Full Length Article

Functional brain correlates of motor response inhibition in children with developmental coordination disorder and attention deficit/hyperactivity disorder

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ABSTRACT

Motor impairment is associated with developmental coordination disorder (DCD), and to a lesser extent with attention-deficit/hyperactivity disorder (ADHD). Previous functional imaging studies investigated children with DCD or ADHD only; however, these two disorders co-occur in up to 50% of cases, suggesting that similar neural correlates are associated with these disorders. This study compared functional brain activation in children and adolescents (age range 8–17, M = 11.73, SD = 2.88) with DCD (n = 9), ADHD (n = 20), co-occurring DCD and ADHD (n = 18) and typically developing (TD) controls (n = 20). When compared to TD controls, children with co-occurring DCD/ADHD showed decreased activation during response inhibition in primary motor and sensory cortices. These findings suggest that children with co-occurring DCD and ADHD display significant functional changes in brain activation that could interfere with inhibition of erroneous motor responses. In contrast to previous studies, significant alterations in brain activation relative to TD controls, were not found in children with isolated DCD or ADHD. These findings highlight the importance of considering co-occurring disorders when investigating brain function in children with neurodevelopmental disorders.

1. Introduction

Developmental coordination disorder (DCD) and attention-deficit/hyperactivity disorder (ADHD) are neurodevelopmental disorders that are prevalent in paediatric populations with approximately 6% and 5% of children affected, respectively (American Psychiatric Association, 2013; Blank, Smits-Engelsman, Polatajko, & Wilson, 2011). DCD is characterized by significant impairments in motor coordination and/or planning that interfere with activities of daily living and negatively impact academic productivity,
vocational success, leisure and play (American Psychiatric Association, 2013; Zwicker, Missiuna, Harris, & Boyd, 2010). Individuals with ADHD display a persistent pattern of inattention and/or hyperactivity-impulsivity that interfere with normal functioning and development (American Psychiatric Association, 2013). DCD and ADHD have also been associated with increased risk of cognitive executive dysfunction (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Leonard, Bernardi, Hill, & Henry, 2015; Wilson et al., 2017), psychosocial problems (Cairney, Rigoli, & Piek, 2013; Cocks, Barton, & Donnelly, 2009; Dewey, Kaplan, Crawford, & Wilson, 2002; Rasmussen & Gillberg, 2000; Riley et al., 2006) and poorer academic functioning (Harpin, 2005; Kirby & Sugden, 2007; Zwicker, Harris, & Klassen, 2013).

Previous research has noted that children with DCD have issues with attention (Zwicker, Missiuna, Harris, & Boyd, 2012), and children with ADHD exhibit problems with motor functioning, amongst other domains (Crawford, Kaplan, & Dewey, 2006), and studies that have investigated the co-occurrence of DCD and ADHD in children suggest that it may be as high as 50% (Kaplan, Wilson, Dewey, & Crawford, 1998; Martin, Pick, & Hay, 2006; Moreno-De-Luca et al., 2013; Pieters et al., 2012; Williams, Omizzolo, Galea, & Vance, 2012). This high degree of comorbidity, along with the analogous symptomology, is consistent with the possibility of a shared or similar etiology. Elucidating the neural substrates of singular and co-occurring disorders is fundamental to identifying a unified understanding of poor motor and attention development and their eventual remediation.

Task-based functional magnetic resonance imaging (fMRI) has been used to increase our understanding of the neural correlates that underlie normal and atypical brain functioning. However, the field of functional imaging research in DCD is relatively new and a limited number of task-based fMRI studies have been conducted in children with this disorder. Further, these studies have used a wide range of fMRI task paradigms to examine differences between children’s brain function including Go/No-go tasks (Querne et al., 2008), visually guided tracking (Kashiwagi, Iwaki, Narumi, Tamai, & Suzuki, 2009), finger sequencing (Liciari et al., 2015; Reynolds et al., 2015), hand clenching (Liciari et al., 2015), visual motor reaction time (Debrabant, Gheyens, Caeyenberghs, Van Waelvelde, & Vingerhoets, 2013), trail-tracing (Zwicker, Missiuna, & Boyd, 2009; Zwicker, Missiuna, Harris, & Boyd, 2011) and motor sequence learning (Biotteau et al., 2017), which support differential brain activation in children with DCD in both loci and magnitude during performance of these tasks, particularly with respect to fronto-parietal and fronto-cerebellar motor circuitry (Fuelscher et al., 2018). However, activation patterns across these studies are inconsistent (Biotteau et al., 2016; Peters, Maathuis, & Hadders-Algra, 2013), which is likely a consequence of the heterogeneity of the participants (i.e., in many of the studies participants were not screened for co-occurring disorders), small sample sizes, and differences in the fMRI task paradigms (Biotteau et al., 2016; Fuelscher et al., 2018).

