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Learning new gait patterns: Age-related differences in skill acquisition and interlimb transfer

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ABSTRACT

Evidence from upper-extremity literature suggests that the normal ageing process affects an individual's ability to learn and retain a motor skill, but spares their ability to transfer the skill to the untrained, opposite limb. While this phenomenon has been well-studied in the upper-extremity, evidence in the lower-extremity is limited. Further, it is unclear to what extent age-related differences in motor learning and transfer are dependent on visual feedback of the motor task. Therefore, the purpose of this study was to examine the effects of ageing on motor learning, retention, and interlimb transfer during walking with and without visual feedback. Forty-four subjects (24 young; 20 older adults) were tested on a treadmill over two consecutive days. On day 1, subjects learned a new gait pattern by performing a foot-trajectory tracking task that necessitated greater hip and knee flexion during the swing phase of the gait. On day 2, subjects repeated the task with their training leg to test retention, then with their untrained leg to test interlimb transfer. Trials without visual feedback were also collected on both days. Results indicated that older adults had reduced ability to learn the task, and also exhibited lower retention and inter-limb transfer. However, these differences were dependent on visual feedback as the groups performed similarly when feedback was removed. The findings provide novel evidence indicating that ageing impairs learning, retention, and transfer of motor skills in the lower-extremity during walking, which may have implications for gait therapy after stroke and other geriatric conditions.

1. Introduction

Walking is a highly skilled motor behavior that is acquired during infancy, but can be diminished or lost with ageing. Further, ageing increases the risk of chronic diseases like diabetes and arthritis, falls, fractures, and other neurological injuries (e.g., stroke), which can lead to severe gait impairments. Hence, skill learning during walking is an important component of gait rehabilitation in the elderly (Vanswearingen and Studenski, 2014); where, throughout the course of training, they will have to learn, unlearn, and relearn a number of skills related to walking. However, evidence indicates that as we age, our ability to acquire and utilize motor skills is diminished (Mahncke et al., 2006; Ren et al., 2013; Seidler et al., 2010; Vanswearingen and Studenski, 2014), and many older adults do not regain full mobility following injury. Apart from the learning process itself (i.e., skill acquisition), other components of learning, such as retention, consolidation (i.e., offline changes in motor performance after initial acquisition), and transfer (either to new task variants or to the opposite, untrained limb) are also essential processes to facilitate gait recovery during rehabilitation. However, the role of these processes in ageing and skill acquisition during gait is not well understood.

Studies that examine skill learning and other associated components of learning (i.e., retention, transfer, etc.) in older adults are often performed in the upper-extremity. Many of these studies have shown that older adults retain the ability to learn new motor skills, but both the rate at which they learn and their final performance level are reduced in comparison with young adults (Onushko et al., 2014; Rogasch et al., 2009; Seidler-Dobrin and Stelmach, 1998; Smith et al., 2005). Evidence from motor retention research, however, is conflicting, with some studies showing similar levels of retention between age groups (Rogasch et al., 2009; Smith et al., 2005). Interestingly, a majority of the studies that have evaluated the interlimb transfer effects suggest that older

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adults have greater transfer (Graziadio et al., 2015; Wang et al., 2011), and attribute this finding to increased recruitment of both brain hemispheres while performing basic motor skills (Graziadio et al., 2015; Wang et al., 2011). However, a central issue in studying the effects of ageing on motor learning is the widespread inconsistency in the findings. This inconsistency is most likely multifactorial and could be due to the learning mechanism studied (e.g., skill, adaptation, etc.), type of tasks used (continuous, discrete), characteristics of the sample population (e.g., age, cognitive and physical capacities), and data measurement and data analysis techniques (training duration, rest/breaks, measured variables, processing methods). This issue is further complicated because our broader understanding of motor learning with ageing is primarily based on a synthesis of literature from studies examining different components of learning, which is due to a lack of studies that have comprehensively evaluated multiple components of learning, such as skill acquisition, retention, interlimb transfer, etc.

Despite the large body of work in ageing and motor learning, there is a paucity of research examining the effects of ageing on motor learning of a functionally relevant task, such as walking. This is particularly important considering that many of the findings in the upper-extremity may not be applicable to learning with the lower extremity. Much of what we know about age-related differences in motor learning in the lower-extremity is from investigations that have studied the effects of ageing during motor adaptation on a split belt treadmill (Bruijn et al., 2012; Malone and Bastian, 2016; Roemmich et al., 2014; Sombric et al., 2017). While motor adaptation is an important aspect of learning, there are fundamental differences between skill learning and motor adaptation, which limit the generalizability of the results between these paradigms (Bastian, 2008; Krakauer and Mazzoni, 2011; Sternad, 2018). For example, motor adaptation tasks typically involve perturbation, where the participant adapts and learns to improve performance to pre-perturbation levels through sensory-prediction errors (followed by an aftereffect when the perturbation is removed); whereas, skill acquisition tasks generally do not involve perturbation and the participant improves performance based on success-based exploration (Krakauer and Mazzoni, 2011).

