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# Aging and the recovery of postural stability from taking a step

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ABSTRACT

The study examined the effect of aging adults (young: 18-26 years vs. old: 66-73 years) on the recovery of postural stability from taking a single volitional step that varied in direction (forward, backward, sideways) onto force platforms. The recovery of postural stability (as indexed by an exponential decay function) was determined from the dynamic stability of the motions of the center of pressure (COP), center of mass (COM) and virtual time to contact (VTC). The findings showed that in all step directions the older adults required more time to securely perform the step and were less stable after the second foot contact with the surface of support. The decay rate of the recovery of the COP, COM and VTC stable dynamics was reduced and the minimum of VTC lower in the old in contrast to the young adults. The findings reveal that even in taking a single step with preferred spatial–temporal dynamics older adults are slower and less stable in recovery of stance through more closely challenging the limits of the postural stability boundary and its associated potential of a fall.


## 1. Introduction

Stepping is one of the most prevalent mechanisms to restore balance and avoid falling after a perturbation [2,12,15]. The experimental paradigm of releasing participants from a forward-leaning position has gained insight into the compensatory stepping mechanisms in aging adults [2,25,29]. It has been shown that the recovery performance among the elderly is inferior to that of young adults. For instance, old adults showed a delayed reaction [29], a reduced step length [10], a slower stepping velocity [29] and a reduced maximum release angle [6,25]. Most strikingly is the finding that old adults tend to use multiple steps to recover balance that is assumed to indicate a greater risk of falls [5,6,10,12,15,25,30].

Comparatively little is known about the balance recovery from the very common activity of daily living: namely, that of taking a single step to another postural location [7,9,13,18]. Recovering balance from taking a single step is fundamental to preserving functional mobility. It is, therefore, important to increase the understanding of age-related changes in the stability of volitional stepping [7] to determine factors that might contribute to a greater risk of falling. Furthermore, it is essential to analyze the preferred spatial–temporal dynamics of spontaneous daily maneuvers [3,22].

Our previous research has shown that the time to reacquire a stable upright standing posture after taking a forward step was increased in old people compared to young adults [7]. However, critical parameters of recovery from a step, such as the initial instability, the stabilization rate and the level of recovered postural stability have previously not been quantified among the elderly. Therefore, here we model the temporal and spatial characteristics of recovering upright stance from taking a single step. We investigated this adaptive postural motion in relation to the base of support by calculating the virtual time to contact (VTC) [20] in order to determine the instantaneous stability and risk of falls throughout the recovery process [8]. Thus, we are examining the extension of the role of VTC in the regulation of quiet standing [5,20] to the time to recover postural stability from taking a step.

The purpose of this study was to investigate the recovery of postural stability from the natural and common task of taking a single step to change postural location. This process was examined as a function of age (young vs. old adults) and the direction of taking a step (forward, backward and sideways). We hypothesized that the recovery rate of adaptation and level of postural stability, as indexed by the relaxation dynamics of center of mass (COM), center of pressure (COP) and VTC, would be influenced by aging and the step direction. It was predicted that aging would slow the process of the recovery of stability [7,23] but also lead to a smaller

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safety margin of stability in VTC [20]. Furthermore, based on the demonstrated directional effects on step performance during the initiation of compensatory stepping in response to a visual cue [11,17] it was hypothesized that the direction of taking a volitional step would also mediate the rate of the recovery of stabilization from taking a single step, and that a sideways step would be the least stable step direction for recovery of stability [27].

## 2. Methods

### 2.1. Participants

Twenty-four adults free from neurological or neuromotor disorders and a history of falling volunteered for this study. There were 12 young adults (7 females and 5 males) with a mean age of $22.2 \pm 2.6$ years and 12 old adults (6 females and 6 males) with a mean age of $69.7 \pm 2.3$ years. All participants were non-fallers and stated to be right leg dominant. They provided written informed consent approved by the Institutional Review Board of the Pennsylvania State University.

### 2.2. Instrumentation

Force platform data were collected using two adjacent AMTI (American Mechanical Technology, Inc., Watertown, MA) strain gauge force platforms. The ground and the platforms were at the same level. In addition, the QUALISYS motion capture system (Qualisys AB, Gothenburg, Sweden), consisting of six ProReflex cameras, 22 passive reflective skin markers and the QUALISYS Track Manager Software were used. Both kinematic and kinetic data were synchronized and sampled at 100 Hz.

