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The ability of 6- to 8-year-old children to use motor imagery in a goal-directed pointing task

Steffie Spruijt [a,*], John van der Kamp [b,c], Bert Steenbergen [a,d]

[a] Behavioural Science Institute, Radboud University Nijmegen, 6500 HE Nijmegen, The Netherlands
[b] Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, 1081 BT Amsterdam, The Netherlands
[c] Institute of Human Performance, University of Hong Kong, Hong Kong, China
[d] School of Psychology, Australian Catholic University, Melbourne campus, Fitzroy, VIC 3065, Australia

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ABSTRACT

It has been suggested that motor imagery ability develops gradually between 5 and 12 years of age, but ambiguity remains over the precise developmental course before 9 years. Hence, we determined the age-related differences in the use of motor imagery by children on the mental chronometry paradigm. In addition, we examined whether the use of motor imagery is related to cognitive and hand abilities. To this end, we compared duration of actual pointing and imagined pointing on a radial Fitts' task in 82 children (three age groups; 6-, 7-, and 8-year-olds). In line with previous studies, we found an age-related increase in temporal congruence between actual and imagined pointing and compliance with Fitts' law. Importantly, however, we showed that only a limited number of 7- and 8-year-olds were actually using motor imagery to perform the imagined pointing task, whereas the 6-year-olds did not employ motor imagery to perform the task. The current results extend previous research by establishing that the age of onset to use motor imagery in the mental chronometry paradigm is not prior to 7 years.

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* Corresponding author.
E-mail address: s.spruijt@pwo.ru.nl (S. Spruijt).

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Introduction

In motor imagery, people imagine themselves moving without actually performing the action. Motor imagery entails the internal activation of a first-person movement representation in working memory devoid of any overt motor output (Decety & Grezes, 1999). Jeannerod (1994) argued that motor imagery and motor preparation are functionally equivalent because they both rely on the same movement representation. Therefore, imagining a movement is predicted to be subject to similar task constraints as motor performance (Decety, Jeannerod, & Prablanc, 1989; Jeannerod, 1995; Lotze & Halsband, 2006).

Mental chronometry is a frequently used experimental paradigm to determine motor imagery ability. Mental chronometry examines whether performing and imagining the same movement corresponds with respect to duration. This temporal congruence between actual and imagined movement performance was indeed shown in studies that used walking or pointing to a target (Bakker, de Lange, Stevens, Toni, & Bloem, 2007; Caeyenberghs, Wilson, van Roon, Swinnen, & Smits-Engelsman, 2009; Cerritelli, Maruff, Wilson, & Currie, 2000; Choudhury, Charman, Bird, & Blakemore, 2007; Decety et al., 1989; Molina, Tijus, & Jouen, 2008; Papaxanthis, Pozzo, Skoura, & Schieppati, 2002). Yet, it can be argued that temporal congruence is not sufficient to conclude that participants actually use motor imagery. Temporal congruence can also be the consequence of alternative strategies, including the use of memories of movement performance, estimates of task duration by counting, and visual imagery in which a movement is typically imagined from a third-person perspective (Cerritelli et al., 2000; Malouin, Richards, Durand, & Doyon, 2008; Munzert, Lorey, & Zentgraf, 2009). Therefore, to establish that motor imagery is used instead of alternative strategies, additional criteria need to be fulfilled. Specifically, because motor imagery is grounded in motor control processes, the pattern of imagined durations should be subject to the same motor constraints as the performance of actual movements (Currie & Ravenscroft, 1997). Thus, to be sure that participants enlist motor imagery and not alternative non-motor strategies, it needs to be verified that imagined performance complies with the same motor constraints as movement performance (Sirigu et al., 1996).

One way to verify the use of motor imagery within the mental chronometry paradigm is to systematically manipulate task difficulty and examine its effect on both actual and imagined movement performance. Actual pointing movements are commonly found to comply with Fitts' law, in which movement duration is lawfully related to task difficulty: movement duration = $a + b$ * index of difficulty, where index of difficulty = log2(2 * distance/width) (Fitts, 1954). Task difficulty is manipulated via systematic manipulation of target width and/or target distance. Consequently, Fitts' tasks are frequently used within the mental chronometry paradigm to study the effect of systematically manipulating task difficulty on actual and imagined movement performance (Cerritelli et al., 2000; Choudhury et al., 2007; Wilson, Maruff, Ives, & Currie, 2001). Participants perform repetitive pointing movements toward a series of targets both by actually performing these movements and by imagining these movements. Based on Fitts' law, the same lawful relation between duration, on the one hand, and task difficulty, on the other, is anticipated for the actual and imagined pointing performance if they emerge from the same (motor) constraints. Indeed, previous research in adults has shown not only temporal congruence but also compliance with Fitts' law during both actual and imagined pointing performance (Cerritelli et al., 2000; Choudhury et al., 2007; Sirigu et al., 1996). From this, it can be concluded that motor imagery contributes to performing the mental chronometry paradigm.

Studies on motor imagery are widespread in the adult population, but only a limited number of studies have examined motor imagery in children. These studies suggest that the capability for motor imagery gradually develops between 5 and 12 years of age (Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; Caeyenberghs, Wilson, et al., 2009; Hoyek, Champely, Collet, Fargier, & Guillot, 2009; Molina et al., 2008; Skoura, Vinter, & Papaxanthis, 2009; Smits-Engelsman & Wilson, 2012). Three studies based this suggestion on the analysis of temporal congruence alone without a systematic manipulation of motor constraints (Hoyek et al., 2009; Molina et al., 2008; Skoura et al., 2009). Three other studies complemented the analyses by examining whether temporal congruence between the actual and imagined pointing performance arises from the same motor constraints (Caeyenberghs, Tsoupas, et al., 2009; Caeyenberghs, Wilson, et al., 2009; Smits-Engelsman &

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