation group. Individuals in the IBMT condition also had lower negative affect and fatigue, and higher positive feelings on the Profile of Mood States (POMS; Tang et al., 2007); see Fig. 1. In addition, a few hours of IBMT can also decrease levels of the stress hormone cortisol and increase immune reactivity (Tang et al., 2007). Using the measurement of Positive and Negative Affect Schedule in the same RCT design, short-term IBMT showed the significantly better positive mood states compared to relaxation (Ding et al., 2014). A similar study showed that in comparison with a waitlist control group, an 8-week mindfulness training program significantly reduced negative moods (Robins et al., 2012). These results indicated that mindfulness meditation can improve self-control such as emotion regulation effectively.

How does mindfulness enhance emotion regulation? Evidences suggest 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). It should be noted that emotion regulation is not always deliberate, but can also operate in non-conscious or implicit levels. 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 (Koole et al., 2015; Tang et al., 2015a). It should be noted that in addition to ACC/mPFC involved in emotion regulation, other brain areas such as dorsal lateral PFC, amygdala, insula and hippocampus also participate the top-down and bottom-up control networks of emotion regulation (Ochsner et al., 2012; Rive et al., 2013).

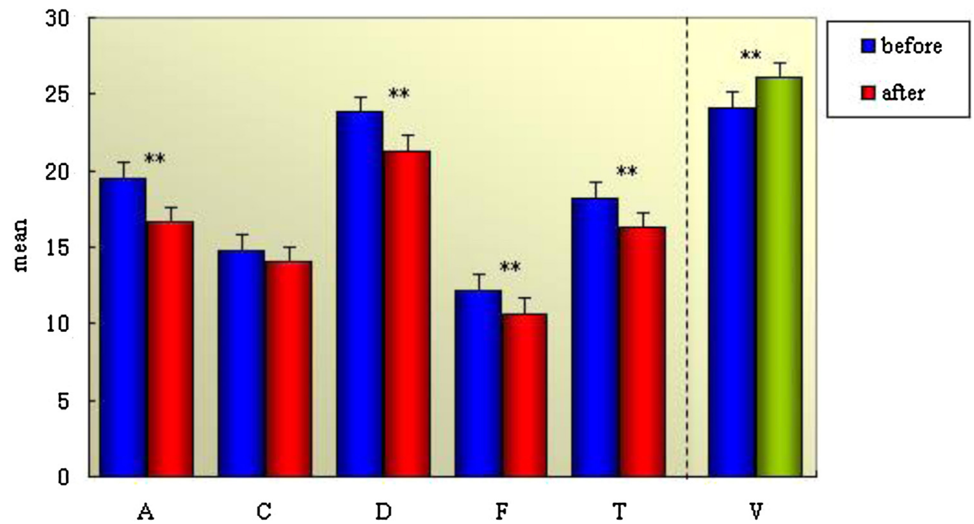

Fig. 1. Comparison of six scales of the POMS before and after IBMT. Blue bar, five negative moods and one positive mood pretraining; red bar, five negative moods posttraining; green bar, one positive mood posttraining. Significance was found in POMS scales of anger-hostility (A), depression-dejection (D), fatigue-inertia (F), tension-anxiety (T), and vigor-activity (V) posttraining in the experimental group. No significant difference was found in POMS scale C (confusion-bewilderment) posttraining. **, *P*average < 0.01. Error bars indicate 1 SD (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

3. Brain mechanisms

The mental process of mindfulness meditation mainly involves attention and self-control (Farb et al., 2007 Holzel et al., 2011; Tang et al., 2012a, 2015a). It is thus reasonable to suggest that the underlying brain mechanisms of mindfulness may involve similar brain regions and networks as these mental processes.

In a RCT study, 46 undergraduates were randomly assigned to IBMT or relaxation groups and conducted brain-imaging assessments before, during, and after 5 days of training (Tang et al., 2009). 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 (Bush et al., 2000; Posner et al., 2007). Since this area is also linked to autonomic nervous system (ANS; Critchley et al., 2003), we thus measured the heart rate variability, an index of sympathetic and parasympathetic activity. We found that compared to relaxation training, 5 days of IBMT significantly improved high-frequency heart rate variability (HRV), suggesting better parasympathetic regulation. Further, our results also showed the frontal midline ACC theta is correlated with high-frequency HRV, indicating that both the ACC and ANS may serve as mediating brain mechanisms linking IBMT with improvements in emotion regulation (Tang et al., 2009).

