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Motor imagery development and proprioceptive integration: Which sensory reweighting during childhood?



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ABSTRACT

It is widely accepted that motor imagery development during childhood may be due to refinement of internal models of action. At the same time, gradual improvement of predictive motor control in children may reflect an increasing ability to integrate the proprioceptive afferences with other sources of sensory information (especially vision). The current study investigated the extent to which motor imagery refinement observed between 5 and 9 years of age was related to the increasing ability to integrate proprioceptive afferences with vision and audition signals. To attain this goal, we compared motor imagery performances of 96 children (32 5-year-olds, 32 7-year-olds, and 32 9-year-olds) who received either visual and auditory inputs (VA condition) or visual, auditory, and proprioceptive inputs (VAP condition) during the imagery task. Motor imagery capacity was evaluated by means of mental chronometry paradigm based on a walking task. Our results revealed that correlations between overt and covert movements gradually increased across age in either the VA or VAP condition. Most important, in 5- and 7-year-olds, covert walking times were significantly longer than overt walking times in the VAP condition, whereas covert walking times were not different from actual walking times in the VA condition. In 9-year-olds, covert walking times were not different from overt walking times in either the VAP or VA condition. We suggest that motor imagery refinement during

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childhood can be partially related to the ability to integrate proprioceptive inputs with other sources of sensory information. Furthermore, our results shed light on the sensory content of motor images in children.

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Introduction

Motor imagery refers to the capacity to mentally rehearse a specific motor action without executing any body movements (Jeannerod, 1994; Mulder, Zijlstra, Zijlstra, & Hochstenbach, 2004). As indicated by Jeannerod (2001), simulation of a body's movement may be accompanied by conscious (explicit motor imagery) or nonconscious (implicit motor imagery) experience. Many functional neuroimaging studies conducted in adults have revealed that shared neural structures, including parietal and prefrontal cortices, supplementary motor area, premotor and primary motor cortices, basal ganglia, and cerebellum, are implicated during both explicit and implicit forms of motor imagery and movement execution (for a reviews, see Decety, 1996; Fadiga & Craighero, 2004; Jeannerod, 2001). This partial overlapping of the central structures involved in overt and covert movement also suggests that motor imagery and movement execution share similar mechanisms of motor control. As a matter of fact, motor imagery is intimately linked to the ability to generate both inverse and forward internal models involved in predictive motor control (Papaxanthis, Pozzo, Skoura, & Schieppati, 2002; Wolpert & Flanagan, 2001). The inverse model determines the appropriate motor command required to achieve some desired movement. As motor commands are sent to the effectors, an efferent copy of these motor commands would be generated and sent to an internal forward model. The efferent copy would allow the motor system to predict and anticipate the sensory consequences of self-generated movements. This sensory prediction would then be compared with the sensorial feedback provided by the execution of movement in order to detect a sensory error. During motor imagery, when the movement is not actually executed, the forward model provides accurate sensory prediction based on the appropriate but blocked motor commands provided by the inverse model (Papaxanthis, Pozzo et al., 2002; Wolpert & Flanagan, 2001). In this way, motor imagery could be defined as an internal dynamical state related to participants' ability to use internal models to predict the sensory consequences of an action (Gabbard, Caçola, & Bobbio, 2011; Grush, 2004; Papaxanthis, Pozzo et al., 2002). From this statement, it follows that performance in motor imagery tasks may depend on the sensory afferences with which participants are provided.

In line with the seminal proposals of Jeannerod (1995) considering motor imagery as being related to feeling of movement and effort, various studies have provided experimental evidence for the simulation of proprioceptive sensations during motor imagery. Based on a mental chronometry paradigm, some of these studies compared real and mental durations under no-load and additional slight load conditions (e.g., performing cyclical shoulder movement while wearing a load of 1 or 1.5 kg) (Gentili, Cahouet, Ballay, & Papaxanthis, 2004; Papaxanthis, Schieppati, Gentili, & Pozzo, 2002; Slifkin, 2008). Results of these studies revealed matching between actual and mental durations under conditions of no load as well as under conditions of load, suggesting that adult participants are able to integrate proprioceptive feedback of a load while imagining a movement to the extent that this charge is not excessive (Slifkin, 2008). As demonstrated by Slifkin (2008), the presence or absence of the actual–mental equivalence depends on how close the load is to the maximum capacity of the effector system for a given action. In the case of heavy load (e.g., a rucksack with 20% of bodyweight on back), motor commands provided by the inverse model would be incomplete, generating an uncertain sensory prediction by the forward model (Munzert, Blischke, & Krüger, 2014; Slifkin, 2008).

In addition to kinesthetic and proprioceptive afferences, other studies have demonstrated that motor imagery may also require the concurrent use of vision and audition (Annett, 1995; Fourkas, Ionta, & Aglioti, 2006; Mizuguchi, Nakata, Uchida, & Kanosue, 2012; Munzert, Lorey, & Zentgraf,

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