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Mild impairments of motor imagery skills in children with DCD

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ABSTRACT

It has been hypothesized that the underlying mechanism of clumsy motor behaviour in children with Developmental Coordination Disorder (DCD) is caused by a deficit in the internal modelling for motor control. An internal modelling deficit can be shown on a behavioural level by a task that requires motor imagery. Motor imagery skills are suggested to be related to anticipatory action planning, but motor imagery and action planning have not been tested within the same child. In the present study, action planning and motor imagery skills were assessed in 82 children between 7 and 12 years of age. Twenty-one of these children met the criteria for DCD, which was assessed by the McCarron Assessment of Neuromuscular Development and 56 of these children were used in the control group. Motor imagery was tested by a mental rotation task of hands that were shown from a back and palm point of view. The results show that motor imagery is affected in children with DCD but only in conditions with complex task constraints (i.e., rotation of hand stimuli presented in palm view). These results provide partial support for the internal modelling deficit hypothesis. We were not able to elicit motor planning deficits in this group, however, and argue that more complex planning tasks may be needed to identify such deficits.

1. Introduction

Motor clumsiness in children (or Developmental Coordination Disorder – DCD) affects around 5–6% of the children of primary school age (Zwicker, Missiuna, Harris, & Boyd, 2012). The disorder has no identifiable medical cause and is not explained by low intelligence (American Psychiatric Association, 2000). However, the underlying mechanism for DCD is still much debated (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2012). One hypothesis receiving converging support is the internal modelling deficit hypothesis (IMD) (Maruff, Wilson, Trebilcock, & Currie, 1999; Wilson et al., 2004; Wolpert, 1997). What remains unclear is whether this putative deficit is related to aspects of action planning in children. In the study presented here we addressed this question by looking at the relationship between motor imagery (used previously to examine internal modelling) and end-state comfort planning in DCD. The concept of internal modelling has become influential in neurocomputational models of motor control and learning. Broadly defined, it comprises two aspects: an inverse modelling process that maps the necessary motor parameters (like force, timing, and trajectory) to achieve a desired goal state, and forward modelling that uses a predictive estimate of the sensory consequences of an action as a means of error correction (Wolpert, 1997). It is in the latter sense that internal modelling has been investigated in a number of studies. More

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precisely, the latter involves use of a forward model of the efference copy to correct for errors in the motor command. The output of the forward model provides a template against which real-time feedback can be compared under tight temporal constraints, and motor output signals can be corrected if needed (Shadmer, Smith, & Krakauer, 2010). This occurs before slower sensory-based feedback can be processed, resulting in stability of the motor system, particularly when the movement is perturbed in some way (e.g., when the visual target changes during the course of an action or when the moving limb is subjected to an unexpected, external force). In the case of overt movement, feedback is generated that is based on both sensory information and the efference copy. In contrast, if a movement is imagined, no sensory-based feedback is available, only that based on putative internal feedback loops (Desmurget & Grafton, 2003). Therefore, motor imagery paradigms have been used to assess the contents of the internal model and how they might be used to implement and control overt behaviour (Crammond, 1997; Lewis, Vance, Maruff, Wilson, & Cairney, 2008; Williams et al., 2011; Wilson et al., 2004; Wilson, Maruff, Ives, & Currie, 2001). Two paradigms regularly used to assess motor imagery capacity in children with DCD are the mental chronometry and the mental rotation paradigm.

