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Motor imagery ability and internal representation of movement in children with probable developmental coordination disorder

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ABSTRACT

It has been hypothesised that deficits in the functioning of the mirror neuron system (MNS) and internal modelling may contribute to the motor impairments associated with DCD. These processes can be explored behaviourally through motor imagery paradigms. Motor imagery proficiency of children with and without probable DCD (pDCD) was examined using a complex hand rotation task to explore whether motor imagery strategies could be used during more complex tasks. Forty-four boys aged 7–13 years participated, 22 with pDCD (mean = 9.90 years ± 1.57) and 22 controls (mean = 9.68 years ± 1.53). Participants completed the task twice: with and without motor imagery instructions. Stimuli were presented in two rotational axes – palm/back, and eight 45° rotational steps. Both groups showed evidence of following the biomechanical and postural constraints of actual movements. Responses of children with pDCD were slower and less accurate than controls, with group differences increasing alongside task complexity. A greater impact of biomechanical constraints for accuracy was observed in the DCD group. The response characteristics of children with pDCD likely reflects a reduced capacity to mentally manipulate a body schema and reduced visuo-motor processing capabilities. Behaviourally, these processes are linked to MNS and internal modelling function, suggesting deficits in these systems may contribute to the movement difficulties characteristic of DCD.

1. Introduction

Affecting up to 6% of school-aged children, developmental coordination disorder (DCD) is a condition characterised by impaired motor coordination and an inability to perform motor skills at an age appropriate level (American Psychiatric Association [APA], 2013; World Health Organisation [WHO], 2010). Although there is a relatively good understanding of the motor impairments impacting children with DCD, little is known about the underlying aetiology. While the definition states that the condition is not associated with any identifiable hard neurological signs, it has long been suspected that the motor difficulties experienced are neurologically based, with recent research exploring potential underlying neurocognitive mechanisms (Brown-Lum & Zwicker, 2015; Debrabant, Gheysen, Caeyenberghs, Van Waelvelde, & Vingerhoets, 2013; Kashiwagi, Iwaki, Narumi, Tamai, & Suzuki, 2009; Langevin, MacMaster, Crawford, Lebel, & Dewey, 2014; Langevin,

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MacMaster, & Dewey, 2015; Licari et al., 2015; McLeod, Langevin, Goodyear, & Dewey, 2014; Querne et al., 2008; Zwicker, Missiuna, Harris, & Boyd, 2010, 2011, 2012). Meta-analyses and reviews exploring performance deficit characteristics of DCD highlight the extensive range of tasks in which children with DCD experience difficulties, suggesting that numerous brain regions may be implicated in this disorder (Blank, Smits-Engelsman, Polatajko, Wilson, & European Academy for Childhood Disability, 2012; Brown-Lum & Zwicker, 2015; Kashiwagi et al., 2013; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013; Zwicker, Missiuna, & Boyd, 2009). Recent hypotheses suggest deficits in visuo-motor translation (Blank et al., 2012), visuo-spatial processing, and internal (forward) modelling (Adams, Lust, Wilson, & Steenbergen, 2014; Wilson et al., 2013) may lead to the characteristics commonly seen in DCD. Each of these neurological processes are linked to the functioning of the mirror neuron system (MNS) (Reynolds et al., in press; Rizzolatti & Craighero, 2004; Schippers & Keysers, 2011; Werner, Cermak, & Aziz-Zadeh, 2012), dysfunction of which has recently been hypothesised to be involved in the motor deficits characteristic of DCD.

The MNS is a cluster of multimodal neurons in the central nervous system that fire when a person observes, imagines or acts out a movement performed by another. It is thought to aid visual learning through modelling the behaviour and action of others (Iacoboni & Dapretto, 2006). The internal rehearsal of movement, commonly referred to as motor imagery, is an important component of this system and studies have revealed activation of the same neural regions when imagining performance to that of the physical execution of a task (Decety, 1996; Page, Levine, & Leonard, 2007). Motor imagery has been demonstrated to be a valuable mechanism in both a clinical and sporting capacity to assist the acquisition and development of motor skills, likely as a result of these properties (Decety, 1996). In addition to assisting skill development, motor imagery is believed to represent one's ability to plan movements and utilise internal forward models (Sirigu et al., 1996; Williams, Thomas, Maruff, Butson, & Wilson, 2006; Wilson et al., 2004) to predict movement outcomes prior to the availability of sensorimotor feedback (Wolpert, 1997). As a cognition state which activates the MNS, poorer performance on motor imagery tasks by individuals with DCD may suggest some underlying dysfunction of this system (Lust, Geuze, Wijers, & Wilson, 2006; Reynolds et al., in press).

