Developmental Cognitive Neuroscience 14 (2015) 62–70

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn

Dispositional mindfulness is predicted by structural development of the insula during late adolescence

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ARTICLE INFO

Article history:
Received 16 November 2014
Received in revised form 3 July 2015
Accepted 5 July 2015
Available online 9 July 2015

Keywords:
Adolescence
Brain development
Mindfulness
Insula
Self-regulation
Intelligence

ABSTRACT

Adolescence is a critical period of development, in which the increasing social and cognitive demands of independence need to be met by enhanced self-regulatory abilities. The cultivation of mindfulness has been associated with improved self-regulation in adult populations, and it is theorized that one neurodevelopmental mechanism that supports this capacity is the development of the prefrontal cortex. The current study examined the neurodevelopmental mechanisms associated with dispositional mindfulness in adolescence. Using a longitudinal within-persons design, 82 participants underwent structural magnetic resonance imaging (MRI) assessments at approximately ages 16 and 19, and also completed self-reported measurements of mindfulness at age 19. It was hypothesized that adolescents who demonstrated greater thinning of frontal cortical regions between the age of 16 and 19 would exhibit higher dispositional mindfulness levels at age 19. Results indicated that, contrary to predictions, adolescents with higher levels of mindfulness demonstrated less thinning in the left anterior insula. By contrast, higher IQ was associated with greater thinning of the right caudal middle frontal and right superior frontal regions. The involvement of insula development in mindfulness is consistent with a direct role for this structure in managing self-regulation, and in doing so concords with recent models of self-referential interoceptive awareness.

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Over the adolescent period, teens spend increasingly less time under direct adult supervision (Turner et al., 1993). Given this burgeoning independence, an essential ability to be learnt is self-regulation – a skill set that involves the cultivation of behavioural self-control, the capacity to cope with negative emotions, and the ability to maintain goal-directed behaviour (Blakemore and Robbins, 2012; Spear, 2010). Failure of self-regulation during the adolescent period can lead to maladaptive behaviours such as excessive risk-taking, and poor mental health outcomes such as depression (Abela and Hankin, 2011; Casey et al., 2008).

The dispositional trait of mindfulness, which reflects the tendency towards present-moment awareness, has been associated with positive psychological functioning, including enhanced self-regulation (Brown and Ryan, 2003; Raes and Williams, 2010). Based on the theoretical accounts introduced by Kabat-Zinn (1982), a two-construct model of dispositional mindfulness has been proposed, capturing individual differences in (1) attention and awareness and (2) acceptance and non-reactivity (Bishop et al., 2006). However, Brown and Ryan (2003) have suggested attention to the moment to be the single most critical construct of mindfulness, subsuming acceptance and non-reactivity. Higher levels of dispositional mindfulness are thought to facilitate self-regulation, because they are permissive of present-moment focussed states of consciousness that allow the mind to break free from maladaptive patterns of thinking and behaviour (Chambers et al., 2009; Kumar et al., 2008). Further, dispositional mindfulness in adolescents has been shown to predict recovery from depression (Chambers et al., 2014). Higher levels of dispositional mindfulness have been measured as a positive outcome of mindfulness-based intervention (MBI) participation – which often involves mindfulness-based meditation practice (Baer, 2003). However, given the complexity of such interventions, the exact mechanisms that produce this outcome are still not understood (Nyklíček and Kuijpers, 2008; Shapiro et al.,

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http://dx.doi.org/10.1016/j.dcn.2015.07.001
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2008). Given that dispositional mindfulness can be assessed as a trait within normal populations without specific training, including adolescent populations, research into the emergence of mindfulness over development provides an alternative perspective from which to investigate the mechanisms that determine dispositional mindfulness.

The adolescent period is a unique time for the development of the brain, and specific patterns of maladaptive behaviour that reflect poor self-regulation during the adolescent period have been attributed to a normative imbalance between executive frontal and subcortical development. For example, risk-taking behaviours, such as dangerous driving, unsafe sex and drug abuse can have severe health consequences for teens (Arnett, 1992; Erickson and Chambers, 2007). “Dual systems” models of adolescent development have suggested that risk-taking behaviour becomes more prevalent when subcortical reward and affective systems such as the nucleus accumbens and amygdala develop quickly and early over the adolescent period, temporarily dominating the more slowly developing prefrontal executive systems (Casey et al., 2005; Gladwin et al., 2011; Somerville et al., 2010; Steinberg, 2010). The relative over-activity of the subcortical systems is thought to lead to increased sensation-seeking, impulsivity and emotional reactivity (Carlo et al., 2012; Cook et al., 2013; Pearson et al., 2013).