Numerous fMRI studies have also been conducted with individuals with ADHD (Booth et al., 2005; Cortese et al., 2012; Hart, Radua, Mataix-Col, & Rubia, 2012; O’Halloran et al., 2018; Smith, Taylor, Brammer, Toone, & Rubia, 2006; Suskauer et al., 2008). A recent meta-analysis suggests that in children with ADHD, the frontoparietal and ventral attention networks are hypoactivated; specifically the bilateral frontal, right parietal, and right temporal regions, as well as the bilateral putamen (Cortese et al., 2012). Hypoactivation was also noted in the medial superior frontal gyrus/supplementary motor area, right somatomotor system and in the putamen, bilaterally. In contrast, ADHD-related hyperactivation was found primarily in the right angular gyrus/middle occipital gyrus, posterior cingulate cortex, and midcingulate cortex (Cortese et al., 2012). In many of these studies, however, children were not screened for co-occurring disorders, and specifically for DCD.

Executive functions are a cluster of higher order cognitive skills (Diamond, 2013) including response inhibition, which refers to the ability to intentionally suppress dominant, automatic, prepotent responses to successfully complete a task (Nigg, 2000). Numerous studies have reported deficits in response inhibition in children with ADHD (Barley, 1997; Rubia, 2011; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and previous research has suggested that on tasks demanding response inhibition, children with DCD perform significantly worse than typically developing children (Bernardi, Leonard, Hill, & Henry, 2016; Pratt, Leonard, Adayinka, & Hill, 2014). In functional brain imaging studies, the Go/Nogo task is frequently used to investigate response inhibition. This task typically requires the child to initiate a motor response to a specific “Go” cue, and inhibit the motor response to the “Nogo” cue (Wodka, Simmonds, Mahone, & Mostofsky, 2009). Studies of children with ADHD that have investigated functional brain activity during Go/Nogo task performance, have reported frontostriatal-thalamo-parietal brain dysfunctions during performance of inhibition tasks, specifically in the right inferior frontal cortex (IFC), supplementary motor area (SMA), caudate, and thalamus (Aron & Poldrack, 2005; Booth et al., 2005; Durston et al., 2003; Epstein et al., 2007; Hart et al., 2012; Mostofsky et al., 2003; Suskauer et al., 2008). To date, only one fMRI study has used the Go/Nogo task to examine response inhibition in children with DCD (Querne et al., 2008). Results suggested dysfunction in the attentional brain network and the prefrontal cortex, including the middle frontal cortex, anterior cingulate cortex, and inferior parietal cortex in children with DCD.

In summary, the research literature suggests that children with DCD and ADHD display deficits in response inhibition, one of the three core executive functions (Diamond, 2013; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000), and that these deficits are associated with dysfunction in frontostriatal-thalamo-parietal pathways (Hart et al., 2012; Querne et al., 2008). DCD and ADHD frequently co-occur (i.e., up to 50%); however, very few studies have investigated the effect of this co-occurrence on brain function (McLeod, Langevin, Dewey, & Goodyear, 2016; McLeod, Langevin, Goodyear, & Dewey, 2014) and no studies have specifically investigated the impact of co-occurring DCD and ADHD on functional brain activity during the performance of a motor inhibition task. Therefore, the primary aim of this study was to investigate alterations in functional brain activity during performance of a motor inhibition task in children with co-occurring DCD and ADHD compared to children with singular DCD or ADHD and typically developing (TD) controls. We hypothesized that children with co-occurring DCD and ADHD, DCD only, and ADHD only would show decreased blood-oxygen-level-dependent (BOLD) responses in regions of the brain that have been associated with response inhibition, such as the right inferior frontal cortex (Aron & Poldrack, 2005) and posterior parietal regions (Querne et al., 2008) compared to TD children. Given that fMRI activation is critically paradigm dependent, that previous studies have only reported on differences in activation between children with DCD only and TD controls or ADHD only and TD controls, and that no fMRI studies...
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