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The association of gray matter volumes in the frontoparietal attention network with temperamental effortful control in young adults: A voxel-based morphometry study

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ABSTRACT

Structural MRI studies have identified a link between cortical maturation and temperamental effortful control (EC), which is a trait-like risk factor for psychopathology during adolescence. However, little research has explored the underlying neural basis of EC in adults. We aimed to examine the relationship between EC and brain structure in young adults. High-resolution T1-weighted images were acquired from 27 undergraduates who completed the Adult Temperament Questionnaire-short form. The data were analyzed with SPM8 using voxel-based morphometry (VBM). A priori region of interest (ROI) analyses indicated that EC was positively associated with gray matter volumes in brain regions that included the bilateral dorsolateral prefrontal cortex, the left supplementary motor area, the right orbitofrontal cortex, the left anterior cingulate cortex, and the left superior and inferior parietal lobes. These results suggest that temperamental EC in young adults is related to variations in gray matter volumes, particularly within the frontoparietal attention network, and yield insight into the relation between the vulnerability to psychopathology and the neurobiological basis of individual differences in temperamental EC.

1. Introduction

Temperament refers to endogenous basic tendencies of thoughts, emotions, and behaviors; is genetically influenced; and has been assumed to have a neurobiological basis (Whittle et al., 2006). Moreover, temperament is observable from infancy and exhibits marked stability across time and situations (Rothbart and Rueda, 2005). A great number of studies have shown that temperament is an important risk factor for the development of psychopathology (Nigg, 2006). Specifically, temperamental effortful control (EC) in children and adolescents prospectively predicts externalizing problems over time (Valiente et al., 2011). Among adults, poor EC has been associated with certain impulsive and externalizing behaviors, such as compulsive buying and binge eating (Müeller et al., 2012; Meehan et al., 2013), and negatively associated with subclinical depression and anxiety (Moriya and Tanno, 2008). Some recent studies have examined the underlying neural correlates of temperamental EC in adults (Posner and Rothbart, 2009; Kanske and Kotz, 2013). In the present study, we used voxel-based morphometry (VBM) to investigate the relationship between temperamental EC and brain structure in young adults.

Temperamental EC is a construct that consistently arises from factorial analyses of data collected with temperament questionnaires and describes an individual's capacity for self-regulation (Rothbart, 2007). More specifically, EC has been defined as the ability to shift and focus attention and to inhibit a dominant response and/or activate a subdominant response (Rothbart et al., 2011). Physiologically, temperamental EC has been reported to be associated with respiratory sinus arrhythmia (RSA) activity that reflects parasympathetic nervous system functioning in response to an attentional challenge (Beauchaine, 2001). For example, stronger RSA responses to challenges have been shown to be associated with better regulation (Santucci et al., 2008). RSA

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reactivity in such situations is considered to be direct indicator of EC because the reactivity of the heart rate is directly suppressed by neo-cortical action during attention control (Nigg, 2006).

As EC develops in the second or third years of life and beyond, children can deploy their attention more voluntarily, which allows them to take in additional sources of information and plan more efficient strategies for coping and thus regulate reactive emotions and actions (Nigg, 2006; Rothbart, 2007). For example, higher levels of EC in 2-year-old children are associated with greater P3a evoked potential responses to repeated novel sounds (Pesonen et al., 2010). In 4- to 8-year-old children, increased N2 amplitude of the evoked potential in response to incongruent flankers relative to congruent flankers during a cued flanker task is associated with less efficient executive attention (Buss et al., 2011). In 8- to 13-year-old children with attention-deficit/hyperactivity disorder (ADHD), lower EC is associated with reduced NoGo P3 amplitudes (Wiersema and Roeyers, 2009). Surprisingly, the ability to resolve conflict in the flanker task remains approximately the same from age seven to adulthood (Rothbart et al., 2007).

Furthermore, EC has been associated with the function of the executive attention network during cognitive tasks such as task switching, working memory tasks and sequential inhibition tasks (Posner and Rothbart, 2009; Posner, 2012). These tasks have been related to activity in the frontoparietal attention system (Ernst and Fudge, 2009). For example, functional neuroimaging studies suggest that dispositional EC is positively associated with activities in the prefrontal cortex (PFC) and posterior parietal regions (Kanske and Kotz, 2013; Kennis et al., 2013). Specifically, activation of the lateral orbitofrontal cortex (OFC) has been associated with response inhibition during cognitive interference tasks (Horn et al., 2003; Rolls and Grabenhorst, 2008). The dorsolateral prefrontal cortex (DLPFC) is involved in inhibitory control, working memory, and directing attention (Keehn et al., 2013). Moreover, the superior parietal lobe (SPL) is involved in voluntary shifts of attention (Corbetta et al., 2000; Berger et al., 2007), and the inferior parietal lobe (IPL) is implicated in response inhibition during the emotional stop signal task (Pawliczek et al., 2013). Recently, a near infrared spectroscopy study suggested that reduced levels of EC in 3- to 5-year-old normal children are associated with compromised small-world properties of the PFC network during the viewing of naturalistic stimuli (Fekete et al., 2014).

