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Corticospinal excitability during motor imagery is reduced in young adults with developmental coordination disorder

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ABSTRACT

While a compelling body of behavioral research suggests that individuals with developmental coordination disorder (DCD) experience difficulties engaging motor imagery (MI), very little is known about the neural correlates of this deficit. Since corticospinal excitability is a predictor of MI proficiency in healthy adults, we reasoned that decreased MI efficiency in DCD may be paralleled by atypical primary motor cortex (PMC) activity. Participants were 29 young adults aged 18–36 years: 8 with DCD (DCD) and 21 controls. Six participants with DCD and 15 controls showed behavioral profiles consistent with the use of a MI strategy (MI users) while performing a novel adaptation of the classic hand laterality task (HLT). Single-pulse transcranial magnetic stimulation (TMS) was administered to the hand node of the left PMC (hPMC) at 50 ms, 400 ms or 650 ms post stimulus presentation during the HLT. Motor-evoked potentials (MEPs) were recorded from the right first dorsal interosseous (FDI) via electromyography. As predicted, MI users with DCD were significantly less efficient than MI using controls, shown by poorer performance on the HLT. Importantly, unlike healthy controls, no evidence of enhanced hPMC activity during MI was detected in our DCD group. Our data are consistent with the view that inefficient MI in DCD may be subserved by decreased hPMC activity. These findings are an important step towards clarifying the neuro-cognitive correlates of poor MI ability and motor skill in individuals with DCD.

What this paper adds

- Individuals with DCD are less efficient when performing motor imagery relative to controls.
- Young adults with DCD do not show the increase in corticospinal excitability during motor imagery performance that is observed in controls.
- Inefficient motor imagery in DCD may be subserved by decreased primary motor cortex activity.

1. Introduction

Developmental coordination disorder (DCD) is a neurodevelopmental disorder characterized by a reduced ability to employ motor skills, resulting in difficulties engaging the physical and social environment (APA, 2013). Curiously, the motor problems occur in the absence of any currently identifiable cause with symptom onset arising early in development. Across the developmental span,

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individuals with DCD are at increased risk of psychological disorder, social isolation and tend to adopt a sedentary lifestyle (Gagnon-Roy, Jasmin, & Camden, 2016; Zwicker, Harris, & Klassen, 2013). Consequently, they are at increased risk of obesity, cardio respiratory and vascular disease, and arterial stiffness (Cairney, Veldhuizen, King-Dowling, Faught, & Hay, 2017; Joshi et al., 2015; Philips et al., 2016). These common psychosocial and medical corollaries are made all the more concerning by the prevalence rates of DCD, which range between 1.8–5.5% (Lingam, Hunt, Golding, Jongmans, & Emond, 2009).

Symptom expression in DCD is highly heterogeneous and idiopathic which is a common feature of neurodevelopmental disorders. Given this, it is perhaps unsurprising that concerted efforts to establish the aetiology of DCD over the last 20 years have yielded varied accounts (for reviews see Gomez & Sirigu, 2015; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). While it is unlikely that a unitary aetiology exists, there is a weight of evidence supporting the view that individuals with DCD experience difficulties engaging in motor imagery (MI) (Adams, Lust, Wilson, & Steenbergen, 2014). It is largely accepted that MI (i.e. the mental simulation of movement without overt movement occurring) provides insight into one's capacity to generate forward models of movement (Guillot, Di Rienzo, MacIntyre, Moran, & Collet, 2012). Briefly, forward models allow the nervous system to predict the sensory consequences of an impending movement prior to, and during, it taking place (Desmurget & Grafton, 2000; Izawa & Shadmehr, 2011; Wolpert et al., 2011). The accuracy of the movement is then monitored in real time by way of comparison between the actual and expected (as per the forward model) consequences of the unfolding action. Should the two data sources differ, an error signal is generated and used to update the movement seamlessly. By reducing the nervous systems reliance on slow corticospinal feedback, forward models provide stability to the motor system, facilitating rapid and efficient corrections should they be required. This forward modeling process is thought to be subserved by a distributed 'dorsal' neural network, incorporating fronto-parieto-cerebellar circuitry (Blakemore & Sirigu, 2003; Desmurget & Grafton, 2000; Izawa & Shadmehr, 2011).

