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Gait variability in healthy old adults is more affected by a visual perturbation than by a cognitive or narrow step placement demand

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ABSTRACT

Gait variability measures have been linked to fall risk in older adults. However, challenging walking tasks may be required to elucidate increases in variability that arise from subtle age-related changes in cognitive processing and sensorimotor function. Hence, the study objective was to investigate the effects of visual perturbations, increased cognitive load, and narrowed step width on gait variability in healthy old and young adults. Eleven old (OA, 71.2 ± 4.2 years) and twelve young (YA, 23.6 ± 3.9 years) adults walked on a treadmill while watching a speed-matched virtual hallway. Subjects walked: (1) normally, (2) with mediolateral visual perturbations, (3) while performing a cognitive task (serial seven subtractions), and (4) with narrowed step width. We computed the mean and variability of step width (SW and SWV, respectively) and length (SL, SLV) over one 3-min trial per condition. Walking normally, old and young adults exhibited similar SWV and SLV. Visual perturbations significantly increased gait variability in old adults (by more than 100% for both SWV and SLV), but not young adults. The cognitive task and walking with narrowed step width did not show any effect on SWV or SLV in either group. The dramatic increase in step width variability when old adults were subjected to mediolateral visual perturbations was likely due to increased reliance on visual feedback for assessing whole-body position. Further work is needed to ascertain whether these findings may reflect sub-clinical balance deficits that could contribute to the increased fall risk seen with advancing age.

1. Introduction

Approximately one-third of adults over 65 fall annually with a majority of these falls occurring during locomotion [1]. The underlying causes of these falls presumably arise from a number of physiological factors including reduced sensory acuity [2,3], diminished executive function [4], reduced cognitive capacity [5], decreased muscle strength [6,7], and slowed neuromuscular function [6]. Although these phenomena are common features of aging, the manner in which they affect balance function during walking is not well understood. For example, even if an individual scores in the normal range for all of these physiological areas, subtle age-related changes may disrupt old adults' ability to maintain balance in a challenging environment and contribute to a first fall.

Prior studies have used gait variability to characterize balance during walking [8–10]. In fact, substantial differences in gait variability (e.g. standard deviation or coefficient of variation of stride time, step width or step length over many steps) have been reported between old adults with and without a history of falls [11,12]. Compromised mediolateral balance is particularly relevant as it requires fine sensorimotor control of foot placement from step to step [8]. However, healthy old adults often exhibit gait variability similar to young adults during normal, unencumbered walking [4]. Hence, gait variability during normal walking may not be sufficiently robust to identify old adults at risk of a first fall.

In the literature, challenging walking task paradigms have been used to elucidate the influence of aging on walking performance [9–11,13–16]. These challenging walking tasks are often designed to target the functional consequences of aging on sensory, cognitive and/or neuromuscular function. For example, the use

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of altered lighting conditions, vibrating insoles or virtual environments can manipulate sensory feedback and alter gait variability [8,14,17]. Attention-demanding tasks during walking, such as mathematical calculations, have also been shown to preferentially increase gait variability in old adults [10,13,15]. Finally, manipulating foot placement using balance beams or obstacles may reveal differences in neuromuscular function, reflecting an inability to cope with challenges present in the physical environment [16,18]. These additional task requirements have shown promise to expose age-related differences in balance during walking; however, their comparative effects are not yet well understood.

The purpose of this study was to investigate the effects of perturbed visual feedback, increased cognitive load, and narrowed step width demands on gait variability in healthy old and young adults. We first hypothesized that during unencumbered walking, old and young adults would walk with similar step width variability (SWV) and step length variability (SLV). Second, with the addition of challenging task requirements, SWV and SLV would increase more in old adults than young adults. Our clinical motivation was to identify relative increases in old adults' SWV and SLV that point to opportunities for early diagnosis of age-related balance deficits.

2. Methods

2.1. Subjects and experimental protocol

Eleven old adults (mean ± standard deviation; age: 71.2 ± 4.2 years, height: 1.64 ± 0.06 m, mass: 66.9 ± 9.6 kg, 10 female) and twelve young adults (age: 23.6 ± 3.9 years, height: 1.69 ± 0.25 m, mass: 70.7 ± 11.3 kg, 7 female) participated in this study. Subjects were included if they walked without an assistive device, were free of orthopedic injuries in the prior six months, had no neurological injury or pathology, and met the American College of Sports Medicine cardiovascular guidelines for exercise. Additionally, subjects could not have experienced an unexpected fall [19] in the previous six months. They were also required to score in the normal range on the Dynamic Gait Index (DGI) [20], a series of eight walking tasks (e.g. turning one's head while walking, changing speeds, navigating stairs) each worth up to three points. Individuals scoring below 19 are considered to be at an increased risk of falling. The old adults in this study scored an average of 23.8 ± 0.6 on the DGI. All subjects provided written informed consent as per the University of Wisconsin-Madison Health Science Institutional Review Board.

