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Neuromuscular variability and spatial accuracy in children and older adults

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ABSTRACT

Our ability to control movements is influenced by the developmental status of the neuromuscular system. Consequently, movement control improves from childhood to early adulthood but gradually declines thereafter. However, no study has compared movement accuracy between children and older adults. The purpose of this study was to compare endpoint accuracy during a fast goal-directed movement task in children and older adults. Ten pre-adolescent children (9.7 ± 0.67 yrs) and 19 older adults (71.95 ± 6.99 yrs) attempted to accurately match a peak displacement of the foot to a target (9° in 180 ms) with a dorsiflexion movement. We recorded electromyographic activity from the tibialis anterior (agonist) and soleus (antagonist) muscles. We quantified position error (i.e. spatial accuracy) as well as the coordination, magnitude, and variability of the antagonistic muscles. Children exhibited greater position error than older adults (36.4 ± 13.4% vs. 27.0 ± 9.8%). This age-related difference in spatial accuracy, was related to a more variable activation of the agonist muscle (R^2: 0.358; $P < 0.01$). These results suggest that an immature neuromuscular system, compared to an aged one, affects the generation and refinement of the motor plan which increases the variability in the neural drive to the muscle and reduces spatial accuracy in children.

1. Introduction

Our ability to control movements requires a high degree of accuracy and is influenced by the developmental status of the neuromuscular system. The neuromuscular system approaches full maturity after the first two decades of life and progressively deteriorates through late adulthood (Gogtay et al., 2004; Fling et al., 2011; Mufuler et al., 2011; Douaud et al., 2014; Sussman et al., 2016). Consequently, our ability to control movements improves from childhood to early adulthood but gradually declines thereafter (Vandervoort, 2002; Seidler et al., 2010; Vasudevan et al., 2011; Douaud et al., 2014). This led to the speculation that children and older adults exhibit similar movement control (Leversen et al., 2012; Douaud et al., 2014). However, no study has investigated endpoint accuracy between these two age groups. The purpose of this study, therefore, was to compare endpoint accuracy during a fast goal-directed movement task in children and older adults.

The developmental status of the neuromuscular system directly impacts movement control (Douaud et al., 2014). Consequently, the immature neuromuscular system of children results in slower and more variable movements. For example, children exhibit greater coactivation (Lambertz et al., 2003; Grosset et al., 2008) and a more variable (Fox et al., 2014) activation of the antagonistic muscles than young adults. This altered neuromuscular activation of children is associated with longer and more variable reaction times (Favilla, 2006; Tamnes et al., 2012; Davies et al., 2015), inaccurate and more variable reaching (Takahashi, 2003) and single-joint goal-directed movements (Fox et al., 2014; Davies et al., 2015), and more variable visuo-motor tracking (Hay and Redon, 1997; Deutsch and Newell, 2001; Fox et al., 2014) than young adults. The neuromuscular system of older adults also results in slower, less accurate, and more variable movements. For example, older adults, compared with young adults, exhibit an altered and a more variable activation of the involved muscles (Chen et al., 2012; Kwon et al., 2012, 2014; Moon et al., 2015; Park et al., 2017). The altered neuromuscular activation of older adults is associated with slower and less accurate goal-directed movements with the upper and lower limbs (Chen et al., 2012; Kwon et al., 2014), less accurate and more variable visuo-motor tracking performance (Vaillancourt et al., 2003; Christou, 2011; Chen et al., 2014), and impaired performance during functional tasks, such as walking and driving (Donath et al., 2015; Lodha et al., 2016). These results suggest that movement control improves from childhood to early adulthood and declines towards late adulthood.

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The few studies that compared movement control between children and older adults compare tasks that require a stimulus identification prior movement execution. For example, Yan et al. (2000) asked children, young, and older adults to reach for a target as fast as possible after the presentation of a visual stimulus (i.e. RT task) (Yan et al., 2000). Both young children (~6 years) and older adults (~74 years) reacted slower and with more variable movement trajectories than young adults (~24 years). However, age-related differences are task specific and even small variations in the participant's age can influence the results.

To our knowledge, there is no study that compares movement endpoint accuracy of children relative to older adults. Spatial endpoint accuracy is critical for many activities of daily living. For example, while walking, spatial accuracy is essential to appropriately clear obstacles and steps to avoid tripping or falling (Nagano et al., 2011). Therefore, characterizing endpoint accuracy in children and older adults will allow us to examine whether an immature and an aged neuromuscular system affects movement control differently.

The purpose of this study, therefore, was to compare spatial movement accuracy between children and older adults. We asked participants to perform fast goal-directed movements with ankle dorsiflexion while we recorded electromyographic (EMG) activity of the primary agonist and antagonist muscles. We hypothesized that spatial endpoint accuracy, and its underlying neuromuscular activity, would be similar between children and older adults.

2. Materials and methods

2.1. Participants

Ten pre-adolescent children (9.7 ± 0.67 yrs.; 4 Females) and 19 older adults (71.95 ± 6.99 yrs.; 9 Females) participated in the study. All participants were right-footed and reported being healthy without any known neurological impairments. This study was approved by the Institutional Review Board of the University of Florida and conducted in accordance with the Declaration of Helsinki. All participants signed a written informed consent before participating.

