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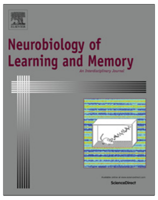

Age-related forgetting in locomotor adaptation

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ABSTRACT

The healthy aging process affects the ability to learn and remember new facts and tasks. Prior work has shown that motor learning can be adversely affected by non-motor deficits, such as time. Here we investigated how age, and a dual task influence the learning and forgetting of a new walking pattern. We studied healthy younger (<30 yo) and older adults (>50 yo) as they alternated between 5-min bouts of split-belt treadmill walking and resting. Older subjects learned a new walking pattern at the same rate as younger subjects, but forgot some of the new pattern during the rest breaks. We tested if forgetting was due to reliance on a cognitive strategy that was not fully engaged after rest breaks. When older subjects performed a dual cognitive task to reduce strategic control of split-belt walking, their adaptation rate slowed, but they still forgot much of the new pattern during the rest breaks. Our results demonstrate that the healthy aging process is one component that weakens motor memories during rest breaks and that this phenomenon cannot be explained solely by reliance on a conscious strategy in older adults.

1. Introduction

The ability to recall motor skills is important for our everyday lives. Anecdotally, we know there are certain motor skills we never forget after they are mastered, such as how to ride a bike or drive a car. However, studies of other types of learning (e.g., declarative learning) demonstrate that memories can be weakened as time elapses (see Backman, Small, and Wahlin (2001) for review). Age has been shown to be an important factor for declarative memory; healthy older subjects forget things more easily than younger ones (see LaVoie and Cobia (2007) for review).

Does healthy aging affect our ability to recall motor memories? Specifically, we asked how motor memories created through adaptation are influenced by age and time. The effects of healthy aging have previously been studied in both skill tasks (i.e., learning tasks that require the acquisition of a new pattern of muscle activations (Krakauer, 2009; Robertson, Pascual-Leone, & Miall, 2004)) and in adaptive learning (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2011). Some studies have shown that motor learning is similar between young and old subjects (Bock & Schneider, 2002; Huang & Ahmed, 2014; Roller, Cohen, Kimball, & Bloomberg, 2002), while others show degradation of learning in older healthy adults (Anguera et al., 2011; Fernandez-Ruiz, Hall, Vergara, & Diiaz, 2000; Huang & Ahmed, 2014; Jordan, 1978; McNay & Willingham, 1998; Warabi, Noda, & Kato, 1986; Wright & Payne, 1985). One explanation for the discrepancies in the literature is the extent to which different motor learning tasks engage explicit strategies. Explicit learning can be impaired in older compared to younger adults, whereas implicit, non-strategic, recalibration mechanisms may remain intact (Bock, 2005; Hegele & Heuer, 2013; Heuer, Hegele, & Sülzenbrück, 2011; McNay & Willingham, 1998). Thus, one hypothesis is that motor learning tasks that can involve more cortical, strategic planning should show greater differences due to aging (Anderson, Craik, & Naveh-Benjamin, 1998; Anguera et al., 2011).

Here we investigated age-related effects on both the ability to adapt to a walking perturbation and the ability to recall the walking pattern following rest breaks during learning. Adaptation is an error-driven process that adjusts existing sensorimotor mappings of well-learned movements to account for new, predictable demands (Martin, Keating, Goodkin, Bastian, & Thach, 1996). Walking is a behavior that relies less on cortical processing compared with other motor learning tasks that are typically studied in aging (e.g. reaching, finger sequencing). Our well-characterized walking adaptation paradigm perturbs subjects via a split-belt treadmill by driving one leg faster than the other (Reisman, Block, & Bastian, 2005). Additionally, our prior work has shown that a dual task can slow adaptation in healthy young adults, which is

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hypothesized to be due to a decreased reliance on conscious or explicit learning processes (Malone & Bastian, 2010). In this study, we first asked if there were differences between young and older subjects in the rate and extent of their adaptation. We then asked if the passage of time weakened the learned motor pattern in young and older healthy adults. Finally, since forgetting was present, we used a dual task to reduce any explicit or strategic components to the walking adaptation, since those processes might be degraded during healthy aging. Our results suggest that aging is associated with a loss of motor memory over short time periods that cannot be explained by a reliance on explicit or strategic processes.

2. Materials and methods

2.1. Subjects

Thirty healthy volunteers (11 males, 19 females) participated in this study. All subjects gave informed written consent before participating. The protocols were approved by the Johns Hopkins Institutional Review Board.

2.2. Experimental protocol

Split-belt walking adaptation was studied using a custom-built treadmill (Woodway, Waukesha, WI). The treadmill had two separate belts driven by independent motors – these belts could be driven at the same speed (“tied-belts”) or at different speeds (“split-belts”). Speed commands for each belt were sent to the treadmill through a custom MATLAB (MathWorks, Natick, MA) computer interface. Subjects were positioned in the middle of the treadmill with one leg on each belt and wore a safety harness that was suspended from the ceiling. The safety harness was adjusted such that it would catch subjects if they fell, but it did not support their body weight while they stood. At the beginning of each trial, subjects were not informed of the upcoming speeds of the treadmill belts and were told to refrain from looking down at the belts. Subjects held onto a ground-referenced rail while the belts were moving. During breaks, subjects remained on the treadmill (either standing or seated).