1.1. Motor imagery in DCD

In the case of Fitts' Law, the systematic relationship between target size (or item difficulty) and movement time has been used to investigate the nature of motor imagery and the structure of internal modelling (Crammond, 1997). If participants enlist MI then Fitts' Law should apply to both executed and imagined movements, suggesting an ability to represent internally the coordinates of a prospective action (forward modelling) (Decety, Jeannerod, & Prablanc, 1989). Research suggests deficits of motor imagery in children with DCD (Lewis et al., 2008; Maruff, Wilson, Trebilcock, & Currie, 1999). The performance of these children did not conform accurately to Fitts' Law, they performed imagined movements faster than executed movements, and the movement duration of executed and imagined movements did not correlate, unlike controls (Wilson et al., 2001). In the mental rotation paradigm participants have to determine the laterality of pictures of rotated hands (Sekiyama, 1982). Importantly, if participants are engaged in motor imagery to solve the task, the response time profile should be subject to the same biomechanical constraints as during actual hand rotations (Parsons, 1994). Thus, as well as a general increase in response time with increasing angle of rotation, response times for hands oriented in a lateral direction should be larger than those oriented medially given the biomechanical awkwardness associated with the former. This has been shown on the behavioural level (ter Horst, van Lier, & Steenbergen, 2010) and further substantiated at the neurophysiological level (Jongsma et al., 2013; ter Horst, Jongsma, Janssen, Lier, & Steenbergen, 2012). Children with DCD have been shown to be less accurate than typically developing children and show only a modest trade-off in response time as a function of the angle of rotation, unlike controls (Williams et al., 2011; Williams, Thomas, Maruff, & Wilson, 2008; Wilson et al., 2004). Taken together, impaired motor imagery was evident in children with DCD. In line with the internal modelling hypothesis, motor imagery skills have been linked repeatedly to motor execution skills (Driskell, Copper, & Moran, 1994; Gentili, Papaxanthis, & Pozzo, 2006). For example, previous research has shown that imagined rehearsal is an effective way to improve sport performances in healthy adults. In addition, motor imagery training has been shown to improve the motor skills of stroke patients, although the effects are less strong than standard physical therapy (Braun, Beurskens, Borm, Schack, & Wade, 2006; Crajé, van der Graaf, Lem, Geurts, & Steenbergen, 2010; Page, Levine, & Khoury, 2008; Sharma, 2006).

1.2. End-state comfort planning in DCD

Another aspect of motor control and motor planning that is thought crucial to skill is the ability to judge endpoint comfort states. This occurs, for example, when an object must be grasped and then manipulated in order to achieve a desired new position. A control parameter in this type of skill is the ability to anticipate end-state postures that are biomechanically efficient and comfortable. This can be observed behaviorally when individuals grasp and manipulate objects; comfort of the start posture is sacrificed to enable a comfortable posture at the end of the task, a phenomenon referred to as the end-state comfort effect (Rosenbaum & Jorgensen, 1992). Like traditional motor imagery tasks, this requires the ability to form an accurate egocentric representation of the body, to extract its relationship to objects in the workspace, and to map the prospective changes in self-object relations that would occur to achieve a desired end-state. Under closed conditions, skilled performers achieve the necessary computations in a seamless manner, and with little conscious effort. Efficient movements of this type require that the visuospatial and biomechanical demands of an action are taken into account before movement starts (Johnson-Frey, McCarty, & Keen, 2004). Or, in the case of tool use, that the desired outcome of movement is predicted in relation to the biomechanical, cognitive, or physical constraints of the task (Herbort, 2012; Steenbergen, van der Kamp, Smithsman, & Carson, 1997).

Two lines of research point to a causal link between MI and the anticipatory planning for end-state comfort. First, studies using neuro-imaging techniques showed that similar neural structures show activation during imagery of end state postures and the actual planning of a movement (Hanakawa, Dimyan, & Hallett, 2008; Lacourse, Orr, Cramer, & Cohen, 2005). Common structures involved are the primary and supplementary motor areas, the cerebellum and the parietal cortex (Stephan et al., 1995). Second, for post stroke patients MI training is reported to have beneficial effects on motor rehabilitation (Page et al., 2008; Sharma, 2006). Collectively, these lines of evidence indicate a close functional relationship between MI ability (and training), end-state control, and functional skill. As a consequence, deficits in motor imagery will have consequences for motor control and skill acquisition. In Cerebral Palsy (CP), for example, deficits exist in both motor