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Age-related alterations in reactive stepping following unexpected mediolateral perturbations during gait initiation

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ABSTRACT

Background: A common technique to regain stability following an unexpected perturbation is reactive stepping, aimed to control the accelerated center of mass (COM). Many older adults (OA) struggle to execute the fast, coordinated stepping strategy required to arrest COM movement within the base of support (BOS) during these unexpected events, likely due to age-related physiological declines. Recent ecological data also suggests that many falls in OA occur due to errors in transferring or shifting body weight during activities of daily living. The present study utilized gait initiation, which requires a coordinated transition from quiet stance to dynamic gait, as an example of one of these difficult transitional movements.
Research Question: Our goal was to combine this inherently unstable task, gait initiation, with an unexpected mediolateral (ML) perturbation of the support surface to examine age-related changes in reactive stepping patterns during a novel transitional gait task.
Methods: A total of 18 young adults (YA) and 16 OA (> 65 years) performed 35 trials containing 10 unexpected ML perturbations of the support surface. To quantify age-related differences, we calculated step width, length, time and COM velocity in the first two steps following the perturbation.
Results: We observed that, in general, OA walked slower and took shorter, faster steps (reducing time in single support) compared to YA. Following the perturbation, OA altered their stepping patterns by reducing their BOS (more narrow step width compared to YA), and required more than the two steps used by YA to complete the goal-directed task.
Significance: These age-related changes are concerning as a multi-step recovery strategy has been previously associated with an elevated risk of falls in OA.

1. Introduction

Falls are a leading cause of preventable emergency room visits with 30% of older adults (OA) falling at least once a year [1,2]. A possible mechanism for these falls may be related to insufficient/ineffective balance recovery mechanisms produced by OA when faced with an unexpected loss of balance [3,4]. A prevalent strategy aimed to recover balance involves an alteration to the size of the base of support (BOS). The most commonly used strategy is compensatory stepping [4,5], requiring a quick and coordinated response, much faster than a volitional stepping effort [6]. Due to age-related declines in both reaction time [7] and peak muscle strength [8], it is likely that OA struggle with executing the fast and coordinated swing foot placement required to arrest the center of mass (COM) within the [4,5].

To examine these reactive steps, researchers can experimentally induce an unexpected perturbation [9]. In contrast to slips induced by a low friction environment (e.g. glycerin on travel path) a mechanical perturbation platform facilitates experimental control over which foot is perturbed, slip distance and when in the gait cycle the perturbation occurs [9]. In OA, falls occurring in the medio-lateral (ML) direction are of significant concern as a greater proportion of falls have been reported in the frontal plane [5,10]. It has previously been argued that falls in the ML direction are of particular concern in an OA population due to increased instability in this direction [11,12], possibly attributed to reduced hip strength and mobility [11].

To our knowledge only two studies have used a ML perturbation delivered during an over ground walking task [11,14] and one stepping in place task [5]. A study which analyzed responses to ML perturbations during quiet stance and when stepping in place, revealed OA often used more than two small sideways directed recovery steps, whereas younger adults (YA) required no more than two [5]. OA possibly employ this strategy as it reduces time spent in single limb support (swing

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time) [5]. These additional steps may also be required to counteract any instability generated as a result of their initial stepping response [5]. Previous work during a dynamic tasks reported that OA take shorter and more narrowed steps (reduced step length/width) following a perturbation and take more steps to return to pre-perturbation gait patterns [11]; in YA, stride length decreased following a perturbation, however stride time increased for both the perturbed and unperturbed limb [14].

An interesting study conducted by Robinovitch et al. [10] video captured 226 real world falls in OA residing in an assisted living facility, providing critical ecological data that revealed the most abundant mechanism (41%) was due to an incorrect transfer or shift of body weight. We argue that gait initiation (GI) is an excellent example of a critical and challenging transitional locomotor task. Representing a transition from quiet stance to dynamic motion. During GI, the central nervous system coordinates a series of anticipatory postural strategies to laterally shift the COM to the stance limb [15], creating instability in the ML direction [16]. If an externally applied perturbation was applied during this transfer phase, reactive stepping would be necessary. Only one published study has analyzed responses to a perturbation delivered during GI [17] and this prior work focused on AP slip perturbations (glycerin treated surface) at the initial heel contact (HC).

Our goal was to combine an internal perturbation (GI) with a *concurrent,* externally driven perturbation (support surface translation) to ascertain age-related differences in the recovery stepping patterns generated while completing a goal oriented locomotor task. It was hypothesized that OA would experience greater difficulty in attenuating the destabilizing effects of the perturbation. As has been previously reported, we expected that OA would walk with a reduced velocity and shorter step lengths compared to YA (even in non-perturbed trials) and that OA would generate small 'shuffle' steps following perturbation – depicted by a series of short and narrowed steps taken rapidly in order to minimize their time spent in single support.