The experimental paradigm was the same for all subjects (Fig. 1A). Subjects were naïve to the task and began the experiment with three one minute tied-belt trials (1.0 m/s, 0.5 m/s, 1.0 m/s). Then, everyone was exposed to three five-minute exposures to split belts (0.5 ms/ and 1.0 m/s, with each subject’s dominant leg on the slow belt). After each split-belt trial, subjects had a five-minute rest break. Subjects were allowed to either sit or stand on the treadmill without walking during these breaks. Once subjects completed the third exposure to the split-belts, they received another break and then were de-adapted on tied belts at 0.5 m/s for five minutes.

In the first part of the experiment, we tested for the effect of age on locomotor adaptation and forgetting. All participants were classified based on age. We screened subjects to rule out any neurological or cognitive conditions. Subjects in the ‘Younger’ group were less than 30 years of age ($N = 10$, mean age = 22.5 years, standard deviation = 2.6 years; 6 female & 4 male). Subjects in the ‘Older’ group were over 50 years of age ($N = 10$, mean age = 54.9, standard deviation = 2.8 years; 6 female & 4 male).

Then, because we saw forgetting in the ‘Older’ group, we investigated the role of conscious processes on adaptation and forgetting of healthy older adults. We compared our ‘Older’ group to a new group of healthy older adults, ‘Older Distraction’ ($N = 10$, mean age = 52.8, standard deviation = 5.8 years; 7 female & 3 male). Subjects older than 50 years were randomized between the ‘Older’ and ‘Older Distraction’ group. While the ‘Older’ subjects were given no instructions during adaptation, the subjects in the ‘Older Distraction’ group were given a dual-task to complete during their split-belt adaptation periods (Malone & Bastian, 2010). The ‘Older Distraction’ group watched a television program unrelated to walking and were instructed to count the number of times a particular word was said using a hand-held counter. Additionally, they were asked to focus their attention on the television program so that they could answer questions about the program’s visual scenes after the adaptation block finished. Subjects scored 89% (standard deviation 5.3%) on the dual-task. Therefore, these subjects were distracted by both audio and visual stimuli.

2.3. Data collection

Kinematic data were collected at 100 Hz using Optotrak (Northern Digital, Waterloo, ON). Infrared-emitting markers were placed bilaterally over the toe (fifth metatarsal head), ankle (lateral malleolus), knee (lateral femoral epicondyle), hip (greater trochanter), pelvis (iliac crest), and shoulder (acromion process) (Fig. 1B). Voltages reflecting treadmill belt speeds were recorded directly from treadmill motor output at 1000 Hz. Marker position and analog data (treadmill belt speeds) were synchronized and sampled simultaneously using Optotrak software. Heel strike times were approximated using the maximum angle of the limb (Fig. 1B); toe-off time was approximated to be the minimum limb angle.

2.4. Data analysis

In this study, our primary measurement was step length symmetry, which has previously been shown to adapt robustly to split-belt walking (Choi & Bastian, 2007; Choi, Vining, Reisman, & Bastian, 2009; Malone & Bastian, 2010; Reisman, Wityk, Silver, & Bastian, 2007; Reisman, Wityk, Silver, & Bastian, 2009; Reisman et al., 2005; Vasudevan & Bastian, 2010). Step symmetry (SS) was defined as the normalized difference between the step lengths (SL) of the ‘fast’ and ‘slow’ leg:

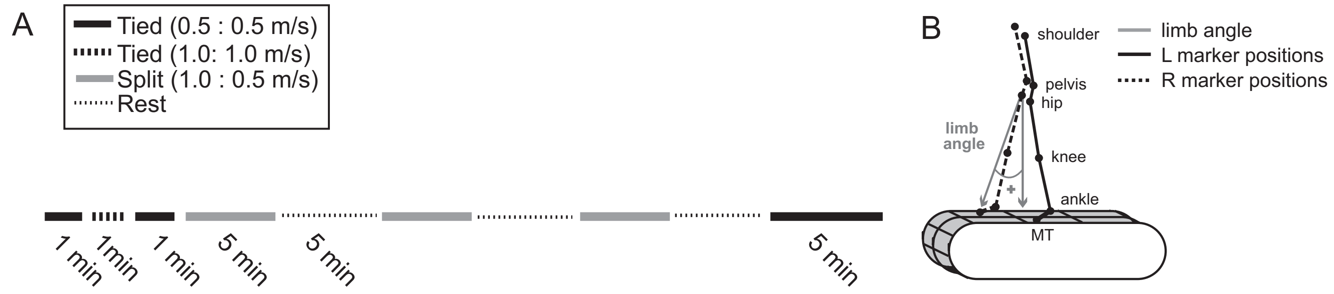

Fig. 1. (A) Diagram of marker location and limb angle convention. (B) Experimental paradigm showing the periods of split-belt waking in gray lines and tied walking in black. All subjects sat or stood for five minutes between adaptation blocks.