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The influence of task paradigm on motor imagery ability in children with Developmental Coordination Disorder

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A B S T R A C T

Children with Developmental Coordination Disorder (DCD) have difficulty imagining movements such that they conform to the customary temporal constraints of real performance. We examined whether this ability is influenced by the choice of task used to elicit motor imagery (MI). Performance of typically developing (TD) ($n = 30$) and children with DCD ($n = 30$) was compared on two tasks: the Visually Guided Pointing Task (VGPT) and the Computerized Virtual Radial Fitts Task (C-VRFT). Since the VGPT places higher demands on executive functions like working memory but requires less spatial planning, we reasoned that the C-VRFT would provide a purer measure of motor imagery (or simulation). Based on our earlier work, we predicted that imagery deficits in DCD would more likely manifest on the C-VRFT. Results showed high correlations between tasks in terms of executed and imagined movement time suggest that both tasks measure MI ability. However, group differences were more pronounced in the imagined condition of the radial Fitts' task. Taken together, the more spatially complex C-VRFT appears to be a more sensitive measure of motor imagery, better discriminating between DCD and TD. Implications for theory and practice are discussed.

1. Introduction

Children with Developmental Coordination Disorder (DCD) have difficulty performing coordinated movements which, by definition, affects their functioning in daily life (American Psychiatric Association, 2013). Building knowledge of the underlying motor control deficits in DCD through research is critical for designing interventions that can ameliorate their motor control issues (Smits-Engelsman et al., 2013).

Among other issues in motor control, a recent meta-analysis regarding the underlying deficits associated with DCD reported moderate to large effect sizes on measures of predictive motor control, consistent with the internal modeling deficit (IMD) account of DCD (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). Internal modeling is thought to be critical for online control and the process of motor learning. A critical aspect of control is the capacity of the motor control

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system to model its own dynamics or, more precisely, the systematic relationship between input and output signals. This function enables the performer to predict the consequences of a movement (forward internal model) and to calculate the necessary control parameters (e.g. force, timing, distance, etc.) to enable the realization of a desired goal state (inverse model) thereby ensuring the efficiency of the motor system (Kawato, 1999; Shadmehr & Krakauer, 2008; Wolpert & Miall, 1996).

In a comprehensive meta-analysis of the literature, Wilson et al. (2013) assemble converging data that show children with DCD have a reduced ability to develop and update internal models and, as such, require more time and practice to build action representations. Further to the IMD account, immaturities in neurodevelopment (Hyde & Wilson, 2013) have been suggested in DCD, specifically in areas of the brain that process and store action representations such as the posterior parietal cortex and cerebellum (Desmurget et al., 1999; Desmurget & Sirigu, 2009).

Motor Imagery (MI) is a cognitive process that can be studied via different methods. MI is defined as the ability to mentally represent discrete motor tasks or a sequence of movements without active movement (Decety, 1996; Jeannerod & Decety, 1995). To best elicit MI, participants are asked to imagine and feel themselves making movements from a first-person, egocentric perspective (Gabbard, 2009; Vogt, Di Rienzo, Collet, Collins, & Guillot, 2013).

