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Mind-Body Practices and the Adolescent Brain: Clinical Neuroimaging Studies

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Abstract

Background—Mind-Body practices constitute a large and diverse group of practices that can substantially affect neurophysiology in both healthy individuals and those with various psychiatric disorders. In spite of the growing literature on the clinical and physiological effects of mind-body practices, very little is known about their impact on central nervous system (CNS) structure and function in adolescents with psychiatric disorders.

Method—This overview highlights findings in a select group of mind-body practices including yoga postures, yoga breathing techniques and meditation practices.

Results—Mind-body practices offer novel therapeutic approaches for adolescents with psychiatric disorders. Findings from these studies provide insights into the design and implementation of neuroimaging studies for adolescents with psychiatric disorders.

Conclusions—Clinical neuroimaging studies will be critical in understanding how different practices affect disease pathogenesis and symptomatology in adolescents. Neuroimaging of mind-body practices on adolescents with psychiatric disorders will certainly be an open and exciting area of investigation.

Keywords

Breathing practices; complementary and alternative medicine; meditation; neuroimaging; yoga

INTRODUCTION

Mind-body practices constitute a large and diverse group of practices that can substantially affect neurophysiology in both healthy individuals and those with various psychiatric disorders. Examples of such practices include yoga postures, meditation interventions, tai chi, qi gong, hypnosis among many others. Over the past several decades, the neurobiological effects of mind-body practices have been incorporated into numerous theoretic models (Benson, Beary & Carol 1974; Newberg, Iverson 2003; Brown, & Gerbarg,

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CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

2005; Porges, 2007; Taylor *et al.*, 2010). Their clinical value in psychiatric disorders is a recent but expanding area of investigation (Balasubramaniam, Telles & Doraiswamy 2012) including in adolescent patients (Black, Milam, & Sussman, 2009). In addition to the neurobiological effects, experimental studies of mind-body practices demonstrate that they can activate homeostatic mechanisms by modulating autonomic nervous system function (Bernardi, Gabutti, Porta, & Spicuzza, 2001; Brown & Gerbarg, 2005; Raghuraj, Ramakrishnan, Nagendra & Telles, 1998; Telles, Gaur, & Balkrishna, 2009), neuroendocrine responses (Fan, Tang & Posner, 2013), inflammatory activity (Weber, Arck, Mazuerk, & Klapp, 2002; Kiecolt-Glaser, Marucha, Atkinson, & Glaser, 2001) and cardiovascular function (Innes, Bourguignon, & Taylor, 2005; Innes & Vincent, 2007; Agte, Jahagirdar, & Tarwadi, 2011).

In spite of the growing literature on the clinical and physiological effects of mind-body practices, very little is known about their impact on central nervous system (CNS) structure and function in adolescents with psychiatric disorders. Neuroimaging studies have begun to identify how these practices induce such changes in adult populations. This overview highlights these findings in a select group of mind-body practices including yoga postures, yoga breathing techniques and meditation practices. Findings from these studies provide insights into the design and implementation of future neuroimaging studies with adolescents with psychiatric disorders.

GENERAL CONSIDERATIONS FOR NEUROIMAGING RESEARCH IN ADOLESCENTS

A number of practical aspects need to be considered in designing neuroimaging studies with adolescent patient populations. Among these include efforts to minimize the effects of head motion and other imaging artifacts (Johnston, Mwangi, Matthews, Coghill, & Steele, 2012). The success rate of completing single sessions of functional magnetic resonance imaging (fMRI) varies depending on the age of the subject as well as the co-morbid psychiatric disorder. A neuroimaging study with children with attention-deficit/hyperactivity disorder (ADHD) found a single session success rate of 78% compared to 96% for age and gender-matched controls. Within the ADHD group completion rates were 82% for children aged 10–12 years old compared to 70% for 7–9 year olds (Yerys *et al.*, 2009). This study highlights the importance of modifying the number of recruited adolescents based on differences in success rates among different patient populations.

Different neuroimaging modalities have their own advantages and limitations with respect to evaluating mind-body practices in adolescents. Electroencephalography (EEG) is valuable because it is relatively non-invasive and has very high temporal resolution on the order of milliseconds. Unlike other neuroimaging modalities, it is silent and does not induce claustrophobic symptoms or require exposure to radioactivity. Moreover, it is compatible with a diverse set of body positions and is relatively tolerant of movement associated with various mind-body practices. As a modality, EEG is limited by its spatial resolution and bias towards detecting synchronized activity. It is unable to detect changes in neurotransmitter levels or brain activity deep in the CNS. Nevertheless, EEG may be particularly valuable in the study of adolescents with psychiatric disorders since it is noninvasive and poses no significant risk on these patients.