If 5 days of short-term IBMT improves emotion regulation supported by the ACC activity, what will happen following longer IBMT practice? We expected longer IBMT practice could induce structural change related to ACC. Previous results using MRI diffusion tensor imaging, have shown that training results in changes in white matter efficiency as measured by fractional anisotropy (FA). We randomly assigned 45 U.S. 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 before and after training. Results showed that around 10 h of IBMT (within 4 weeks) increased FA in the corona radiata, an important white-matter tract connecting the ACC to other structures, see Fig. 2 (Tang et al., 2010).

To measure the time-course of white matter change from 2-weeks to 4-weeks of mindfulness meditation, we used the indexes of radial diffusivity (RD) and axial diffusivity (AD). Reductions in RD have been interpreted as improved myelin but reductions in AD involve other mechanisms, such as axonal density. We found 2-weeks IBMT reduced AD. However, after 4-weeks training with IBMT, both RD and AD decrease accompanied by increased FA, indicating improved efficiency of white matter involves increased myelin as well as other axonal changes (Tang et al., 2012b). This dynamic pattern of white matter change involves the ACC, a part of the brain network related to self-control, which could provide means for intervention to improve or prevent mental disorders.

Could brief training induce brain structure change? Although the neural mechanisms of mindfulness meditation are not fully understood at this time, increasing empirical evidences have shown the positive effects on brain functional and structural changes including white matter and gray matter (Tang et al., 2015a). Recent studies have also suggested the benefits following brief mindfulness (Tang and Posner, 2013). For example, 4 sessions of mindfulness training can significantly enhance the ability of diverse cognitive functions and mood (Zeidan et al., 2010). A single practice session of whole body dynamic balance learning also induces both white matter and grey matter changes (Taubert et al., 2010). Would it be possible that the white matter change is due to motion artifact? We (and others) have used motion correction parameters as a covariate in the analyses following the standard FSL analyses (Tang et al., 2010, 2012b; Taubert et al., 2010). To verify the AD/RD and FA analysis and results, we have invited imaging experts to re-analyze the same dataset independently and got same significant results. Moreover, the longitudinal study design ensures each single voxel's eigenvalue directions are congruent in the pre- and post-training scans because they came from same subject. Thus, it is unlikely the current results are noise or artifacts (Tang et al., 2010, 2012b).

Our previous studies indicated 1-week IBMT improved mood states using POMS (Tang et al., 2007). In a study using diffusion tensor imaging (Tang et al., 2012a,b), in comparison to relaxation training 2-weeks IBMT showed significant reductions in anger-hostility (A), confusion-bewilderment (C), depression-dejection (D), fatigue-inertia (F), and total mood disturbance (TMD) in POMS. After 2-weeks IBMT, there was a significant correlation between TMD change (an index of emotion regulation) and AD decrease at the left posterior corona radiata, indicating the training-induced change in mood was correlated with the ACC structural changes, see Fig. 3. Because deficits in activation and connectivity of the