One of the ways in which mindfulness is theorized to aid self-regulation is via interactions that involve both frontal executive and subcortical brain systems. Creswell et al. (2007), for example, examined the link between mindfulness, executive function and subcortical brain region activity. Using a cross-sectional design, dispositional mindfulness was measured along with individual differences in neural response to affect-labelling during functional magnetic resonance imaging (fMRI). When other measures of psychological distress were controlled for, higher levels of dispositional mindfulness were associated with widespread PFC activation and left insula activation in synchrony with attenuated amygdala responses during affect-labelling. This apparent synergy between frontal cortical and subcortical regions was interpreted to reflect a potential neurobiological pathway through which higher levels of mindfulness could promote adaptation and improve frontal regulation of subcortical activity. However, without a longitudinal examination, such adaptive changes over time could not be confirmed. Further, this study was performed using a young adult, rather than an adolescent, sample, and analysis was restricted to fMRI.

Given the marked, and well-documented developmental changes in brain structure during adolescence, investigation of structural brain development, and its relation to the emergence of dispositional mindfulness during adolescence, is of interest. Cortical grey matter has been documented to follow an inverted U-shaped trajectory, with cortical thickness and volume peaking during childhood and then thinning over the adolescent period to early adulthood (Giedd et al., 2009; Shaw et al., 2006, 2008). While recent evidence points towards a normative peak in cortical thickness occurring well before the adolescent period (Tamnes et al., 2010a,b), examination of cortical development in relation to cognitive ability suggests that some individuals have delayed thickening. For example, in a cohort-sequential study, it was observed that the cortices of those with superior IQ underwent protracted and increased thickening into early adolescence, followed by greater thinning from mid- to late adolescence (Shaw et al., 2006). The delayed peaking in thickness and subsequently greater thinning within the higher IQ group were identified in the frontal cortical regions of the right frontal superior cortex and right medial prefrontal cortex as well as left temporal gyrus. Moreover, greater cortical thinning has also been associated with superior working memory capacity and inhibitory control in adolescents (Tamnes et al., 2010a,b, 2013). Given the association of superior cognitive ability with better functional outcomes, greater thinning over late adolescence could be considered to reflect more adaptive abilities. The above quasi-longitudinal designs reveal macro changes that would not necessarily be observed within a cross-sectional analysis. In particular, Shaw and colleagues' (2006) finding that the pattern of normative cortical thinning in the frontal cortices corresponds to quantifiable cognitive outcomes is both an example of a longitudinal design revealing a trend, as well as an invitation to examine how patterns of frontal cortical development over adolescence could vary with other constructs.

While the relationship between structural brain development during adolescence and the emergence of individual differences in dispositional mindfulness has not yet been examined in adolescent populations, MRI studies have examined related issues in adults subsequent to the developmental cortical thinning of adolescence. Increases in cortical thickness have been noted amongst long term meditators throughout frontal brain areas, in particular within the medial PFC, inferior PFC, superior frontal cortex, (Kang et al., 2013; Lazar et al., 2005; Vestergaard-Poulsen et al., 2009) and right orbito-frontal cortex (Luders et al., 2009). The insula has a particularly salient history in morphological studies of brain-mindfulness associations, with increased thickness of the right anterior insula associated with both increased number of years of meditation (Lazar et al., 2005), as well as dispositional mindfulness (Murakami et al., 2012). Similarly, increased grey matter concentration within the right anterior insula has been associated with greater meditation experience (Hölzel et al., 2008).

The insula is theorized to have a governing role in the maintenance of interoceptive awareness – the subjective awareness of internal body states (Bar-On et al., 2003; Craig, 2003). The anterior insula has been associated with subjective feeling states that may refer to interoceptive information; the posterior insula appears to be involved in conveying information of a homeostatic nature, including pressure and touch, and may also contain primary interoceptive representations (Craig, 2009). While interoceptive awareness is theorized to be associated with a largely automated regulatory mechanism, it may also inform higher-order cognitions that guide decision-making, particularly towards reduced-stress outcomes (Liotti et al., 2001; Craig, 2003; Critchley, 2005; Singer et al., 2009; Farb et al., 2013). Since it draws upon deliberate body scanning practices, mindfulness meditation may tap into the same (potentially) insular-centric mechanisms that underlie automated interoceptive awareness.

Given the cross-sectional nature of studies examining the association between mindfulness and brain structure to date, as well as the absence of standardized measurement of mindfulness across these studies, it is unclear to what extent brain structural change is associated with improved dispositional mindfulness levels, or indeed whether structural change may represent a developmental marker or precursor of trait mindfulness. Nevertheless, compelling meta-evidence is presented in these studies of the association between long-term practises that arguably enhance mindfulness (Nyklíček and Kuijpers, 2008), with changes in the structure of the PFC and insula cortex, which are areas of the brain implicated in capacities that undergo substantial development during adolescence. These capacities include emotional regulation, changes in self-perspective and conscious awareness (Creswell et al., 2007; Steinberg, 2005), which have been theorized to have corresponding neurological mechanisms that are related to mindful awareness (Hölzel et al., 2011; Modinos et al., 2010). Therefore, it is reasonable to speculate that development of the PFC and insula regions during adolescence might support the development of dispositional mindfulness.

Further, the unique neurobiological and developmental changes that occur over the adolescent period particularly mandate study of the relationship between brain development and mindfulness

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