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Leg preference associated with protective stepping responses in older adults

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ABSTRACT

Background: Asymmetries in dynamic balance stability have been previously observed. The goal of this study was to determine whether leg preference influenced the stepping response to a waist-pull perturbation in older adult fallers and non-fallers.

Methods: 39 healthy, community-dwelling, older adult (>65 years) volunteers participated. Participants were grouped into non-faller and faller cohorts based on fall history in the 12 months prior to the study. Participants received 60 lateral waist-pull perturbations of varying magnitude towards their preferred and non-preferred sides during quiet standing. Outcome measures included balance tolerance limit, number of recovery steps taken and type of recovery step taken for perturbations to each side.

Findings: No significant differences in balance tolerance limit ($P \geq 0.102$) or number of recovery steps taken ($\eta^2_{\text{partial}} \leq 0.027$; $P \geq 0.442$) were observed between perturbations towards the preferred and non-preferred legs. However, non-faller participants more frequently responded with a medial step when pulled towards their non-preferred side and cross-over steps when pulled towards their preferred side ($P = 0.015$).

Interpretation: Leg preference may influence the protective stepping response to standing balance perturbations in older adults at risk for falls, particularly with the type of recovery responses used. Such asymmetries in balance stability recovery may represent a contributing factor for falls among older individuals and should be considered for rehabilitation interventions aimed at improving balance stability and reducing fall risk.

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1. Introduction

Aging effects on lateral balance are apparent. Laterally-directed falls, which result in landing impact near the hip, increase the risk of hip fracture (Hayes et al., 1993). Older adults tend to be less efficient in recovering from standing balance perturbations and to select less effective stepping strategies in response to lateral challenges to standing balance (Mille et al., 2005). Decreased ability to control lateral balance or to respond to lateral perturbations to balance stability effectively, in turn, increases risk of falling (Hilliard et al., 2008). Stepping responses to lateral standing balance perturbations are well-characterized. Three recovery stepping strategies are commonly observed (Maki et al., 2000; Mille et al., 2005; Yungher et al., 2012): 1) a lateral side step with the passively loaded leg; 2) an unloaded crossover step with the passively unloaded leg in front of or behind the body; and 3) an unloaded step with the passively unloaded leg that moves medially towards the passively loaded leg followed by a lateral step with the passively loaded leg (Fig. 1).

Older adults use multiple step recoveries more than younger adults (Patton et al., 2006). Older adult fallers also begin taking steps at lower perturbation magnitudes (Patton et al., 2006) and have a lower "balance tolerance limit" (BTL, limit at which multiple step rather than single step recovery strategies are used) than older adult non-fallers (Yungher et al., 2012). Younger adults often use lateral side-stepping strategies when exposed to lateral waist-pull perturbations whereas older adults tend to use crossover stepping response strategies (Mille et al., 2005, 2013). These studies have mostly focused on responses to perturbations in one direction only (Patton et al., 2006) or grouped outcomes from perturbations to the left and right together (Mille et al., 2005; Yungher et al., 2012); they have not yet examined whether stepping responses are dependent on the perturbation direction with respect to leg preference.

Asymmetries in dynamic balance stability have been observed using various mechanical (McAndrew Young et al., 2012; Rosenblatt and Grabiner, 2010) and nonlinear measures of stability (Granata and Lockhart, 2008). However, these stability asymmetries have not always been statistically significant and their clinical significance remains unknown. One previous study indicates that asymmetries in dynamic stability may be associated with fall-risk status in older adults (Granata and Lockhart, 2008). As such, asymmetries in dynamic stability may represent a previously unrecognized precipitating factor for falls in older adults.

Leg preference has been indicated as a potential contributing factor to balance asymmetries (Rosenblatt and Grabiner, 2010). The "preferred" or "dominant" leg depends on the activity. Peters (Peters, 1988) suggested that the preferred leg is the leading or "manipulating" leg and the non-preferred leg is the support leg. In a one-leg standing balance or ball-kick test, the leg on which an

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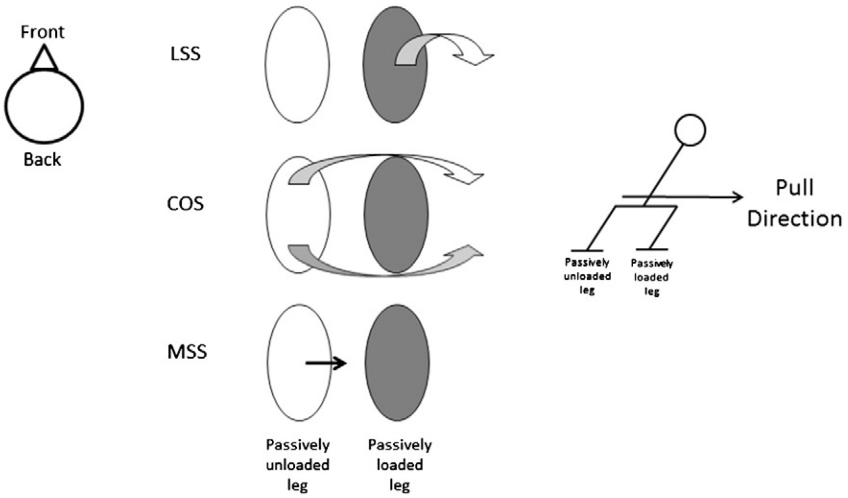