Functional MRI primarily measures changes in cerebral blood flow. In general, this is a valid method for measuring cerebral activity since a brain region that is activated during a specific task will experience a concomitant increase in blood flow. The coupling of blood flow and activity provides a method for observing which parts of the brain have increased activity (increased blood flow) and decreased activity (decreased blood flow). Functional MRI has very good spatial resolution and can be co-registered with an anatomical MRI scan that can be obtained in the same imaging session. This allows for a very accurate determination of the specific areas of the brain that are activated. FMRI also has very good temporal resolution where images can be obtained over very short time intervals, as short as a second. This allows for the detection of rapid brain activity changes. Thus, if a subject is performing several different breathing techniques sequentially while in the MRI, the differences in blood flow could be detected in each of those tasks. Finally, fMRI does not involve any radioactive exposure. Thus, it carries a very low risk and would be more acceptable to use in adolescent populations. The disadvantages of this modality are that images must be obtained while the subject is in a scanner which is a claustrophobic environment and can make up to 100 decibels of noise. This can be very distracting when individuals are performing various mind-body practices and can interfere with practices that require certain postures or body movements. However, several investigators have successfully utilized fMRI and have performed the studies by having subjects practice their mind-body technique at home while listening to a tape of the fMRI noise so that they become acclimated to the environment (Lazar *et al.*, 2005). Currently, fMRI cannot be used to evaluate individual neurotransmitter systems.

PET and SPECT imaging modalities also have advantages and disadvantages. These include relatively good spatial resolution for PET (comparable to fMRI) and slightly worse for SPECT imaging. PET and SPECT images can also be coregistered with anatomical MRI, but this must be obtained during a separate session and therefore, matching the scans is more difficult. PET and SPECT both require the injection of a radioactive tracer. Depending on the radioactive tracer used, a variety of unique functional parameters can be measured including blood flow, metabolism (which more accurately depicts cerebral activity), and many different neurotransmitter components. The ability to measure these neurotransmitter systems is unique to PET and SPECT imaging. Such tracers can measure either state or trait responses following mind-body practices in adolescents with psychiatric disorders. Some of the more common radioactive materials such as fluorodeoxyglucose (measures glucose metabolism) can be injected through an intravenous catheter when the subject is not in the scanner. The tracer becomes “locked” in the brain during the injection period and the patient can then be scanned after completing their practice, still allowing for measurements associated with the practice. This allows for a more conducive environment for performing mind-body practices (Newberg *et al.*, 2001). While the radioactive dose used with these modalities is fairly low, this can impose regulatory challenges in performing studies on adolescents. Another major drawback to PET and SPECT imaging is that these techniques have generally poor temporal resolution. Depending on the tracer, the resolution can be as good as several minutes or as poor as several hours or even days. It would be very difficult to use PET or SPECT to study several different meditative states in the same imaging session. However, two or three states might be measured in the same session if the appropriate radiopharmaceutical is used (Lou *et al.*, 1999). Ultimately, the selection of neuroimaging modality in studying the effects of different mind-body practices on adolescents with psychiatric disorders will depend on the specific goals of the study. Let us consider several different mind-body practices to better evaluate the potential for developing research studies in the adolescent psychiatric population.

THE EVIDENCE BASE AND FUTURE DIRECTIONS

Yoga Postures (Asanas)

Yoga is an eight-limbed holistic system of health that includes a number of different mind-body practices. The yoga asanas are represented in the third limb of this system as organized by Patanjali (circa 400 B.C.). According to the Council for Scientific and Industrial Research (CSIR), at least 1300 different yoga postures have been described in ancient texts (Sinha, K. 2011). While the experiential effects of these poses have been described by experienced yoga instructors (Iyengar, 1977); there is a growing interest in understanding the molecular, physiological and clinical aspects of these postures. How yoga postures impact CNS activity is to date a largely unexplored area of investigation. The neuromodulatory effects of yoga postures on adolescents with psychiatric disorders remains to be determined.

