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# Age-related changes in mediolateral dynamic stability control during volitional stepping

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The control of mediolateral dynamic stability during stepping can be particularly challenging for older adults and appears to be related to falls and hip fracture. The specific mechanisms or control challenges that lead to mediolateral instability, however, are not fully understood. This work focussed on the restabilisation phase of volitional forward stepping, subsequent to foot contact, which we believe to be a principal determinant of mediolateral dynamic stability. Twenty younger (age 24 ± 5 years; 50% women) and 20 older participants (age 71 ± 5 years; 50% women) performed three different single-step tasks of various speed and step placement, which varied the challenge to dynamic stability. The trajectory of the total body centre of mass (COM) was quantified. Mediolateral COM incongruity, defined as the difference between the peak lateral and final COM position, and trial-to-trial variability of incongruity were calculated as indicators of dynamic stability. Older adults exhibited increased instability compared to young adults, as reflected by larger COM incongruity and trial-to-trial variability. Such increases among older adults occurred despite alterations in COM kinematics during the step initiation and swing phases, which should have led to increased stability. Task related increases in instability were observed as increased incongruity magnitude and trial-to-trial variability during the two rapid stepping conditions, relative to preferred speed stepping. Our findings suggest that increased COM incongruity and trial-to-trial variability among older adults signify a reduction in dynamic stability, which may arise from difficulty in reactive control during the restabilisation phase.



## 1. Introduction

Although falls among older adults (OA) continue to present a major public health concern in Canada [1], the specific mechanisms underlying such age-related increase in fall risk remain uncertain. While both internal and external factors contribute to fall risk [2], the occurrence of a fall ultimately depends on the ability of the individual to utilise reactive balance control strategies to recapture stability, following self-generated or external perturbations to the balance control system. As falls are common among OA during stepping or walking [3–5] and occur most often due to incorrect body weight transfers (i.e. self-generated perturbation) [5], better understanding of the mechanisms underlying age-related decline in dynamic stability during such tasks can facilitate approaches for reducing fall risk. The present work seeks to advance understanding of the challenges to dynamic stability control during voluntary stepping.

Highly relevant to lateral falls and hip fracture [6–10], OA appear to have particular difficulty controlling mediolateral dynamic stability during both reactive forward stepping [11] and walking [12–15]. The substantial similarity between age-groups in many kinematic and temporospatial stepping parameters during the initiation and swing phases suggests that mediolateral instability may arise from events occurring during later phases of movement, after foot contact [11,16,17]. Few studies have focussed specifically on the control of mediolateral dynamic stability during restabilisation, despite the fact that this may represent the earliest opportunity to substantially influence the kinematics of the centre of mass (COM) subsequent to movement initiation. We believe the ability to effectively control the total-body COM during the restabilisation phase of stepping to be a principal determinant of mediolateral dynamic stability, regardless of the means by which stepping is initiated (i.e. self-initiated or by external perturbation). The purpose of this study is to extend our previous work with younger adults [18], to characterise age-related differences in mediolateral COM kinematics during the restabilisation phase of voluntary forward stepping.

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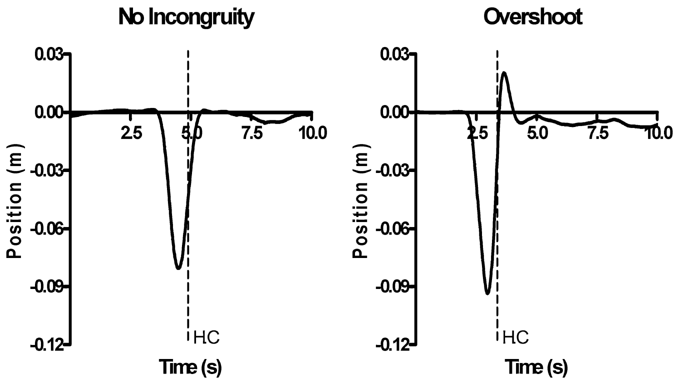


**Fig. 1.** Representative centre of mass (COM) position-time waveforms depicting a trial with no incongruity (left) and overshoot (right). HC signifies heel-contact. Incongruity is defined as the difference between the local peak COM position following HC and the final COM position.