Fig. 1. Step type definitions for lateral side step (LSS), crossover steps (COS) and a medial side step (MSS). During a COS, the stepping limb can either cross in front of or behind the stance limb.

individual stands is the non-preferred leg and the lifted or kicking leg is the preferred or dominant leg. Previous work indicates that leg dominance, where dominance was defined as the kicking leg, does not appear to influence unperturbed single-leg standing postural balance of young adults (Alonso et al., 2011). However, no studies have investigated this relationship in older adults. Moreover, marked asymmetries in minimum toe clearance, an indicator of potential to fall, between the dominant and non-dominant limbs during walking in older adults at high-risk for falls have been observed (Nagano et al., 2011).

We wanted to determine how leg preference affected balance recovery strategies in older adults with and without a history of falling following a perturbation to standing balance. We defined the preferred/non-preferred leg based on the suggestion of Peters (Peters, 1988) using a one-leg balance test and administered lateral standing balance perturbations at the waist in the directions of participants' preferred and non-preferred legs. We reasoned that participants' balance would be more challenged when individuals were perturbed towards their non-preferred, or stabilizing, leg because the stabilizing leg was also the less dexterous leg and as such less likely to be used to quickly respond to the balance perturbation. We hypothesized that older individuals, regardless of fall status would (1) be more likely to take multiple, riskier recovery steps at a lower perturbation magnitude (i.e. have a lower BTL), (2) require more recovery steps and (3) utilize less biomechanically favorable stepping strategies (i.e. use more crossover steps) when perturbed towards their non-preferred (i.e. support) side. We further hypothesized that older adults with and without history of falling would exhibit systematic differences in the numbers of steps and stepping strategy utilized to recover their standing balance. Specifically, we predicted that older adults with a history of falling would take more steps and use crossover stepping strategies more frequently than older adult non-fallers when pulled towards their non-preferred, or stabilizing, leg.

2. Methods

Thirty-nine healthy, community dwelling older adult volunteers participated (20 males/19 females, 65–87 years old). Potential participants underwent a telephone screen and medical examination. Exclusion criteria included: 1) cognitive impairment (Folstein Mini Mental Score <24); 2) sedative use; 3) non-ambulatory; 4) any clinically significant functional impairment related to musculoskeletal, neurological, cardiopulmonary, metabolic or other general medical problems; 5) participated in any regular vigorous or muscle strengthening exercise regimen; and 6) Centers for Epidemiological Studies Depression Survey score >16. All participants provided written, informed consent prior to participation, and the study was approved by the Institutional Review Board at the University of Maryland School of Medicine and the Baltimore Veteran's Administration Medical Center.

Participants were grouped into faller and non-faller cohorts based on fall history in the 12 months prior to the study (Lord et al., 1999). A fall was defined as “coming to rest unintentionally on the ground or lower level, not as a result of a major intrinsic event (such as stroke) or overwhelming hazard” (Tinetti et al., 1988). Any individual who fell 1 or more times in the past year was classified as a faller.

The experimental setup has been previously presented (Yungher et al., 2012). Briefly, participants received 60 lateral waist-pull perturbations of varying magnitude during quiet standing using a custom stepper motor waist-pull system for inducing protective stepping (Pidcoe and Rogers, 1998). Participants wore a belt around their waist to which cables for the waist-pull system were attached and through which the perturbations were applied. The application point of the perturbation was standardized for different body types by aligning the pulling cables with the same anatomical landmarks (pelvis markers) for each subject. Six trials were conducted for each of 5 different pull intensities to the left and to the right (2 directions × 5 intensities × 6 repetitions). The smallest pull magnitude (Level 1) caused a displacement of 4.5 cm at 8.6 cm/s. The largest pull magnitude (Level 5) caused a displacement of 22.5 cm at 50 cm/s. The order in which the trials were presented was randomized to prevent anticipatory and sequence learning effects.

Participants stood in a self-selected, comfortable standing position at the start of each trial with each foot on a separate force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA). Foot tracings, of the self-selected foot placement, ensured consistent foot placement between trials. They were instructed to “relax and react naturally to prevent themselves from falling.” Kinetic data were collected at 600 Hz. Kinematic data were collected using a 6-camera motion analysis system (Vicon, Centennial, CO, USA) at 120 Hz. Reflective markers were placed bilaterally on the following anatomical landmarks: mastoid process, acromion process, lateral elbow joint, radial and ulnar prominences of wrist, anterior and posterior superior iliac spine, greater trochanter, lateral knee and lateral malleolus. A single marker was also placed in the center of the forehead. Wand markers were attached bilaterally to the upper arm, thigh and lower leg.

Numbers and types of steps were documented by observation and kinematic data. Step count was the number of steps taken to recovery

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