Yoga postures induce functional changes in brain activity in both baseline and activated states. A small open pilot study with healthy adults looked at the effects of cerebral blood flow (CBF) before and after a 12 week training program in Iyengar Yoga (Cohen *et al.*, 2009). Iyengar yoga uses various props to facilitate alignment and attainment of specific postures. CBF was measured in select regions of interest (ROI) corresponding to major cortical and subcortical structures. After twelve weeks of training, significant changes in the mean CBF ratio were noted in the baseline (pre- yoga session) scans in the right amygdala, right dorsal medial cortex and right sensorimotor area. After twelve weeks, the activated (post- yoga session) scans showed significantly increased activity in the right dorsal frontal lobe, right prefrontal cortex, right sensorimotor cortex, right inferior frontal lobe, right superior frontal lobe and left dorsal medial frontal lobe. The study was limited by sample size as well as the partial inclusion of breathing techniques and meditation. Despite these limitations, this preliminary study demonstrated that interventions consisting of yoga postures can result in changes in the brain’s baseline and activated states. It also correlated Iyengar yoga training with right hemispheric frontal activation, including areas involved in attention.

An important aspect related to yoga postures in the context of psychiatric disorders is their potential effect on several neurotransmitter systems. Gamma-aminobutyric acid (GABA) is the principal inhibitory neurotransmitter in the CNS and is synthesized within 15–20% of cortical neurons (Markram *et al.*, 2004; Buzsaki, Kaila & Raichle, 2007). Once released into the synaptic cleft, GABA binds to two main GABA receptor subtypes on the postsynaptic membrane, $GABA_A$ and $GABA_{B,}$ often resulting in neuronal hyperpolarization and inhibition. High-affinity GABA transporters (GAT) clear synaptic GABA. Altered GABAergic neurotransmission has been implicated in a number of psychiatric disorders.

Over the last thirty years, multiple lines of evidence demonstrate a low GABAergic state in mood disorders (Brambilla, Perez, Barale, Schettini, & Soares, 2003; Maciag *et al.*, 2010; Kasa *et al.*, 1982). Treatments found to be effective for these disorders increase GABA levels including ECT (Sanacora *et al.*, 2003), tricyclic antidepressants (Martin *et al.*, 1989), SSRIs (Sanacora, Mason, Rothman, & Krystal, 2002; Bhagwagar *et al.*, 2004), lithium (Vargas, Tannhauser, & Barros, 1998), and valproate (Loscher, 1989). Moreover, specific genetic polymorphisms of the $GABA_A$ δ receptor subunit associate with childhood-onset mood disorders (COMD) (Feng *et al.*, 2010). A small cross-sectional study examining children and adolescents (aged 9–17) with major depressive disorder found increased cortical excitability compared to healthy controls (Croarkin *et al.*, 2013). This supports a model of excitatory dysfunction in mood disorders across the age spectrum.

There is evidence that a low GABAergic state also plays a role in the pathogenesis of anxiety disorders (Olivier, Vinkers, & Olivier 2013). Patients with panic disorder (PD), post-traumatic stress disorder (PTSD) and generalized anxiety disorder (GAD) have reduced benzodiazepine binding in various brain regions compared to controls (Tiihonen *et al.*, 1996 Malizia *et al.*, 1998; Bremner, Innis, Southwick, *et al.*, 2000; Bremner, Innis, White, *et al.*, 2000). Moreover, patients with panic disorder have lower levels of cortical GABA as measured by magnetic resonance spectroscopy (MRS) compared to healthy controls (Goddard *et al.*, 2001). Similarly, a small pilot study of patients with social anxiety disorder (SAD) found support for impaired GABAergic function and overactive glutamatergic activity (Pollack. Jensen, Simon, Kaufman, & Renshaw, 2008). Genetic polymorphisms in the GABRA2 gene interact with early childhood trauma and increase the risk of PTSD (Nelson *et al.*, 2009). These studies support the idea that anxiety disorders are associated with low GABAergic states or excitatory dysfunction. Further clinical studies with adolescents are warranted.

ADHD is a developmental disorder characterized by a deficit in behavioral inhibition. GABA regulates motor control and impulsivity in healthy adults (Boy *et al.* 2010; Boy *et al.*, 2011; Sumner, Edden, Bompas, Evans, & Singh, 2010). In a cross-sectional study using MRS, GABA concentrations were found to be significantly reduced in ADHD children (aged 8–12) compared to typically developing subjects (Edden, Crocetti, Zhu, Gilbert, & Mostofsky, 2012). These results suggest ADHD is associated with a GABAergic deficit, which may contribute to disease pathogenesis.