2. Methods

2.1. Participants and inclusion criteria

Sixteen community dwelling OA (9 males, 7 females; age: 75.6 ± 5.3 years, height: 1.70 ± 0.10 m and weight: 72.7 ± 13.4 kg) and eighteen healthy YA (10 males, 8 females; age: 21.7 ± 2.6 years, height: 1.80 ± 0.10 m and weight: 72.8 ± 11.0 kg). All subjects had no prior experience with perturbation studies or preexisting self-reported musculoskeletal, neurological or cardiovascular conditions. Participants were required to be right foot dominant, assessed using the Waterloo Footedness questionnaire [18] which determines footedness via 12 questions that probe preferred foot to complete specific tasks, e.g. kicking a soccer ball. Subjects gave written consent to participate; study was approved by the institutional research ethics board (REB#16OC003).

2.2. Protocol

A total of 27 reflective markers and 5 rigidly mounted triads of reflective markers were affixed to anatomical landmarks (e.g. head, trunk, arms, etc.) to track the motion of body segments. The markers facilitated the estimation of a 13-segment COM model (*adapted from* [19] through exclusion of the rib markers as the harness occluded markers from cameras). Kinematic markers were sampled at 100 Hz using 12 passive 3D Optitrack cameras (Natural Point Inc., OR, USA) and data was recorded using Motive software (Natural Point Inc., OR, USA). Gait was initiated from quiet stance via a force plate (FP; 0.60 x 0.90 m; Advanced Mechanical Technology Inc., MA, USA) sampled at 1000 Hz. The FP was mounted on top of a custom robotic platform (3 × 5 m). A ML perturbation was triggered when the FP registered a vertical force equivalent to 104% of the participant's body weight (∼ just prior to lead toe off,). This timing was chosen to simulate a 'real world' slip that might occur on a wet/icy floor. Pilot testing indicated that this was the ∼ onset of the COM lateral transition under the stance limb. At least one practice trial was performed to ensure all participants understood the task. All subjects were asked to initiate gait with the right foot and complete the goal-oriented task ("*Walk to the end of the platform at a comfortable walking pace*"). This study was part of a larger experimental paradigm that used the second force platform to deliver AP perturbations (10 total) upon heel contact of the first step. The orientation of these two force plates on the support surface allowed for us to trigger AP and ML perturbations (with different thresholds) in one experimental session in a random fashion. This reduced the ability of our participants to anticipate the direction of the platform movement and additionally meant that just one laboratory visit for our participants was required, an important consideration for our OA participants. Given the nature of the responses observed, the present study will only report stepping responses following NP and ML directed perturbations; details regarding responses to AP perturbations will follow in a subsequent report.

A total of 35 GI trials were collected in a block randomized design: 4 anterior, 6 posterior, 6 left (LP), 4 right (RP) and 15 no perturbation (NP). Although this experimental design resulted in an unequal number of trials within each perturbation direction, prior research has similarly used between 4–6 trials per perturbation condition [4,5,9,11] Perturbation magnitude was equal in all directions; a total displacement of 18 cm, and a peak velocity and acceleration of 60 cm/s, 2 m/s^2, respectively. A previous study within our lab [11] used similar perturbation characteristics, adapted from [6] and found them to be destabilizing yet safe for an OA population. Since gait was always initiated with the right foot it was expected for a RP to cause a cross-over step and a LP would result in a widening of the subject's initial stance. A pseudo randomized experimental design was utilized to reduce the possibility that participants were anticipating the five different conditions; within each of the three blocks the number of perturbations in each direction was pre-specified and near equal between blocks.

2.3. Data processing

All kinematic data was processed using Visual 3D software (Version 6, C-Motion Inc., MD, USA). Data was interpolated to account for marker occlusion (< 10 frames) and filtered (dual pass 6 Hz Butterworth filter). HC was defined using the vertical velocity of the heel marker. On the descent of this sinusoidal signal, the instant in time when the velocity returned to a value of 0.04 m/s (≥10 frames) was denoted HC [20]. This near-zero threshold velocity has been previously identified by our lab group as an accurate and specific method for identifying temporal events of the gait cycle [20]. Position of the heel marker was subtracted from the iliac marker to identify toe-off (TO) events (*adapted from* [21]).

Step width and length spatial parameters were defined as the lateral and anterior distances between the heel markers in the frontal and sagittal plane at the instant of HC, respectively; negative step width represents a cross-over step (lead foot in front and lateral to trail foot). Swing time was the duration time from the instant of TO to HC. Whole-body COM velocity was taken at the instant of Step 1 and 2 HC. Analyses focused on the recovery steps following the perturbation (*adapted from* [5]); by this definition included two steps; a lateral step, followed by a forward directed step by the contralateral limb. The nature of the goal directed task required subjects to walk forward to the end of the platform. We noted if additional recovery steps (> 2) were required to attenuate the effect of the elicited perturbation. To this end, we adapted the recovery step definition proposed by Maki et al. [5] and counting the number of additional steps required (following the expected two steps) for the participant to return to forward progression.