### 2.3. Tasks and procedures

The experimental conditions were taking a step forward, backward and sideways from an original posture of side-by-side quiet stance. The task goal was to take one single step from a stationary position and subsequently stand as still as possible for the remaining duration of the trial without further adjustments to the foot placement. An audio signal marked the beginning of data recording. Participants were then free to initiate the step when they were ready (no reaction protocol). Therefore, the total trial duration was 40 s to ensure subsequent data analysis of the first 25 s after the step was completed. In the forward and backward step conditions, participants were asked to stand at a comfortable distance to the platforms and take a step forward or backward onto the platforms. Each foot should be placed on one of the two platforms. Participants were asked to not look down when taking the step and looking instead at a focal point at eye level on the wall. Throughout the trial, arms were crossed above the chest. When taking a step sideways, participants stood close to the edge of one platform and then took a step sideward, so that one foot was placed on each of the platforms as in the forward and backward step conditions. Each step direction was repeated three times and the order of step direction was randomized for each participant. All steps were taken with the right foot first and the participants were free to choose their preferred pace and distance when taking a step. As a safety precaution for the elderly participants a second experimenter stood in reaching distance back of the participant throughout the experiment.

### 2.4. Data processing

Custom written MATLAB (MathWorks, Natick, MA) codes were used to process the data. Prior to computing the center of pressure (COPnet) position, the ground reaction force and moment signals were digitally low-pass filtered with a 4th-order zero-lag Butterworth filter with a cutoff frequency at 10 Hz. Furthermore, based on the low-pass filtered (cutoff frequency at 6 Hz) marker locations, the total body center of mass (COM) was computed as the weighted sum of the center of mass positions of the head, upper arms, forearms/hands, thorax/abdomen, pelvis, and thighs, shanks and feet [28].

The onset of the stabilization phase after taking a step (*t0*) was based on the vertical ground reaction forces (GRF) of the two force platforms (Fig. 1). Similar to [18], the time instant *t0* was defined as the instant at which the second foot touched the force platform and exceeded $0.15\times$ body weight the first time. Subsequent data analysis examined the postural adjustments during the first 25 s following time instant *t0*.

### 2.5. Data analysis

The step time and length were provided as standard metrics of taking a step [2,10,29]. The step time was defined as the time elapsed between lifting the right foot and ground contact of the left foot (time instant *t0*). The step length was normalized by leg length.

Further, we computed the 2D displacement (anterior–posterior (AP) and medial–lateral directions (ML)) between two consecutive time instants for both the COP and COM. Dividing the resultant 2D displacement time series by *dt* gave the COP and COM velocity time series that were used to quantify the magnitude of postural motion. In addition, boundary-relevant postural stability was assessed through computing the virtual time-to-contact (VTC) time series of the vertical projection of the COM with the 2D stability boundary [8,20]. The VTC algorithm is provided in Appendix A.

The COP and COM velocity time series and the VTC time series were further processed using a sliding window algorithm. During each window of 1 s width the RMS of the signal was computed. The resultant RMS time series of 24 s length was used to analyze the recovery process from taking a step. The stabilization process was modeled with the best fit of an exponential decay function of the RMS time series [18] of each variable (COP and COM velocity, and VTC):

$$yFit = yIn\,f + a \cdot e^{-\lambda t} \quad (1)$$

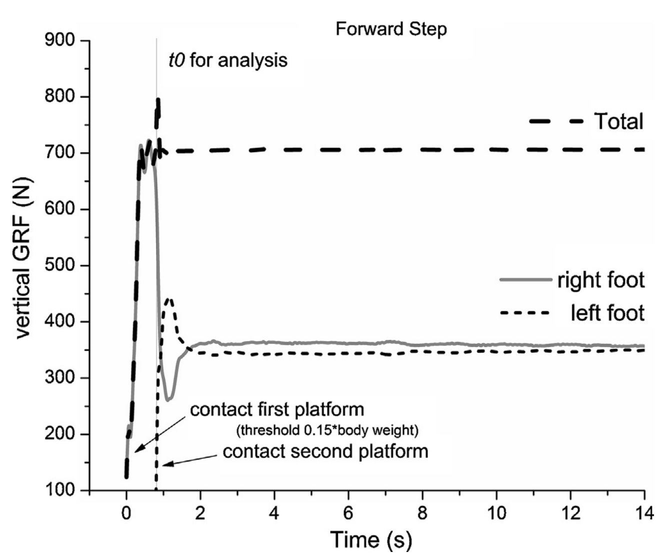


**Fig. 1.** Representative vertical ground reaction force (GRF) profiles of the right and left foot and the total GRF when taking a step forward.