A systematic review of the literature finds evidence to support the role of yoga in treating symptoms of mood disorders, anxiety disorders and ADHD (Balasubramaniam *et al.* 2012). Given that low GABAergic activity or excitatory dysfunction is a feature of many of these disorders, one group hypothesized that yoga postures might decrease symptoms in these disorders by increasing brain GABA levels (Streeter *et al.*, 2007). MRS can be utilized to non-invasively detect changes in endogenous GABA levels (Puts & Edden, 2012). The study compared changes in brain GABA levels following a sixty-minute yoga posture session in established yoga practitioners to changes following a sixty-minute reading session in a control group. The yoga session was associated with a 27% (p= 0.018) increase in GABA levels while the control group did not demonstrate any changes. A follow-up randomized control study of yoga-naïve subjects compared the effects of a 12-week yoga asana intervention to a metabolically matched walking intervention on symptoms of mood, anxiety and thalamic GABA levels (Streeter *et al.*, 2010). The yoga asana intervention was associated with greater improvements in mood and anxiety, which correlated with increased thalamic GABA levels. These studies were limited by small sample sizes and excluded individuals with psychiatric disorders.

Future neuroimaging studies assessing the impact of yoga interventions on adolescents with psychiatric disorders may first focus on adolescents with mood disorders, anxiety disorders and ADHD. Assessing changes to brain activity following standardized yoga training programs will be critical in identifying brain regions affected by these mind-body practices. Following yoga training, fMRI can identify changes in brain structure and function with high spatial resolution. MRS can determine whether yoga poses can increase GABA levels in adolescents with psychiatric disorders. The use of SPECT and PET can determine whether yoga poses can affect levels of other neurotransmitters and correlate these changes with anatomical regions. Future studies could also look at different yoga posture sequences to determine their variable effects on brain activity. Concurrent clinical assessments can determine whether specific neuromodulatory effects correlate with symptomatic improvements.

Yoga Breathing Techniques

Yoga breathing techniques are self-regulatory mind-body practices that involve the voluntary control of different aspects of respiration including the length, frequency, intensity, pattern and directionality of the breath. Yoga breathing or *pranayama*, involves manipulation of *prana*, the Sanskrit term for life-force energy also known as *chi* in Chinese traditions. Yoga breathing encompasses a number of techniques such as paced breathing (Udo *et al.*, 2013), resonance breathing, ujjayi breathing (Telles & Desiraju, 1991), unilateral or alternate nostril breathing (Sinha, Deepak, & Gusain, 2013), kapalabhati pranayama (Telles, Singh, & Balkrishna, 2012), Sudarshan Kriya (Zope & Zope, 2013) among many others. While initially passed down within specific teacher-to-student lineages, many of these techniques have spread widely to many regions of the world (Telles & Singh, 2013).

Preclinical studies documenting the effects of stress on adolescence (Eiland & Romeo, 2013) show that chronic stress can induce structural changes in the CNS (Oztan Aydin, & Isgor, 2001; Radley *et al.*, 2005) and predispose to depressive behaviors (Isgor, Kabbaj, Akil, & Watson, 2004). Interventions featuring yoga breathing techniques can mitigate stress (Kjellgern, Bood, Axellson, Norlander and Saatcioglu 2007; Pilkington, Kirkwood, Rampes, & Richardson, 2005; Sharma, Sen, Singh, Bhardwaj, Kochupillai 2003; Vedamurthachar *et al.*, 2006), rapidly alter gene expression (Qu, Olafsrud, Meza-Zepeda, & Saatcioglu, 2013), modulate autonomic nervous system activity (Telles, Maharana, Balrana, & Balkrishna, 2011; Telles, Singh, & Balkrishna, 2011) and improve cognitive performance (Telles, Joshi, & Prasoon, 2012). Theoretical models propose that these practices alter the interoceptive messages from the respiratory system to higher CNS centers via modulation of vagal activity resulting in shifts in attention, perception, emotional regulation and behavior (Streeter, Gerbarg, Saper, Ciraulo, & Brown, 2012; Brown, Gerbarg, & Muench, 2013). Initial clinical studies demonstrate that interventions featuring yoga breathing techniques can relieve symptoms of major depressive disorder, generalized anxiety disorder, post-traumatic stress disorder, panic disorder and obsessive-compulsive disorder (Brown, Gerbarg, & Muench, 2013).

