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Assessing motor imagery using the hand rotation task: Does performance change across childhood?

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This study examined at what age children can engage in the hand rotation task (as a measure of motor imagery); whether engagement changes across development and; the influence of age and motor skill on performance. Children were aged 5–12 years ($N = 101$; 52 girls), with no IQ or motor skill impairment. Less than 40% of 5–6 year olds completed the hand rotation with sufficient accuracy for further analysis, compared with 80% of 7–8 year olds, and 90% aged 9 and above. From age 7, either or both response time (RT) and accuracy conformed to the biomechanical constraints of corresponding physical movements. Although RT did not improve with age, accuracy did, with 11 year olds significantly more accurate than 7 and 8 year olds. Importantly, efficiency (RT/accuracy) improved with age and both age, in months, and motor skill level were significant predictors of efficiency, accounting for 35% and 8% of variability, respectively. Improvements in motor imagery ability during childhood are likely the result of increased neural efficiency, developing as the result of complex interactions between endogenous and exogenous factors. This highlights the need for a multidisciplinary approach to further our understanding of the emergence of motor imagery ability.

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1. Introduction

Motor imagery paradigms, which require individuals to produce a dynamic simulation of movement (without any overt accompanying movement), are increasingly being used to investigate the ability of an individual to mentally represent movement. Internal representations of movement are thought to play a critical role in a number of motor control processes, including mental rehearsal and observational learning (Jeannerod, 2001), motor planning (Wolpert & Ghahramani, 2000), and online movement control (Desmurget & Grafton, 2000; Izawa & Shadmehr, 2011). These representations are dynamic, in that they are constantly updated as a result of an individual's movement interactions with their environment and changes in body kinematics that occur during development (Choudhury, Charman, Bird, & Blakemore, 2007; Miall & Wolpert, 1996; Wolpert, Ghahramani, & Jordan, 1995). It is currently unclear at what age these representations form or become consciously accessible, but it has been suggested that children must first gain some level of implicit knowledge of the relationship between the motor commands they generate, the environment and the effects on their moving body before they can accurately generate an internal representation of movement (Caeyenberghs, Wilson, Van Roon, Swinnen, & Smits-Engelsman, 2009). Understanding the emergence and development of these internal representations is crucial to our understanding of motor development and to enable us to better understand the atypical motor imagery performance of children with motor skill impairment (see below). To examine these representations, we need to be sure that the motor imagery tasks being utilized are age-appropriate.

Currently, the majority of studies examining motor imagery in children have utilized tasks that have been borrowed from adult studies and though for the most part these tasks are supported by neuroimaging data that indicates they can effectively engage participants in motor imagery (e.g., de Lange, Helmich, & Toni, 2006; Kosslyn, Digirolamo, Thompson, & Alpert, 1998; Parsons, 1987; Parsons & Fox, 1998), their valid use in children is less well established. Therefore, the first aim of this experimental study was to explore whether one such task, the hand rotation task, engages children aged 5–12 years in motor imagery. To establish this, response times and accuracy to posturally congruent and posturally incongruent stimuli were compared in order to confirm the presence of biomechanically constrained movement simulations (indicating the use of motor, rather than visual, imagery: see below). Following this, if analyses were to indicate that children were effectively engaged in motor imagery while performing the hand rotation task, the study aimed to determine how performance changes across age and what influence motor skill level has on performance.

1.1. The hand rotation task

A widely used task to assess motor imagery capacity is the hand rotation task (see, for example, Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; de Lange et al., 2006; Deconinck, Spitaels, Fias, & Lenoir, 2009; Funk, Brugger, & Wilkening, 2005; Parsons, 1987, 2003; Ter Horst, Van Lier, & Steenbergen, 2010; Williams, Anderson, et al., 2011; Williams, Thomas, Maruff, Butson, & Wilson, 2006). In this task participants are required to make a decision on the laterality of a stimulus hand that can be presented at varying degrees of angular rotation, as well as in different views (back versus palm) and sometimes in different postures (Ionta & Blanke, 2009; Ter Horst et al., 2010). Neuroimaging and self-report data indicate that the task can elicit the use of motor imagery when participants imagine moving their own hand into the position of the stimulus hand to aid in determining laterality (de Lange et al., 2006; Kosslyn et al., 1998; Parsons, 1987; Parsons & Fox, 1998). For many years, researchers interpreted linear increases in response time that occurred in line with rotation of the stimulus from 0° (fingers up) to 180° (fingers down) as evidence that motor imagery was occurring (Caeyenberghs, Tsoupas, et al., 2009; Lust, Geuze, Wijers, & Wilson, 2006; Mutsaarts, Steenbergen, & Bekkering, 2007; Williams et al., 2006, 2004). However, visual imagery, a functionally and neurophysiologically distinct form of imagery involving the rotation of objects, follows the same pattern of response (i.e., response increases with angular rotation of stimulus). For studies without corroborating neuroimaging data, the challenge was to demonstrate that the task was indeed