At the beginning of each session, subjects walked along a 10 m walkway at a comfortable pace. We used the average of two times taken to traverse the middle 6 m of the walkway to prescribe subjects' treadmill speed. During the treadmill familiarization period, three old adults reported being unsure that they could complete the treadmill walking trials at their over-ground speed. We therefore reduced the treadmill speed by 10% for these subjects. To ensure subject safety, old adults used a harness during treadmill testing that was adjusted such that it would prevent a full fall but was slack enough to allow free movement around the treadmill surface without providing substantial haptic feedback. Subjects then completed a series of four 3-min walking trials on a split-belt instrumented treadmill (Bertec, Columbus, OH) presented in a random order. The four conditions included normal walking (Normal), mediolateral visual perturbations (Visual), a cognitive challenge (Cognitive), and narrow step width (Narrow), each described in detail below. All tasks were performed with the subject facing a semi-circular rear-projection screen, which displayed a virtual hallway moving at the same speed as the treadmill (Fig. 1a). This system was described in more detail by O'Connor et al. [8]. To investigate the confounding effects of walking speed, young adults repeated all conditions at 80% of their preferred speed.

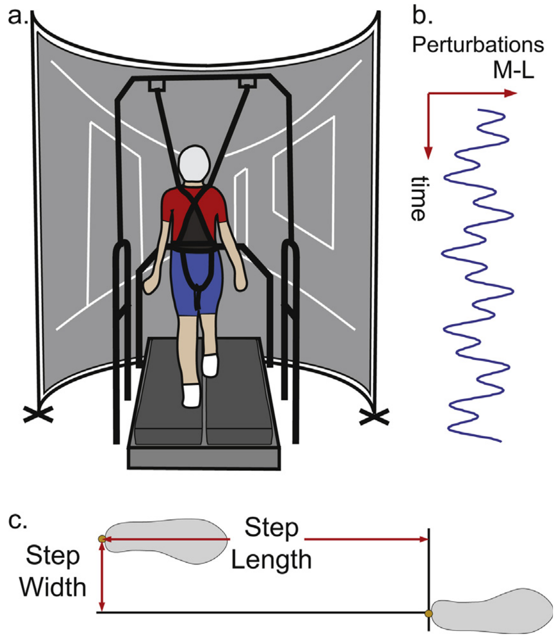

Fig. 1. Experimental setup. (a) Subject walks on a split-belt treadmill surrounded by a semi-circular projection screen. A rear-projected virtual hallway moved at the same speed as the treadmill. Old adults wore a harness during testing that was adjusted to prevent falls but still allow free movement around the treadmill surface. (b) During the visual perturbation trial, we added a mediolateral perturbation consisting of a sum of sinusoids to the virtual hallway motion. (c) Step width and step length were calculated from heel kinematic data for both left-right and right-left steps.

For the normal walking condition, subjects were asked to walk normally while watching the virtual hallway. During the visual perturbation condition, a continuous mediolateral motion consisting of the sum of two sinusoids (0.135 and 0.0442 Hz) with 0.175 m amplitudes was added to the speed-matched virtual hallway (Fig. 1b) [8,17]. This mediolateral motion was applied such that the fore-ground translated at the full amplitude of the perturbation while the end of the hall remained nearly stationary. This ensured that perturbations challenged walking balance and not control of heading. During the cognitive challenge condition, subjects walked while counting backwards by sevens starting at a prescribed random three-digit number [4]. In the event that subjects reached zero before the trial was complete, they continued from a new prescribed three-digit number. For the narrow step width task [16], subjects were asked to place each step on the 1 cm gap separating the two treadmill belts as if they were on a balance beam. During this trial, subjects were allowed to look at their feet as needed.

2.2. Measurements and data analysis

Three dimensional pelvic and foot kinematics were recorded at 100 Hz using a passive motion capture system (Motion Analysis, CA) to track retro-reflective markers placed on the sacrum and both heels. Kinematic data were low-pass filtered at 8 Hz using a 4th order Butterworth filter. We then identified heel strikes from peaks in the fore-aft position of the heel markers relative to the sacral marker [21]. We computed right-left and left-right step width (SW) values from consecutive mediolateral heel positions averaged over a period from 12–25% of the gait cycle (heel-strike to heel-strike), corresponding to mid-stance prior to heel-rise [22] (Fig. 1c). Step length (SL) was computed as the relative fore-aft position of successive heel markers at 20% of each gait cycle plus