Initial brain imaging studies have utilized EEG to measure the effects of different yoga breathing techniques on brain activity (Vialatte, Bakardjian, Prasad, & Cichocki, 2009). Bhramari Pranayam is a yogic breathing technique that involves placing the hands in specialized positions resulting in ear canal closure and the production of a buzzing sound with nasal exhalation. An EEG study showed that this technique can induce a localized, high frequency gamma wave activity over the left tempero-parietal lobe that remains stable during and for several minutes after the technique (Vialatte *et al*., 2009). Evoked potential (EP) and Event-related potential (ERP) techniques have also been employed to study the neurobiological effects of yoga breathing. These techniques involve the averaging of EEG activity time-locked to the presentation of various stimuli. Auditory evoked potentials recorded during ujjayi breathing (resistance breathing) resulted in improved transmission of auditory information at the level of the thalamus (Telles, Joseph, Venkatesh, & Desiraju, 1993). Right unilateral nostril breathing showed EP changes localized to the right cerebral and subcortical regions (Raghuraj & Telles, 2004). Following high-frequency yogic breathing (HFYB), there was a significant improvement in the P300 auditory oddball task and better performance in a letter cancellation task suggesting an improvement in attention performance (Telles, Raghuraj, Arankalle, & Naveen, 2008; Joshi & Telles, 2009). A functional near-infrared spectroscopy study showed increased deoxyhemoglobin over the dorsolateral prefrontal cortex following HFYB, suggesting activation in a region associated with attention and executive function (Telles *et al*., 2011).

Future neuroimaging studies assessing the impact of yoga breathing interventions on adolescent psychiatric disorders may first focus on the effects on adolescents with mood disorders, anxiety disorders, substance abuse disorders and ADHD. The application of functional neuroimaging studies will be critical in identifying the state and trait effects of these techniques with greater spatiotemporal resolution. Sudarshan Kriya Yoga (SKY), a yogic breathing technique that involves controlled, rhythmic breathing at various frequencies induces a state of restful awareness (Zope & Zope, 2013). Initial clinical studies in adults have demonstrated that this technique can reduce symptoms of major depressive disorder and anxiety disorders (Brown, Gerbarg & Muench, 2013). A study of 445 adolescents (ages 14–18) treated with a multi-component yoga program featuring SKY demonstrated significantly reduced measures of impulsivity as compared to a control group (Ghahremani *et al*., 2013). What role this yoga breathing technique and others may have in alleviating symptoms of adolescent psychiatric disorders remains to be determined. How these techniques modulate the structure and function of the adolescent brain is an important area of investigation.

Meditation

Meditation includes a broad number of mind-body techniques that promote self- awareness and self-regulation. Many meditation techniques can be conceptualized as falling along a continuum between two categories– focused attention (FA) meditation and open monitoring (OM) meditation. FA meditation involves bringing one's awareness on a pre-specified sound, image or sensation as an anchoring point. An emphasis is placed on learning to identify and disengage from mental distractions and return attention onto the primary object. Overtime, practitioners develop the ability to effortlessly sustain awareness without distractions. Open monitoring meditation involves maintaining a state of unattached observation despite ongoing mental activity without focus on a specific object. A central aim of this practice is to develop a reflexive awareness of mental activity (Lutz, Slagter, Dunne, & Davidson, 2008). Specific meditation techniques can include features from both categories.

The study of meditation interventions for psychiatric disorders is an expanding area of interest. In adults, meditation interventions have been shown to improve outcomes in depression (Teasdale *et al.*, 2000), anxiety disorders (Evans *et al.*, 2008; Goldin & Gross, 2010; Kearney *et al.*, 2013), substance abuse disorders (Bowen *et al.*, 2009, Brewer *et al.*, 2009) and pain syndromes (Kabat-Zinn, Lipworth, & Burney, 1985). In adolescents, a review of 16 clinical studies (including 11 RCTs) highlighted effectiveness of meditation interventions in anxiety, depression and ADHD (Black, Milam, & Sussman, 2009). Small to medium effects sizes were noted across the studies. These studies were limited by small sample size, diversity of participants and study-design factors.