2.2. Experimental approach

Participants completed one testing session in which they performed a goal-directed task with ankle dorsiflexion. At the beginning of the session, we explained the experimental procedures and the goal-directed task to the participants. Each participant performed the following procedures within the session: (1) maximal voluntary contraction (MVC) with ankle dorsiflexion; (2) 3–5 goal-directed movement practice trials at a different target from the actual target; (3) 50 goal-directed movement trials with ankle dorsiflexion.

2.3. Experimental setup

Participants sat with their left hip joint flexed to ~90° with 10° abduction, the knee flexed at ~90°, and the ankle was plantar flexed to ~15°. The left foot rested on a customized foot device with an adjustable footplate and was strapped over the metatarsals to ensure a secure position and a simultaneous movement between the device and the foot (Fig. 1A). The axis of rotation of the customized foot device was positioned in line with the axis of rotation of the left ankle to allow only dorsiflexion and plantarflexion of the ankle. We chose the left leg because the task would be more novel for the non-dominant than for the dominant limb in both children and older adults.

Force. The maximum voluntary force exerted during the MVC task was measured with a force transducer (model 41BN, Honeywell, Morris- town, NJ). The ankle force signals were high-pass filtered at 0.03 Hz, amplified 50 times (Bridge-8, World Precision Instruments), sampled at 1000 Hz with a NI-DAQ card (model USB6210, National

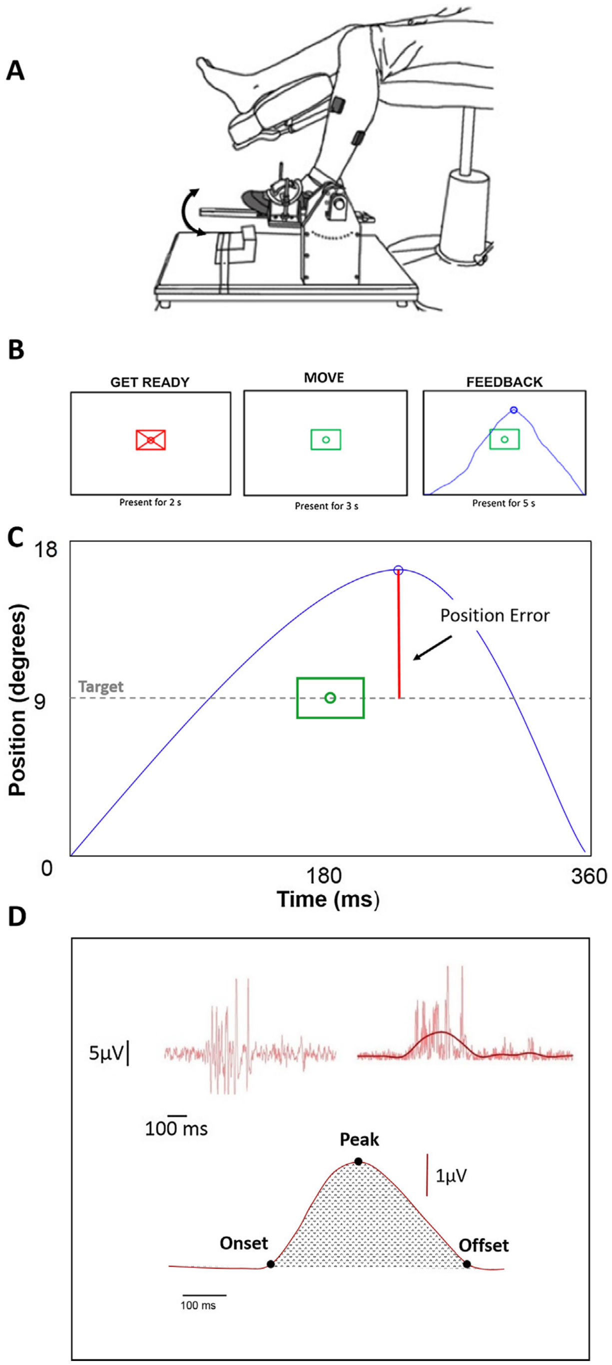

Fig. 1. Experimental set up and goal-directed task. A. The left foot was placed and rested on a customized foot device with an adjustable foot plate and secured by a strap over the metatarsals. Participants performed fast back and forth goal-directed movements with ankle dorsiflexion. B. The task was divided into 3 phases: GET READY, MOVE, and FEEDBACK. During the GET READY phase, participants viewed a red target on the monitor for 2 s and remained relaxed. In the MOVE phase participants initiated the movement (no reaction was required) when the target switched from red to green color. The FEEDBACK phase started at the end of the MOVE phase and lasted for 5 s. Participants received visual feedback of their performance (movement trajectory) relative to the target (9° - 180 ms) C: We quantified position endpoint as the absolute vertical displacement from zero to peak performance. D: We quantified the EMG bursts area from the agonist muscle by detrending, rectifying, and 6 Hz low-pass filtering the interference EMG. We then determined the onset, offset, and peak of each burst to calculate individual muscle activity. The shaded area under the EMG curve represents the *EMG burst area.* (see METHODS for more details). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)