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Full Length Article

Development of motor imagery and anticipatory action planning in children with developmental coordination disorder – A longitudinal approach

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ABSTRACT

Children with impaired motor coordination (or Development Coordination Disorder – DCD) have difficulty with the predictive control of movements, evidenced by cross-sectional studies that show impaired motor imagery and action planning abilities. What remains unclear is whether this deficit in predictive control reflects immaturity of the motor system (a developmental delay) or some deviation from normal development (a disorder). To advance this discussion the present study used a longitudinal design to examine the development of motor imagery and action planning in children with DCD. Thirty children were included in the DCD group (aged 6–11 years) and age- and gender-matched to 30 controls. The DCD group had a mABC-2 score ≤ 16th percentile, the control group > 20th percentile. Motor imagery was assessed with the hand rotation task, action planning with a test for end-state comfort. Children participated in three measurements, with one year in between measurements. Results showed that children with DCD were slower and less accurate than their typically developing peers in all subsequent years but were able to improve their motor imagery ability over time. Furthermore, children with DCD showed less planning for ESC at the start of the present study, but were able to catch up with their peers during two-year follow up. These results exemplify that improvement of motor imagery and action planning ability is possible in DCD, and they lend theoretical support to the use of new training techniques that focus on training motor imagery to improve motor skills in children with DCD.

1. Introduction

Children with Developmental Coordination Disorder (DCD) show impaired motor abilities, in the absence of an identifiable developmental or neurological impairment (DSM-V – American Psychiatric Association, 2013). A prominent hypothesis about the etiology of DCD is the internal modeling deficit (IMD) hypothesis (Wilson & Butson, 2007; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). In two recent systematic reviews, an underlying deficit in motor control and learning was linked specifically to the predictive control of movements (Adams, Lust, Wilson, & Steenbergen, 2014; Wilson et al., 2013). Predictive control is thought critical to the production of fluid, well-coordinated and efficient movements because it enables the performer to make online adjustments based on forward estimates of limb position (Flanagan, Vetter, Johansson, & Wolpert, 2003; Shadmehr,

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Smith, & Krakauer, 2010). What remains unclear is if and to what extent this ability develops in DCD. This is important in understanding the nature of the impaired performance and to further explore the possibilities and necessity of interventions aimed at improving predictive control in DCD, such as motor imagery training (Adams, Smits-Engelsman, Lust, Wilson, & Steenbergen, 2017; Adams, Steenbergen, Lust, & Smits-Engelsman, 2016; Wilson, Thomas, & Maruff, 2002; Wilson et al., 2016). Evidence so far, has been mainly gathered from cross-sectional studies (e.g. Deconinck, Spitaels, Fias, & Lenoir, 2009; Hyde & Wilson, 2013; Williams, Omizzolo, Galea, & Vance, 2013). The present study used a longitudinal design to describe and examine time related change of predictive control in children with DCD.

Two aspects of predictive control are motor imagery and anticipatory action planning. First, motor imagery involves the mental rehearsal or simulation of a motor task in the absence of overt movement (Decety, 1996; Sirigu et al., 1995). This implies mental representation (or internal modelling) of the motor task that is also important for the forward estimates of limb positions. A commonly used paradigm is the mental rotation paradigm in which laterality judgments of limb stimuli are made (e.g. left and right hands) displayed at different angles of rotation, and from different viewpoints as well (e.g. back vs. palm view). For limb-related stimuli, use of motor imagery is inferred when the biomechanical constraints of the simulated movement are reflected in the pattern of response time or error data. For example, for laterally orientated stimuli response times are longer than for medially orientated (Parsons, 1994; ter Horst, van Lier, & Steenbergen, 2010). Second, anticipatory action planning can be defined as the ability to take into account the demands of a given task and its ultimate goal when first manipulating an object (e.g. (Johnson-Frey, McCarty, & Keen, 2004). Adults prefer a less comfortable initial grasp if it allows a comfortable end posture (e.g.(Rosenbaum, vanHeugten, & Caldwell, 1996; Rosenbaum et al., 1990) referred to as the *end-state comfort effect*. Accurate mental representation of the task is a prerequisite for accurate anticipatory motor planning. The grip types used at the start and end of the task can be used to assess action planning (Craje, Aarts, Nijhuis-van der Sanden, & Steenbergen, 2010; Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001).