Structural magnetic resonance imaging (MRI) studies have revealed a link between EC and cortical maturation during adolescence (Nelson et al., 2005). For example, a leftward asymmetric pattern in the folding of the anterior cingulate cortex (ACC) is associated with greater levels of EC in young adolescents (Whittle et al., 2009). Changes in EC mediate the relationship between greater thinning of the left anterior cingulate cortex and improvements in socioemotional functioning, including reductions in psychopathological symptoms (Vijayakumara et al., 2014). Improvements in working memory are related to cortical volume reductions in the bilateral prefrontal and posterior parietal regions in children and adolescents (Tamnes et al., 2013). Specifically, greater EC abilities are associated with larger volumes of the left orbitofrontal cortex in healthy early adolescents (Whittle et al., 2008). Furthermore, adolescents with ADHD exhibit increased gray matter (GM) volumes in the left inferior parietal lobule (Brieber et al., 2007). Adults with deficits in attention (e.g., ADHD) exhibit decreased cortical thicknesses in the prefrontal, lateral IPL, and cingulate cortices (Rommelse et al., 2011). The elderly exhibited a positive correlation between EC score and GM volume in the supplemental motor area (SMA) (Sakai et al., 2012). Nevertheless, whether temperamental EC is associated with variations in the GM volumes of the frontoparietal attention network remains to be determined.

The present study used VBM to investigate the correlations between temperamental EC and neuroanatomical structures in young adult brains. As the numerous structural and functional imaging studies described above have shown, we hypothesized that the neural substrate of temperamental EC would be located in the frontoparietal attention system. To examine this hypothesis, we collected high-resolution MR images from 27 undergraduates who completed the EC subscale of the Adult Temperament Questionnaire (ATQ)-short form (Evans and Rothbart, 2007). First, we used the new segment tool and the DARTEL workflow implemented in SPM8 to preprocess the structural T1-weighted images. Next, the dorsolateral prefrontal cortex (DLPFC), supplementary motor area (SMA), orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), superior parietal lobe (SPL), and inferior parietal lobe (IPL) cortical regions were defined as a priori regions of interest (ROIs) based on previous results (Corbetta et al., 2000; Horn et al., 2003; Whittle et al., 2009; Rommelse et al., 2011; Sakai et al., 2012; Keehn et al., 2013; Pawliczek et al., 2013; Vijayakumara et al., 2014). We predicted that the EC scores would be positively associated with GM volumes in these cortical ROIs within the frontoparietal attention network.

2. Methods

2.1. Participants

The participants were 27 right-handed undergraduates (12 males and 15 females; age range: 18.19–23.42 years) from East China Normal University. All participants reported having normal or corrected-to-normal visual acuity. None of the participants had prior histories of neurological or psychiatric disorders nor had they experienced anxiety or depression within the last three months. All participants provided written informed consent and were paid approximately $15 for their participation. The relevant institutional ethical committee approved this research.

2.2. Adult Temperament Questionnaire

The participants completed the EC subscale of the ATQ-short form (Evans and Rothbart, 2007), which has satisfactory levels of internal consistency and has been validated in Chinese college-age samples (Lin et al., 2013). The EC scale consists of 19 items that are self-rated on a 7-point scale that ranges from 1 (extremely untrue) to 7 (extremely true). The items refer to the subscales of inhibitory control (e.g., I usually have trouble resisting my cravings for food, drinks, etc.), activation control (e.g., I can keep performing a task even when I would rather not do it), and attention control (e.g., It is very hard for me to focus my attention when I am distressed). The internal consistency of the EC scale in the present study was good (Cronbach's $\alpha = 0.85$). Because we were interested in the EC concept in this study, the three sub-constructs were not analyzed separately.

2.3. Image acquisition

The participants were scanned using a 3-T Trio Tim Magnetic Resonance Imaging scanner (Siemens Company) with a head coil gradient set at East China Normal University. Head movement was minimized using foam padding. A whole brain, high-resolution, three-dimensional, spoiled gradient recalled (SPGR), T1-weighted anatomical scan was acquired for each participant at a resolution of $1 \times 1 \times 1\ mm^3$ (repetition time = 1900 ms, echo time = 3.43 ms, flip angle = 7°, and field of view = $240 \times 240\ mm^2$, 200 contiguous sagittal slices).

2.4. Data processing

The DARTEL workflow approach is more accurate than the traditional VBM approach, is capable of generating a custom-made template from all subjects, and has successfully been used in both healthy subjects (Lu et al., 2014) and patients with brain disease (Liu et al., 2012; Ma et al., 2012). Therefore, structural T1-weighted image data were preprocessed using the DARTEL workflow approach of Statistical Parametric Mapping version 8 (SPM8, www.fil.ion.ucl.ac.uk/spm; Wellcome Department of Imaging Neuroscience, London) on the MATLAB R2010a (Mathworks, Natwick) platform. First, the origin of each participant's structural images was manually set as the anterior commissure. Second, the structural T1-weighted images were segmented into GM, white matter, and cerebrospinal fluid based on the new-segment tool implemented in SPM8, and both the native space and DARTEL-imported versions of the tissues were generated. Third, DARTEL was applied for spatial normalization (Ashburner, 2007). This procedure achieves more