The link between MI and internal models is also shown in studies which demonstrate that MI elicits activation of similar neural networks as those responsible for planning, executing and controlling overt movements. These networks include the parietal cortex, supplementary motor cortex, primary motor cortex, cerebellum and premotor cortex, all of which are activated, albeit to a lesser extent, when imagining movements (Higuchi, Imamizu, & Kawato, 2007; Ryding, Decety, Sjoholm, Stenberg, & Ingvar, 1993). As well, MI conforms to the same kinematic rules and biomechanical and environmental constraints that govern real movements (Decety & Jeannerod, 1995; Jeannerod & Decety, 1995). Notably, imagined movement time is highly correlated with actual movement time (MT), and both show the characteristic trade-off between speed and accuracy that is defined by Fitts' law (Sirigu et al., 1995; Smits-Engelsman & Wilson, 2013a). Indeed, by older childhood, the correlation between real and imagined movement is around .70 (Smits-Engelsman & Wilson, 2013b), and the logarithmic relationship defined by Fitts' law – which describes the trade-off between MT and target size – approaches an R value of .90 (Wilson, Maruff, Ives, & Currie, 2001). Fitts' law is one of the most robust phenomena in motor control, one that is expressed even under conditions of restricted visual feedback (Wu, Yang, & Honda, 2010). For this reason, the Fitts paradigm has been used extensively to examine the structure of motor representations in children and adults. In studies of children, use of possible heuristics like counting movements or time, without reference to task constraints like target size, does not explain the pattern of results on the Fitts task because they would need to draw on explicit knowledge of the trade-off, which is generally not considered by children (Wilson, Maruff, Ives, & Currie, 2001).

While a number of studies have shown motor imagery deficits in children with DCD (Deconinck, Spitaels, Fias, & Lenoir, 2009; Lewis, Vance, Maruff, Wilson, & Cairney, 2008; Maruff, Wilson, Trebilcock, & Currie, 1999; Williams, Omizzolo, Galea, & Vance, 2013; Williams, Thomas, Maruff, & Wilson, 2008), the use of many different paradigms and task constraints has clouded the interpretation of findings across studies. Mental chronometry paradigms involve explicit use of MI and measure ability by the correlation between real and imagined action. The most common tasks require imagined pointing and include the Visually Guided Pointing Task (VGPT) (Maruff, Wilson, Trebilcock, & Currie, 1999; Sirigu et al., 1996) and the Computerized Virtual Radial Fitts Task (C-VRFT) (Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; Caeyenberghs, Wilson, van Roon, Swinnen, & Smits-Engelsman, 2009; Smits-Engelsman & Wilson, 2013a).

Both tasks have been used successfully to assess MI ability in children however, each requires different levels of motor planning, control and executive function, which are relevant when examining MI performance in children with DCD. For the VGPT (Fig. 1A), demands on motor planning are moderate but cognitive demands are relatively high. Participants perform a series of reciprocal tapping movements (consecutive back and forth movements), using a pen, from one side of a line drawn on a page to a target box of varying sizes. Earlier studies using the VGPT have showed that the index of performance is higher during reciprocal movements than during discrete movements and it is suggested that information processing is more economical (Smits-Engelsman, Swinnen, & Duysens, 2006; Smits-Engelsman, Van Galen, & Duysens, 2002).

While executing tasks on the VGPT motor control parameters related to speed, force and amplitude must be set carefully in relation to target location, but the repeated movements to stable locations in space provide the performer with ongoing feedback for error correction. However, at the same time, the performer must keep count of the number of completed movements, enlisting working memory. In the imagined condition, the cognitive demand increases because the performer must not only keep count but also alert the assessor verbally when the imagined movement ends at the appropriate repetition. The motor and cognitive components of the VGPT give it a dual-task quality. A number of studies suggest that children with DCD have problems with executive functioning and dual tasking (Wilson et al., 2013). Taken together, the higher cognitive load may confound the assessment of MI, especially among children with DCD.

The computerized VRFT eliminates the need for counting (and the associated cognitive bias) because a sequence of five distinct targets is presented and participants are not required to indicate task commencement or completion (Caeyenberghs, Wilson, et al., 2009). However, where cognitive demands are reduced in the C-VRFT, motor planning demands are increased which relate more directly to the motor simulation required of the task (Vogt et al., 2013). It requires a sequence of five back-and-forth movements to distinct targets located on a radial axis from a home base (see Fig. 1B). Varied trajectories for each target impose higher motor planning demands on this task compared with the set spatial configuration of the VGPT. In addition, the endpoint characteristics of the movements in the two tasks are different. For the VGPT, surface breaking occurs each time the pen taps inside the target. For the C-VRFT, however, each movement occurs over the surface of a digitizer, stops