Early imaging studies of meditation practices made substantial use of EEG (Banquet, 1973; Hirai, 1974; Hebert & Lehmann, 1977; Corby, Roth, Zarcone, & Kopell, 1978). Over the last fifty years, a large number of studies have looked at the effects of different meditation practices on adult brain EEG activity (Cahn & Polich 2006). These studies demonstrated increased alpha (8–12 Hz) activity in meditators compared to non-meditators while meditating and at rest (Golocheikine 2001, Aftanas & Golocheikine 2005). Combined EEG and fMRI-PET studies correlated increased alpha power to changes in blood flow in the inferior frontal, cingulate, superior temporal and occipital cortices (Goldman, Stern, Engel, & Cohen, 2002). In addition, a number of EEG studies reported increased theta (4–8 Hz) activity during meditation, which is associated with attention-requiring tasks (Aftanas & Golocheikine 2001, Aftanas & Golocheikine 2002). Increased frontal theta activity is believed to be generated by the anterior cingulate cortex or the dorsolateral prefrontal cortex (Asada, Fukuda, Tsunoda, Yamaguchi, & Tonoike, 1999; Ishii *et al.*, 1999). Differences in practitioner experience, meditation techniques and study paradigms likely contributed to differences in measured EEG activity between studies (Cahn & Polich, 2006).

Neuroimaging studies have begun to identify key brain regions affected by meditation practices with greater spatial and temporal resolution. These regions can serve as a focus in determining the neurobiological effects of these practices on adolescents with psychiatric disorders. The Prefrontal Cortex (PFC) is a region of the brain with extensive connectivity with other cortical, subcortical and brain stem regions and is involved in cognition, attention and emotion (Miller & Cohen, 2001). Abnormal PFC activity has been linked to a number of psychiatric disorders (Koelkebeck *et al.*, 2013; Britton *et al.*, 2013; Schulte-Rüther *et al.*, 2013). Brain imaging studies suggest that volitional tasks that require sustained attention initiate PFC activity (Ingvar 1994, Pardo, Fox & Raichle, 1991). A SPECT study of experienced Tibetan Buddhist meditators (n=8) demonstrated increased activity in the dorsolateral prefrontal cortex (DLPFC) during meditation suggesting that activation in this region is associated with volitional aspects of meditation. This study also found activation of the cingulate gyrus, thalamus, orbital and inferior frontal cortices during meditation as compared to baseline states (Newberg *et al.*, 2001). Additional studies assessing volitional meditation practices have confirmed increased activity in prefrontal cortical areas (Hölzel *et al.*, 2007; Engström, Pihlsgård, Lundberg, P., & Söderfeldt, 2010).

The anterior cingulate cortex (ACC) is critical for self-regulation of attention (Bush, Luu, & Posner, 2000, Ochsner *et al.*, 2001), goal-directed behavior (Dosenbach *et al.*, 2007) and emotional behavior (Gasoquoine, 2013). Abnormal ACC activity has been linked to psychiatric disorders including depression, obsessive-compulsive disorder, chronic pain, substance abuse and schizophrenia (Gasoquoine, 2013). In addition, recent neuroimaging of adolescents with mood and anxiety disorders demonstrate aberrant ACC activity and functional connectivity compared to control groups (Connolly *et al.*, 2013; Britton *et al.*, 2013; Cisler Steele, Smitherman, Lenow, & Kilts, 2013). The cingulate gyrus appears to work with the PFC in tasks involving attention (Vogt, Finch, & Olson, 1992). A fMRI study of Kundalini meditators (n=5) with at least four years experience demonstrated activation in the ACC, hippocampal and parahippocampal formation, putamen and the midbrain while in meditation compared to a control state (Lazar *et al.*, 2000). The ACC was also activated during meditation in a SPECT study of experienced Tibetan Buddhist meditators (Newberg *et al.*, 2001), a fMRI study of both experienced and novice meditators (Brefczynski-Lewis *et al.*, 2007) and a fMRI study of Vipassana meditators (Hölzel *et al.*, 2007). Short-term integrative body-mind training (IBMT), a form of mindfulness meditation, alters neural activity in the ACC and improves connectivity of the ACC to other brain regions (Tang *et al.*, 2007; 2010; Tang, Lu, Fan, Yang, & Posner, 2012). This suggests that meditation practices can induce both short term and long-term changes in the ACC.