Deficits in predictive control in children with DCD are evident across many studies (reviewed in Adams et al., 2014; Wilson et al., 2013). Earlier studies showed that children with DCD are able to use motor imagery (as evidenced by increased reaction times to laterally rotated compared with medially rotated hand stimuli), but are slower and less accurate than their typically developing peers (e.g. Adams, Lust, Wilson, & Steenbergen, 2016; Deconinck et al., 2009). Evidence on the nature of age-related changes in motor imagery in DCD is more limited; however, some work suggests that subtle deficits persist into early adulthood (Hyde et al., 2014). On tasks assessing online motor control, there is evidence of development delay in DCD, both in cross-sectional studies (Hyde & Wilson, 2013) and in longitudinal modeling (Ruddock et al., 2016). In the study of Hyde and Wilson (2013) children with DCD showed similar performance as their younger typically developing peers during an online control task. In accordance, in the study of Ruddock et al. (2016) it was found that children with DCD need a more extended period of development to effectively couple online motor control and executive systems when completing anti-reach movements. Longitudinal studies on motor imagery and anticipatory action planning in children with DCD are currently lacking. These studies are warranted to provide insight into the development of motor imagery and action planning abilities over time and might inform therapeutic approaches.

The aim of the present study was to describe and examine changes over time on different aspects of predictive control in children with DCD. We studied the development of motor imagery and action planning in 60 children aged 6–11 years (30 with DCD) over a two year period, with three measurement occasions. Motor imagery was examined using a mental rotation paradigm using hand stimuli, that is also used in developmental studies in typically developing children (Spruijt, van der Kamp, & Steenbergen, 2015). Action planning was examined using the sword task, a task that was validated in children (Craje et al., 2010; Jongbloed-Pereboom, Nijhuis-van der Sanden, Saraber-Schiphorst, Craje, & Steenbergen, 2013). The results of this study may advance the discussion of whether the frequently reported deficit in predictive control in children with DCD (Adams et al., 2014; Wilson review) reflects immaturity of the motor system (a developmental delay) or some deviation from normal development (a disorder). Based on current cross sectional studies (Fuelscher, Williams, Enticott, & Hyde, 2015; Hyde et al., 2014) and the results of the longitudinal modeling on online control (Ruddock et al., 2016) we hypothesized children with DCD to show a developmental delay in motor imagery and action planning skills.

2. Methods

2.1. Participants

A total of 60 children participated in this study, aged 6–11 years during the first measurement (T0). Thirty children (23 boys) met the DSM-V diagnostic criteria for DCD. The 30 control children were gender and age-matched (+/-4 months). Mean age for the DCD group was 8.87 years ($SD = 1.40$), and 8.85 years ($SD = 1.40$) for the control group at T0. Two children in the DCD group and four children in the control group were left-handed, all other children were right-handed. Handedness was assessed by performing the manual tasks of the mABC-2, and confirmed by parent report on the health questionnaire.

The DCD group was recruited through pediatric physical therapists and via an advertisement on a website for parents of children with DCD. In the first year 33 children with DCD participated, gender and age-matched to 33 controls (this population is elaborately described in (Adams et al., 2016). In subsequent years, 30 children with DCD were able to participate at all three time points, and gender and age- matched to 30 controls. Fourteen of the DCD children were recruited via pediatric physical therapists, sixteen DCD children were recruited via an advertisement on a website for children with DCD. Between T0 and T1, 12 of the 27 DCD children received treatment of a pediatric physical therapist ($M = 5.19$ months, $SD = 5.96$). Eight of these 12 children still received treatment by a pediatric physical therapist between T1 and T2 ($M = 2.70$, $SD = 4.62$).