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Cortical thickness, mental absorption and meditative practice: Possible implications for disorders of attention

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ABSTRACT

Mental training techniques rooted in meditation are associated with attention improvement, increased activation and cortical thickening of attention/executive-related brain areas. Interestingly, attention-deficit/hyperactivity disorder (ADHD) is associated with behavioural deficits, hypo-activation and cortical thinning of similar networks. This study assessed the relationship between prior meditative training, attentional absorption, and cortical thickness. Grey matter thickness was measured in 18 meditators and 18 controls. Subjective reports of attentional absorption were modestly higher in meditators and across the entire sample correlated positively with cortical thickness in several regions corresponding to cingulo-fronto-parietal attention networks. Within these regions the meditation group had greater cortical thickness which was positively related to the extent of prior training. Evidence suggesting that meditative practice activates these cortical areas, improves attention and may ameliorate symptoms of ADHD by targeting vulnerable brain regions is discussed.

1. Introduction

The term meditation refers to a family of mental exercises aimed at enhancing the practitioner's ability to attain and maintain a target state, often attentional or affective in nature (e.g. sustained attention or a state of compassion) (Lutz et al., 2008). Although often viewed as spiritual, many such techniques are, for the most part, completely secular and are gaining recognition as clinically relevant (Chiesa and Serretti, 2010). Functional imaging studies have reported that meditating in an MRI scanner activates attention-related cortices such as the anterior cingulate cortex (ACC) and frontoparietal networks (Brefczynski-Lewis et al., 2007; Manna et al., 2010). A number of studies have also reported regional grey matter differences between individuals who meditate and those who do not (Pagnoni and Cekic, 2007; Grant et al., 2010; Holzel et al., 2008, 2010; Lazar et al., 2005; Luders et al., 2009; Vestergaard-Poulsen et al., 2009). In all cases meditators have been found to have more grey matter, in specific regions, than non-meditators. Further, several of these effects have involved regions implicated in attention/executive processing (e.g. ACC, superior and middle frontal gyri and orbitofrontal regions) (Grant et al., 2010; Holzel et al., 2008; Lazar et al., 2005; Luders et al., 2009; Vestergaard-Poulsen et al., 2009). Behaviourally, practitioners of meditation have been shown to perform significantly better on attention and executive function tasks such as the Attention Network Task (ANT), the Stroop Task, attentional blink, Symbol Digit Modalities Test, verbal fluency, and the n-back task (Prakash et al., 2010; Zeidan et al., 2010; Tang et al., 2007; van Leeuwen et al., 2009). While it is certainly possible that there are pre-existing differences in meditators, there is now evidence from longitudinal studies that improvement in attention performance (Lutz et al., 2009; Tang et al., 2007; Zeidan et al., 2010) and increases in grey matter (Holzel et al., 2010, 2011) occur over the course of meditative training. Importantly, preliminary evidence suggests that meditative training may be an effective adjunct treatment for patients suffering from attention-deficit/hyperactivity disorder

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(ADHD). Following an 8 week meditation program, improvements were observed on the ANT, the Stroop Task and the Trail Making Test, as well as in self-reported ADHD symptoms (Zylowska et al., 2008).

In the literature there are parallels between meditative practice and ADHD at several levels. ADHD is characterized by inattention, impulsiveness and hyperactivity. Neuroimaging studies have strongly implicated the fronto-striato-thalamic circuitry in the pathophysiology of this disorder (Bush et al., 2005; Seidman et al., 2005). Functional MRI studies of ADHD have repeatedly shown hypo-activation of the anterior cingulate, dorsolateral and inferior prefrontal cortices as well as the basal ganglia, thalamus, and parietal cortices (Dickstein et al., 2006). Morphometric brain imaging studies have likewise found structural differences, such as cortical thinning, in many of these same areas, in populations of both adults and children with ADHD (Shaw and Rabin, 2009; Seidman et al., 2005). Furthermore, cortical thinning of a subset of these regions has been associated with poor clinical outcome 5 years later (Shaw et al., 2006). While ADHD and cortical thickness have substantial heritability (Durston et al., 2004; Forero et al., 2009; Rimol et al., 2010), morphometric longitudinal studies suggest regional grey matter may also vary as a function of training and performance (Draganski and May, 2008). One particularly notable study found that training naïve participants to juggle resulted in grey matter density increases, concomitant with performance gains, in brain regions previously implicated in processing visual motion (Draganski et al., 2004). Findings such as these suggest that, despite the high likelihood of a genetic predisposition, it may be possible to combat the functional deficits of a disorder like ADHD by targeting the vulnerable cortices with a suitable training intervention. As discussed above, one potential candidate to bolster both grey matter thickness and attention/executive function is meditative practice.

The present study provides initial evidence that cortical, attention-related brain regions, that appear to be sensitive to thinning in ADHD, are related to an experiential measure of attention and are thicker in practitioners of meditation. The analysis took place over two phases. We were first interested in testing the hypothesis that an experiential measure of attention would (a) differ between meditators and controls and (b) relate to grey matter thickness in attention-related brain regions. With evidence to support these hypotheses a post hoc analysis was performed examining the physical overlap between the present results and a report of grey matter thinning observed in a study of ADHD (Shaw et al., 2006).