Despite a degree of variability in the profile of performance across studies, there have been consistent reports of atypical MI ability in children and adults with DCD (Adams, Lust, Wilson, & Steenbergen, 2016; Caçola, Gabbard, Ibana, & Romero, 2014; Deconinck, Spitaels, Fias, & Lenoir, 2009; Fuelscher, Williams, Enticott, & Hyde, 2015; Hyde et al., 2014; Maruff, Wilson, Trebilcock, & Currie, 1999; Reynolds, Licari, Elliott, Lay, & Williams, 2015; Williams, Omizzolo, Galea, & Vance, 2013; Williams, Thomas, Maruff, Butson, & Wilson, 2006), with few exceptions (e.g. Lust, Geuze, Wijers, & Wilson, 2006). Based on the assumption that MI provides insight into the internal action representation, it has been an enduring hypothesis that this common performance deficit may reflect difficulties engaging the internal action representation that precedes purposive movement. While MI deficits have been reported in DCD samples across a variety of paradigms [including visually guided pointing tasks (e.g. Maruff et al., 1999), reach estimation tasks (e.g. Caçola et al., 2014) and whole body transformations (e.g. Williams et al., 2011)], the most frequent and consistent has been during the classic hand laterality task (HLT: Adams et al., 2016; Deconinck et al., 2009; Fuelscher et al., 2015; Hyde et al., 2014; Noten, Wilson, Ruddock, & Steenbergen, 2014; Reynolds et al., 2015; Williams et al., 2011; Williams et al., 2013; Williams et al., 2006; Wilson et al., 2004). The HLT requires participants to determine the laterality of hand images presented on a screen at varying angles (Parsons, 1994). Consistent with reports that participants implicitly engage in MI to complete the task, behavioral profiles are often bound by the biomechanical constraints of movement (Butson, Hyde, Steenbergen, & Williams, 2014; Ionta, Perruchoud, Draganski, & Blanke, 2012; Spruijt, van der Kamp, & Steenbergen, 2015; Ter Horst, van Lier, & Steenbergen, 2010). That is, biomechanically more complex rotations (e.g., lateral) take longer to imagine than simple ones (e.g., medial). Since these constraints are unique to motoric forms of imagery, the manifestation of biomechanical effects on behavioral performance profiles is taken to infer a MI strategy. While children and adults with DCD often show performance profiles consistent with MI use (Adams et al., 2016; Deconinck et al., 2009; Fuelscher et al., 2015; Hyde et al., 2014), they are nonetheless slower and less accurate when doing so.

Despite a weight of behavioral evidence suggesting atypical MI in children and adults with DCD based on their profile of HLT performance, there is very little data speaking to the neurophysiological basis of this deficit. While a single preliminary EEG study failed to find differences in event-related potentials (ERP) within the parietal lobe between children with and without DCD during the HLT (Lust et al., 2006), this was one of the few studies to fail to report atypical MI in individuals with DCD. Though the authors posit a number of experimental explanations for this unusual behavioral effect, given the similar MI performance between individuals with and without DCD the lack of group differences in ERPs is perhaps unsurprising. Importantly, the neurophysiological basis of atypical MI in individuals with DCD remains unknown.

Studies of the MI ability of healthy populations indicate that the poor MI ability of individuals with DCD may be reflected in alterations to corticospinal excitability (Lebon, Byblow, Collet, Guillot, & Stinear, 2012; Williams, Pearce, Loporto, Morris, & Holmes, 2012). Although fMRI studies do not consistently report engagement of the primary motor cortex (PMC) during MI tasks, increases in corticospinal excitability following TMS during MI are widely reported (Héту et al., 2013). These increases are qualitatively similar, though smaller, than those observed during physical performance of the same movements (Grosprêtre, Ruffino, & Lebon, 2016). This also applies to MI occurring during the HLT, despite the broader neural activation identified during this task being somewhat distinct from other types of MI¹ (Héту et al., 2013). For example, recent work has reported that corticospinal excitability projecting from the hand area of the PMC (hPMC) increases significantly during performance (Hyde et al., 2017). It appears, however, that the level of recorded excitability, at least in healthy populations, may be modulated by MI ability (Grosprêtre et al., 2016). Corticospinal

¹ A recent ALE meta-analysis incorporating 75 fMRI studies of MI reported that while implicit measures of MI such as the HLT engage broad motor networks as observed during explicit MI, neural overlap between the distinct forms of MI is surprisingly limited (Héту et al., 2013). For example, implicit MI of the type indexed by the HLT appears to predominantly recruit regions associated with the action representation, including the superior parietal lobule and premotor area (e.g. middle frontal gyrus). Conversely, performance during explicit forms of MI results in greater activity in those regions thought to support motor planning, including supplementary motor areas and the supramarginal gyrus.

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