To our knowledge, only one study has examined the age-related differences in skill learning in the lower extremity: van Hedel and Dietz (2004) found that older subjects had learning deficits while performing a discrete obstacle avoidance task while walking. While this study makes an important contribution to the existing literature, there is ample evidence to suggest that the learning and retention characteristics of continuous and discrete tasks are quite different (Lee and Genovese, 1989; Schmidt et al., 2018), such that continuous tasks have better retention than discrete tasks (Schmidt et al., 2018). Further, virtually no studies in either the upper- or lower-extremities have performed comprehensive evaluation of learning, retention, consolidation, and interlimb transfer to provide a complete picture of the effects of ageing. Therefore, this study was performed to investigate the differences in motor learning, retention, and interlimb transfer between older and young adults when performing a continuous skill learning task during walking. To investigate these effects, subjects performed a foot trajectory-tracking paradigm that has been previously used for gait rehabilitation (Krishnan et al., 2013; Krishnan et al., 2012; Srivastava et al., 2015). The paradigm requires participants to alter their foot trajectory during the swing phase of gait by increasing their hip and knee excursions in the sagittal plane. We hypothesized that older adults would exhibit reduced learning, retention, and interlimb transfer when compared to the young adults.

2. Methods

2.1. Participants

Participants consisted of 44 adults: 20 older (13 women and 7 men) and 24 young (13 women and 11 men) adults. The age criterion for the older adults was 60–75 years, while young adults were eligible if aged between 18 and 35 years. All participants were right leg dominant as determined by their preferred leg for kicking a ball (Krishnan et al., 2017). Participants with a major lower extremity injury or surgery (e.g., joint replacement), history of neurological disorder, or significant cardiac conditions were excluded from the study. Given that skill learning involves a significant cognitive demand, individuals with significant cognitive deficits (Mini-Mental State Examination [MMSE] score < 24) were also excluded. Written informed consent was obtained prior to participation and all procedures were approved by the University of Michigan Human Subjects Institutional Review Board. Full demographics of the participants can be found in Table 1.

Table 1
Demographics of older and young adults.

Group	Age (years)	Weight (kg)	Height (m)	MMSE[a]	Sleep rating[b]
Old	67.2 ± 4.1	73.4 ± 12.1	1.7 ± 0.1	29.4 ± 0.8	3.4 ± 3.3
Young	24.8 ± 6.9	68.0 ± 12.7	1.7 ± 0.1	29.5 ± 0.8	2.5 ± 1.8

Mini-mental state examination (MMSE).
[a] The mini-mental state examination is scored on a range from 0 to 30.
[b] Self-reported sleep rating was scored on a range from 0 to 10, with 0 being the best possible sleep and 10 being the worst possible sleep.

2.2. Experimental protocol

A schematic of the experimental protocol is shown in Fig. 1A. Participants in both groups performed a motor learning task on two consecutive days (older adults: 25.0 ± 5.5 h and young adults: 22.3 ± 2.0 h) wearing the same foot- and legwear (i.e., shorts or spandex). The motor learning task was performed while the participant was walking on a motorized treadmill (Woodway, USA) at 0.89 m/s (2 mph) with their hands placed over a custom-built treadmill rail system (Fig. 2A). On Day 1, the participant practiced the task with their training (Tr) leg. On Day 2, the participant first practiced the same task with their training leg and then with their untrained (i.e., transfer [Tf]) leg. Before beginning the study, it was randomly determined if the participant's right or left leg would be the training leg (older adults: 10 right leg and 10 left leg; young adults: 13 right leg and 11 left leg).

On each day (and for each leg), the experiment consisted of three phases: (1) pre-test phase (Pre), (2) training phase, and (3) post-test phase (Post). During the pre-test phase, the initial performance was established using a foot-trajectory tracking paradigm, where the participant changed their gait to match a target projected on the monitor (Krishnan et al., 2013; Krishnan et al., 2012; Krishnan et al., 2017; Krishnan et al., 2015). The target was created by scaling (1.3×) the swing phase ensemble average of the hip and knee angles obtained from the normal walking (NW) trajectory, and projecting it in the end-point space (further details are given below). Target-matching performance was evaluated both with (TM) and without visual feedback (NV) of their actual trajectory. The training phase consisted of repeated practice of the foot-trajectory tracking task −8 blocks of practice were performed with each block lasting for 1 min and separated by a one-minute rest period. In the post-test phase, the changes in target-tracking performance were evaluated.

2.3. Target-matching task

We used a custom-designed real-time motion tracking system developed using LabVIEW 2011 and NI Vision Assistant (National Instruments Corp., Austin, TX, USA) for the motor learning task (Fig. 2A) (Krishnan et al., 2015; Saner et al., 2017). The system computed the sagittal plane hip and knee kinematics during walking in real-time by tracking the 19 mm retroreflective markers placed on the participant's greater trochanter, lateral epicondyle of the femur, and the