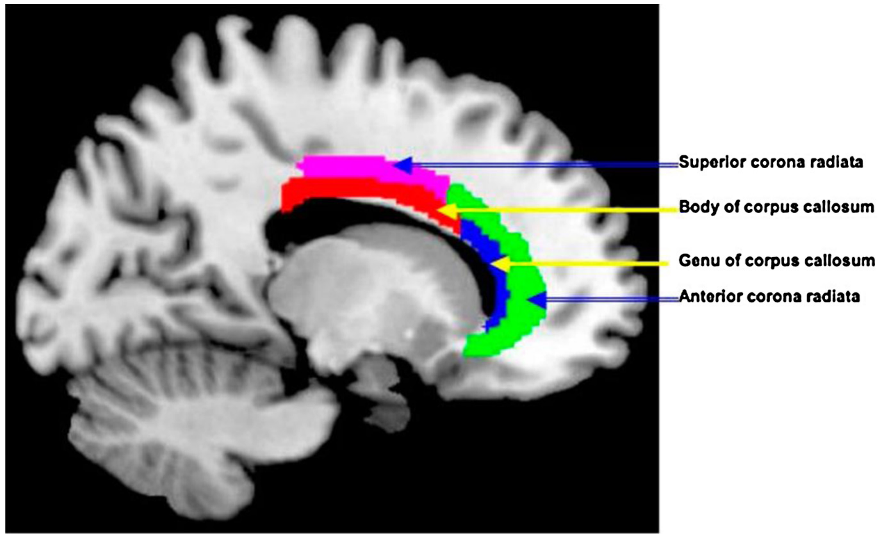

Fig. 2. Demonstration of brain regions with significant FA increases after 10 h of IBMT. The demonstration map shows the significant FA increases in the left anterior corona radiata (green area), the left superior corona radiata (purple area), the genu of corpus callosum (blue area), and the body of corpus callosum (red area) after 10 h of IBMT, all $P < 0.05$ (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

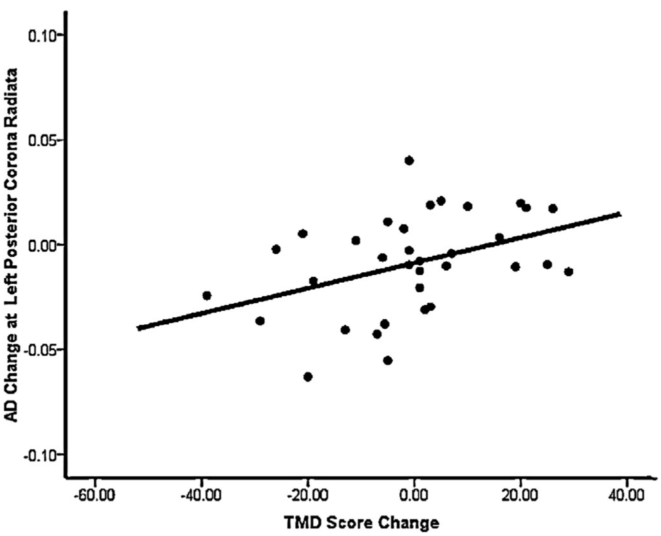

Fig. 3. Correlation between TMD change and AD decrease at left posterior corona radiata after 2-weeks IBMT. The horizontal axis indicates the POMS total score change and the vertical axis indicates the AD change at left posterior corona radiata. A positive Pearson's correlation was observed ($r = 0.409$, $P = 0.016$). TMD, total mood disturbance in POMS.

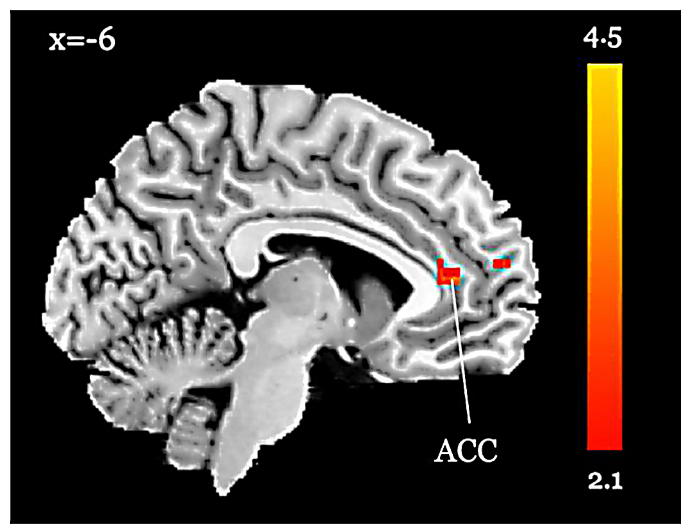

Fig. 4. Increased ACC activity after 2 weeks of IBMT. After 2 weeks of IBMT, we found significantly increased activity at ACC/medial PFC, orbitofrontal cortex, and inferior frontal gyrus/ventrolateral PFC (displayed at Pcorrected < 0.05).

ACC have been associated with many disorders, including mood disorders and substance abuse, the ability to strengthen ACC connectivity through mindfulness training could provide means for improving self-regulation and perhaps reducing or preventing various mental disorders (Tang et al., 2010, 2015a,b). Below we review two examples from addiction research to demonstrate this potential application.