The majority of motor imagery research supports the hypothesis that individuals with DCD are able to adopt a motor imagery strategy for simple tasks, however display different response patterns and accuracy levels compared to their typically developing counterparts (Deconinck, Spitaels, Fias, & Lenoir, 2009; Lust et al., 2006; Williams, Thomas, Maruff, & Wilson, 2008; Williams et al., 2006). Furthermore, motor imagery impairments appear to be greater for individuals who display more severe movement difficulties (Williams et al., 2008). Despite the majority of literature supporting the premise that children with DCD have some level of atypical motor imagery profiles (Wilson et al., 2013), not all individuals with DCD have been found to demonstrate deficits, with some research noting deficits in only a subset of individuals (Wilson, Maruff, Ives, & Currie, 2001; Wilson et al., 2013; Lust et al., 2006; Katschmarsky, Cairney, Maruff, Wilson, & Currie, 2001). The differences in results between studies have likely arisen as a result of the different paradigms employed and their levels of complexity, differences in analysis techniques (e.g. for hand rotation analysing all or analysing only correct responses, analysing biomechanical constraints), and individual differences in severity of DCD and motor impairments (Reynolds et al., in press).

In hand laterality paradigms, differences in the use of one (back view) or two (back and palm views) rotational axes, number of rotational steps, the use or omission of motor imagery instructions, vision or occlusion of hands, and analysis methods, have the potential to have a large impact on the response patterns and whether a motor imagery strategy is used (ter Horst, van Lier, & Steenbergen, 2010). For example, because of the lower complexity level when only back view stimuli are presented, a motor imagery strategy might not be employed, and motor imagery deficits have the potential to not be observed, (ter Horst et al., 2010). Inconsistent analysis of whether response patterns conform to biomechanical constraints (faster and more accurate responses for medial than lateral rotations, and back than palm view for palm down posture) makes it difficult to assess whether a motor imagery strategy has been used, and whether response deficits reflect motor imagery processes.

Motor imagery deficits appear to be more pronounced in individuals with DCD as task complexity increases (Caçola, Gabbard, Ibana, & Romero, 2014; Noten, Wilson, Ruddock, & Steenbergen, 2014) alongside an increased likelihood of engaging in a motor imagery strategy (ter Horst et al., 2010) this highlights the importance of using complex paradigms to explore motor imagery. Despite this, most research has used tasks with only one axis of rotation within a trial. Only three hand rotation studies have explored back and palm responses in children with DCD (Deconinck et al., 2009; Noten et al., 2014; Wilson et al., 2004), with only two incorporating both rotational axes in the same trial (Deconinck et al., 2009; Wilson et al., 2004). One further study has comprehensively explored response patterns for back and palm in adults with pDCD (Hyde et al., 2014). The increased complexity associated with palm view stimuli is highlighted by the observation of Deconinck et al. (2009) that non-congruent hand posture resulted in a significant increase in response time for palm view stimuli but not for back view. These differences in complexity level and response patterns suggest that it may be of value to explore response time and accuracy measures for back and palm view responses separately.

Aside from this observation by Deconinck et al. (2009), no research in children with DCD has specifically analysed back and palm view comparisons in the context of biomechanical constraints and the ability to utilise a motor imagery strategy. Although back and palm response times were explored separately by Noten et al. (2014), no statistical comparisons of the two views were performed. As response accuracy is influenced by biomechanical constraints, and children with DCD been reported to have lower accuracy than controls, it is possible that the analysis of only correct responses may have understated the group differences observed. To date, there has been no assessment of palm view response accuracy during hand rotation tasks.