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Age-related differences in the motor planning of a lower leg target matching task

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While the development and execution of upper extremity motor plans have been well explored, little is known about how individuals plan and execute rapid, goal-directed motor tasks with the lower extremities. Furthermore, the amount of time needed to integrate the proper amount of visual and proprioceptive feedback before being able to accurately execute a goal-directed movement is not well understood; especially in children. Therefore, the purpose of this study was to initially interrogate how the amount of motor planning time provided to a child before movement execution may influence the preparation and execution of a lower leg goal-directed movement. The results displayed that the amount of pre-movement motor planning time provided may influence the reaction time and accuracy of a goal directed leg movement. All subjects in the study had longer reaction times and less accurate movements when no pre-movement motor planning time was provided. In addition, the children had slower reaction times, slower movements, and less accurate movements than the adults for all the presented targets and motor planning times. These results highlight that children may require more time to successfully plan a goal directed movement with the lower extremity. This suggests that children may potentially have less robust internal models than adults for these types of motor skills.
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1. Introduction

Motor actions are highly dependent upon the formulation of a motor plan that is based on a feed-forward or a feedback control strategy. Feed-forward control is based upon an internal model, which is used to predict the outcomes of the motor command being formed; while feedback control uses errors between the internal model and the actual movement trajectory to make online corrections (Mussa-Ivaldi, 1999; Shadmehr & Mussa-Ivaldi, 1994). An internal model is formed by integrating information about the current position and velocity of a limb in space, and can be specified based on the current sensory feedback as well as past experiences (Mussa-Ivaldi, 1999). Proper integration of this information will allow an individual to more accurately control their movement and successfully complete the movement to achieve the desired outcome. Since the environments in which motor tasks are performed are ever changing, an internal model must be robust and adaptable to these changes. Humans are relatively skilled at adapting their internal models based on these ever changing environments. For example, adaptation of an internal model has been seen to occur rather quickly following the implementation of a force field or visuomotor transformation during goal-directed reaching tasks (Contreras-Vidal, 2006; Contreras-Vidal, Bo,

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Boudreau, & Clark, 2005; Ghez et al., 1997; Jansen-Osmann, Richter, Konczak, & Kalveram, 2002; Shadmehr & Mussa-Ivaldi, 1994; Takahashi et al., 2003). The adaptation of the internal model can be seen by an increase in errors when the applied force field or visuomotor transformation is removed, indicating that the internal model has correctly adapted to the preceding environmental dynamics.

The level of preparation of the internal model is dependent upon the amount and type of information provided before movement execution and the time provided to process this information (Pellizzer, Hedges, & Villanueva, 2006). In feedforward or goal-directed motor tasks, the information provided to an individual before motor execution can be manipulated by altering the visual information about the limb's initial location or the position of the target (Pellizzer & Hedges, 2004; Shadmehr & Mussa-Ivaldi, 1994). Furthermore, the amount of time the visual information about the target location is provided to an individual can be altered in order to provide either no processing time or ample processing time (Pellizzer et al., 2006). By quantifying the reaction time, movement time, and accuracy for a goal-directed motor task, one may interrogate the level of preparation and integration of sensory information. Increased reaction and movement times suggest that an individual takes longer to integrate the sensory information, and decreased accuracy suggests that an improper feedforward internal model was selected for the desired movement outcomes. Therefore, the proper integration of sensory information is vital for proper planning of motor actions.

The robustness of an internal model is also dependent upon the amount of previous experience utilizing and adapting the internal model to meet specific task demands (Lukos, Choi, & Santello, 2013; Mussa-Ivaldi, 1999). For example, highly skilled athletes with extensive motor experience, such as elite soccer players, display higher levels of accuracy than non-athletes when faced with changes in task demands such as end point trajectory placement or a moving soccer ball to kick (Egan, Verheul, & Savelsbergh, 2007; Ford, Hodges, Huys, & Williams, 2009). These athletes also display faster reactions times suggesting that they are able to integrate the appropriate sensory cues for a movement and predict the consequences of their results than non-athletes potentially due to extensive experience performing and adapting highly specific action patterns (Montes-Mico, Bueno, Candel, & Pons, 2000; Romeas & Faubert, 2015; Vanttinen, Blomqvist, Luhtanen, & Hakkinen, 2010). Therefore, the amount of preparation before a goal-directed movement is highly dependent upon an individual not only being provided with adequate information concerning limb dynamics and goal of the motor task, but also on the robustness and adaptability of the internal model underlying the motor skill.

It is commonly known that during development, children display less coordinated movements than adults and have incomplete development of their sensorimotor system (Moon et al., 2015). Children also face an even higher amount of ever changing environmental demands due to the growth of their body; especially their lower extremities. Despite reaching similar levels of adaptation to visuomotor transformations or force field application, children display less accurate movements and increased variability in goal-directed arm movements (Contreras-Vidal, 2006; Contreras-Vidal et al., 2005; Jansen-Osmann et al., 2002; Takahashi et al., 2003). Refinements in the accuracy, speed and smoothness of goal-directed arm movements typically occur with increasing age (Contreras-Vidal, 2006). Potentially, the incomplete development of a child's sensorimotor system and deficits in integrating the current state of the system contribute to the increased amount of errors in completing goal-directed upper extremity movements. Additionally, it is possible that children also have less robust internal models underlying their movements, thus, they are unable to address the ever changing dynamics of their limbs (Shadmehr & Mussa-Ivaldi, 1994).

While the development and execution of upper extremity motor plans have been well explored, little research has been conducted exploring how individuals, specifically children, plan and execute rapid, goal-directed motor tasks with the lower extremities. Since the lower extremities are vital for daily locomotion, it is possible that the formulation of internal models for lower extremity motor tasks is planned differently than an upper extremity movement. Moreover, the amount of time that it takes to process and integrate an appropriate amount of visual and proprioceptive information before an individual can accurately execute a goal-directed movement is not well understood. Thus, the purpose of the current study is to interrogate how the amount of motor planning time provided to a child may influence the preparation and execution of a goal-directed knee extension motor task.

2. Methods

Twelve typically developing children (7 females; mean age: 8.2 ± 1.8 years) and 13 healthy adults (7 females; mean age: 26.0 ± 6 years; see Table 1) participated in this research study. All experimental procedures were approved by the University of Nebraska Medical Center Institutional Review Board. All adult subjects signed a written informed consent form and a parent of each child participant gave consent for their child to participate. Additionally, all children provided assent to participate.

Subjects were seated in an adjustable height chair and a table was placed in front of them in such a way that all vision of their lower extremities was occluded (Fig. 1). The back of the chair was also adjustable so that the subject could be appropriately positioned so that their knees were at the edge of the chair and were bent at 90°. During the data collection, neither of the subject's feet was in contact with the floor. We selected to occlude the vision of the lower extremities in order to limit the amount of visual feedback utilized during the experiment by the subjects so that they must rely on their current internal model to make feed-forward predictions. The subjects used their dominant leg for all experimental procedures. Leg dominance was determined by self-report from the adult subjects and from self-report plus kicking a soccer ball for the children

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