4. Application in drug abuse

A review of mindfulness training as a treatment for addiction showed reduction in craving and smoking following training (Brewer et al., 2013). However, many of the studies were criticized because of lack of randomization and weak controls, and the review called for more rigorous and randomized controlled studies (Holzel et al., 2011; Tang et al., 2015a,b). Recently, a few rigorous and randomized studies have tested the effect of mindfulness meditation on addictions (Tang et al., 2013; Bowen et al., 2014). For example, compared to treatment as usual (TAU, 12-step programming and psychoeducation), eight weekly group sessions of cognitive-behavioral relapse prevention (RP) and mindfulness-based relapse prevention (MBRP) showed significantly lower risk of relapse to substance use and heavy drinking. Among those who used substances, significantly fewer days of substance use and heavy drinking were found at the 6-month follow-up. Cognitive-behavioral RP showed an advantage over MBRP in time to first drug use. At the 12-month follow-up, MBRP showed significantly fewer days of substance use and significantly decreased heavy drinking compared with RP and TAU. This finding indicated mindfulness meditation may support long-term outcomes by strengthening the ability to monitor and skillfully cope with discomfort associated with craving or negative affect, thus supporting long-term outcomes (Bowen et al., 2014).

In a randomized mindfulness training study (Tang et al., 2013), participants were recruited for stress reduction purpose and nothing was said about their intention to quit smoking. Before training, smokers demonstrated reduced activity in ACC, PFC, and other areas during rest compared to nonsmokers, consistent with the association between impaired self-control and addiction. Two weeks of IBMT (5 h in total) produced a significant smoking reduction (60%) and quitting (30%) as measured objectively by the carbon dioxide percentage in the lungs, whereas no reduction was found in the relaxation training control. Resting-state fMRI showed increased activity for the IBMT group in the ACC and mPFC, key brain areas for self-control, and these areas were associated with a reduction in smoking behavior, see Fig. 4. To test whether intention related to the reduction of smoking, we measured intention using self-report questionnaires and found that conscious intention did not make a significant difference in smoking reduction. These results suggest that brief mindfulness meditation improves self-control capacity and reduces smoking even without a conscious intention to do so (Tang et al., 2015b). It should be noted that, after ending the 2 weeks of IBMT, an informal study showed that smoking reduction still remained at least a month later. Since the number was small, we do not yet know exactly how long the reduction will last, even though studies have shown that if smokers are tobacco free after seven days, they will likely remain that way for six months (Loughead et al., 2015). However, more research is needed on the lasting effect of mindfulness meditation.

A major problem in overcoming tobacco use is craving. Craving is also a significant factor that can lead to relapse during attempts to quit smoking. Comparing before and after training, the IBMT group showed a significant decrease in craving compared to relaxation group. These results demonstrate that short-term IBMT can significantly reduce craving (Tang et al., 2013). These results lead us to speculate that the increased ACC activity (related to self-control) suppressed craving even without the participants' conscious intention. There are several routes through which mindfulness could influence addiction. IBMT reduced the amount and duration of cortisol to a stressful challenge (Tang et al., 2007), which may work to reduce addiction. Another possible explanation is based on the finding that mindfulness practice leads to a non-judgmental stance (awareness and acceptance) regarding addiction, which could reduce negative emotion, conflict, and stress, and thus lead to reduced smoking. There are clearly other possibilities and these various explanations are not mutually exclusive. In this current study, improved self-control may itself be related to both stress and judgmental changes (Tang et al., 2015b).

5. Conclusion

Emerging evidence has shown that mindfulness meditation induces increased connectivity and activity in ACC/mPFC regions which are involved in emotion regulation. Promoting emotion regulation and improving self-control related brain activity can help in the prevention and treatment of addictions such as tobacco, alcohol, cocaine, as well as other various behavioral disorders including obesity, gambling, and excessive use of the internet that are also associated with self-control deficits. Further research needs to use longitudinal, randomized and actively controlled research designs and larger sample sizes to advance the understanding of the mechanisms of mindfulness meditation in addiction prevention and treatment.

Conflict of interest

None.

Role of funding source

Nothing declared.

Contributors

Only the authors listed are responsible for the content and preparation of this manuscript. YYT, RT and MIP participated in the article preparation, and finalized the manuscript. All authors have approved this manuscript.

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