The insular cortex (IC), a small hidden region of cortex within the lateral sulcus, is implicated in an extensive number of cognitive functions (Nieuwenhuys, 2012) and is believed to represent the neural correlate of awareness (Craig, 2009). The IC functions with the PFC and ACC as part of an interconnected network involved in the regulation of mental activity and behavior (Cole & Schneider 2007). Furthermore, the anterior insula (AIC) is implicated in social emotions such as empathy and compassion suggesting its involvement in awareness of others (Lamm & Singer, 2010). Abnormalities in AIC structure and function has been noted in psychiatric disorders including schizophrenia (Takahasi *et al.*, 2005), conduct disorder (Sterzer, Stadler, Poustka, & Kleinschmidt, 2007), drug addiction (Naqvi & Bechara, 2010) and elevated trait anxiety (Simmons, Strigo, Matthews, Paulus, & Stein, 2006). An fMRI study of experienced practitioners of insight meditation showed that regular practice of meditation was associated with thicker gray matter in the right AIC compared to a control group (Lazar *et al.*, 2005). A study of experienced Vipassana meditators showed greater gray matter concentration in the regions typically activated during meditation including the right AIC (Hölzel *et al.*, 2008). Furthermore, a study of college volunteers found a positive association between tendency for mindfulness (as measured by the Five Facet Mindfulness Questionnaire, FFMQ) and gray matter volume in the right anterior insula (Murakami *et al.*, 2012).

The hippocampus, a limbic system structure located within the medial temporal lobe, is essential in episodic memory and spatial representations (Scoville & Milner, 1957; Eichenbaum Dudchenko, Wood, Shapiro, & Tanila, 1999; Burgess Maguire, & O'Keefe, 2002). Abnormalities in hippocampal structure and function have been described in psychiatric disorders such as post-traumatic stress disorder (Karl *et al.*, 2006), depression (Kempton *et al.*, 2011) and schizophrenia (Wright *et al.*, 2000). Childhood maltreatment is also associated with altered hippocampal structure in adolescents (Whittle *et al.*, 2013). Meditation activates the hippocampus (Lou *et al.*, 1999; Lazar *et al.*, 2000; Hölzel *et al.*, 2007; Engström *et al.*, 2010; Kalyani *et al.*, 2011). Meditation practitioners also demonstrate larger hippocampal total volume (Luders, Kurth, Toga, Narr, & Gaser, 2013), parahippocampal gray matter volume (Leung *et al.*, 2013) as well as enhanced fiber integrity in pathways connecting to the hippocampus (Luders, Clark, Narr, & Toga, 2011).

While neuroimaging studies have identified common areas impacted by mind-body practices, different meditation practices can also result in different brain activity profiles. A PET study of guided meditation revealed different regional activation profiles for different types of guided meditation relative to control conditions (Lou *et al.*, 1999). An fMRI study comparing experienced practitioners of Kundalini (a type of FA meditation) or Vipassana (a type of OM meditation) revealed similar but non-overlapping cortical and sub-cortical activation during meditation compared to control conditions (Lazar *et al.*, 2003). Moreover, the length of time during a single meditation session can affect observed brain activity profiles (Lazar *et al.*, 2005). The comparative effects of different meditation practices, including their respective short-term and long-term effects remains to be determined.

Future neuroimaging studies assessing the impact of meditation interventions on adolescents with psychiatric disorders may first focus on adolescents with mood disorders, anxiety disorders and substance abuse disorders. Whereas interventions involving yoga postures or breathing techniques involve movement and activity; meditation interventions often do not and may initially be more challenging for adolescents. For this reason, guided meditation techniques may be needed especially for novice practitioners or early adolescents. Moreover, studies looking at the effects of different meditation techniques, including both FA and OM practices, will help determine which ones may be most compatible for adolescents with different psychiatric disorders. Given that functional neuroimaging studies in adults have identified key brain areas affected by these practices, these regions may serve as a focus in determining the impact of these practices on adolescents. Studies looking at the effects of these practices as clinical treatments will better allow for correlation of functional changes with clinical symptoms.

CONCLUSIONS

Mind-body practices offer novel therapeutic approaches for adolescents with psychiatric disorders. We have highlighted the evidence by which a subset of these practices can affect

CNS structure and function. Clinical neuroimaging studies will be critical in understanding how different practices affect disease pathogenesis and symptomatology in adolescents. Studies utilizing adequate sample sizes, standardized interventions, tailored imaging modalities and concomitant clinical assessments will provide more robust and relevant data. Neuroimaging of mind-body practices on adolescents with psychiatric disorders will certainly be an open and exciting area of investigation.

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Biographies

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