2. Materials and methods

2.1. Participants

Eighteen Zen meditators (14 male/4 female) were recruited, that had been practicing between 2 and 30 years and had accumulated a minimum of 1000 h of lifetime practice (mean = 6406, SD = 1955, min = 1010, max = 39,439). Eighteen age- and gender-matched control subjects (14 males/4 female) were subsequently recruited. All participants provided informed written consent, approved by a local Ethics Committee (CMER-RNQ 05-06-020). Meditators were recruited from meditation centres in the Montréal area and had an average age of 37.1 yrs (SD = 10.9, range 22–57) and did not differ from controls (average age 37.9 yrs, SD = 10.5, range = 21–55). With the exception of one monk and one nun, all participants were lay practitioners. Control subjects were also from Montreal and had no previous experience with meditation or yoga.

2.2. Self report measures

Participants' trait attentional absorption was measured with the 34-item Tellegen Absorption Scale (TAS), a True/False subscale of the Multidimensional Personality Questionnaire (Tellegen and Atkinson, 1974). The TAS measures one's tendency for "episodes of 'total' attention that fully engage one's representational (i.e. perceptual, enactive, imaginative and ideational) resources" (Tellegen and Atkinson, 1974). Two previous studies have reported higher absorption scores for meditators using this scale (Davidson et al., 1976; Holzel and Ott, 2006), the later also finding correlations between absorption and meditation depth and mindfulness. To further examine this connection we also administered the Five Facet Mindfulness Questionnaire (FFMQ) (Baer et al., 2008). The FFMQ measures skills associated with the construct of mindfulness, namely, the tendencies to be observant (OBS), nonjudgmental (NJ) and nonreactive (NR) toward one's experiences as well as aware in the present moment (AWARE). A meditation experience questionnaire was administered sampling years, hours and frequency (days per week) of lifetime practice.

2.3. MRI acquisition and cortical thickness measurement

A single high-resolution (voxel size = 1 mm^3) T-1 weighted structural MRI image (MP-RAGE) was acquired for each participant on a 3 Tesla Siemens Trio MR scanner (Siemens, Erlangen, Germany). An automated cortical thickness analysis pipeline was employed (Montréal Neurological Institute (MNI)) (Lerch and Evans, 2005). Images were linearly registered, transformed into MNI space and corrected for non-uniformity artifacts (Collins et al., 1994; Sled et al., 1998). Images were then segmented into grey and white matter and cerebrospinal fluid (Zijdenbos et al., 2002). Grey and white matter surfaces were produced using constrained Laplacian anatomic segmentation using proximities (Kim et al., 2005). A surface deformation algorithm (MacDonald et al., 2000) then expanded the white matter surfaces to the surface boundary between grey matter and cerebrospinal fluid, allowing the calculation of cortical thickness. Thickness data were smoothed following surface curvature using a blurring kernel of 20 mm.

2.4. Statistical analyses

Questionnaires were analysed with independent sample *t*-tests and correlated with cortical thickness estimates using Pearson correlations in SPSS. Cortical thickness data were analysed with the general linear model (GLM), controlling for age and gender, in SurfStat (www.stat.uchicago.edu/~worsley/surfstat) and with additional multiple linear regressions in SPSS. Given our explicitly unidirectional hypotheses, 1-tailed tests were used for all analyses.

Estimates of cortical thickness at 81,924 vertices covering the entire cortical mantle were regressed on attentional absorption scores across the whole sample. For this full brain analysis the significance threshold was set to $p < 0.05$, corrected for multiple comparisons using the random-field theory (Worsley et al., 1996) to strictly control type I error. Regions meeting this strict criterion (i.e. showing a relation between absorption and cortical thickness) were then defined as absorption-ROIs. Mean thickness within each ROI was computed. These values were compared between groups and correlated with meditation experience in SPSS. To examine the proximity of the present results with respect to previously reported structural findings in ADHD, MNI coordinates were acquired from Shaw et al. (2006). In the original study these regions exhibited cortical thinning in patients with ADHD and included the right superior medial PFC, temporal pole, left superior medial PFC, precentral gyrus and left medial PFC/cingulate. Circular ROIs with a 15 mm radius were created using SurfStat and compared visually by overlaying the respective maps. Euclidian distance between the peak coordinates from the two studies was also computed.

Finally, we performed a full brain exploratory search for each of the FFMQ subscales as well as regressions with mean cortical thickness within absorption-ROIs. The main effects of group and meditation experience, at the full brain level, have been reported as part of the original study from which this data was acquired, investigating the structural correlates of pain sensitivity (Grant et al., 2010).

3. Results

3.1. Self report measures

Scores for all questionnaires were normally distributed based on the Shapiro–Wilk test. Meditators scored slightly higher than controls on the TAS ($t(34) = 1.91$, $p < 0.05$, $d = 0.64$) indicating a tendency to be more absorbed in their experience. Meditators also scored higher than controls on three of the subscales of the FFMQ (OBS: $t(34) = 3.30$, $p < 0.01$, $d = 1.09$, NR: $t(34) = 3.64$, $p < 0.001$, $d = 1.20$ and AWARE: $t(34) = 2.03$, $p < 0.05$, $d = 0.67$) indicating a greater tendency to be mindful. Across the entire sample TAS scores were positively correlated with OBS scores ($r(34) = 0.39$, $p < 0.01$) and NR scores ($r(34) = 0.32$, $p < 0.05$) suggesting that absorption and mindfulness may have shared experiential dimensions. Absorption scores in the meditation group were predicted by the number of days of practice per week ($r(16) = 0.41$, $p < 0.05$) while years of practice predicted NR scores ($r(16) = 0.47$, $p < 0.05$) with more experience being associated with less reactivity.