Our previous work attempted to gain insight into the 'best possible' control of the COM, given the opportunity to plan and self-initiate stepping, by quantifying the magnitude and trial-to-trial variability of incongruity between the peak and final COM position (Fig. 1). Contrary to initial hypotheses, COM incongruity – specifically, overshoot of the final COM position – was apparent in the vast majority of trials. Moreover, the magnitude of overshoot scaled with step width, without changes in trial-to-trial variability. The high occurrence and consistency of overshoot across trials and task conditions suggested that COM incongruity may be functional, perhaps serving to simplify stability control during restabilisation by reducing the necessity for rapid reactive balance corrections.

From this, our overall hypothesis is that measures of incongruity during the restabilisation phase would reveal age-related differences in control of the COM. We hypothesised that when stepping with self-selected speed and step placement, OA would not use the strategy employed by younger adults, but would, on average, attempt to reduce or remove incongruity between the peak and final COM position. OA would also exhibit increased trial-to-trial variability of incongruity, relative to younger adults. Overall, we believed this would suggest that OA are attempting to employ a strategy to reduce potential instability by maintaining the COM well inside the base of support (i.e. reduced mean incongruity), but that the strategy was not well executed (i.e. increased intertrial variability), due to challenges with reactive control of COM kinematics specific to the restabilisation phase (Fig. 2). Further, we believed that challenging lateral stability, by forcing rapid and narrow-width steps, would cause both age-groups to reduce average COM incongruity to maintain stability. We believed, however, that OA would exhibit further increases in trial-to-trial variability relative to younger adults, suggesting increased dyscontrol during restabilisation.

## 2. Methods

### 2.1. Participants

Twenty healthy young (YA: age 24 ± 5 years; mass 68.1 ± 10.3 kg; height 1.71 ± 0.08 m) and 20 community-dwelling healthy older adults (OA: age 71 ± 5 years; mass 77.0 ± 16.8 kg; height 1.70 ± 0.05 m) participated in the study (50% women per age-group). Participants were free from anatomical, neurological, or cognitive impairments, could stand and walk unaided, had no history of falls and were not using medications that could influence balance control. This study received ethical approval from the institutional Research Ethics Board. All participants provided informed consent in accordance with established institutional policies.

### 2.2. Instrumentation

A motion analysis system (Vicon Motion Systems, Los Angeles, CA) and four force platforms (Advanced Mechanical Technology, Inc., Watertown, MA) arranged in a rectangular array, were used to acquire kinematic (100 Hz) and kinetic data (2000 Hz). Retroreflective calibration markers, of 1 cm diameter, placed on bony landmarks of the upper and lower body [18], were used to define segment endpoints and anatomically relevant local coordinate systems for all body segments. Rigid clusters of 4 markers were used to track segmental position and orientation. Electromyographic (EMG) data (Bortec Biomedical, Calgary, AB), were recorded bilaterally from the tibialis anterior and soleus (2000 Hz). EMG data were used only to standardise the initial conditions and were not further analysed.

### 2.3. Protocol

To obtain kinematic and electromyographic reference values for post-processing, two 60-s duration quiet-standing trials were collected in a standardised side-by-side [19] or forward-stance configuration, with feet on separate force platforms.

Participants completed three separate randomly presented task conditions, each requiring a single voluntary step with the preferred leg into a forward stance configuration (10 successive trials per condition):

1. Preferred step length/width and speed (PREF);
2. Rapid stepping with Preferred step length/width (PREF_RAPID);
3. Rapid stepping with Reduced ML step width (ML_RAPID);

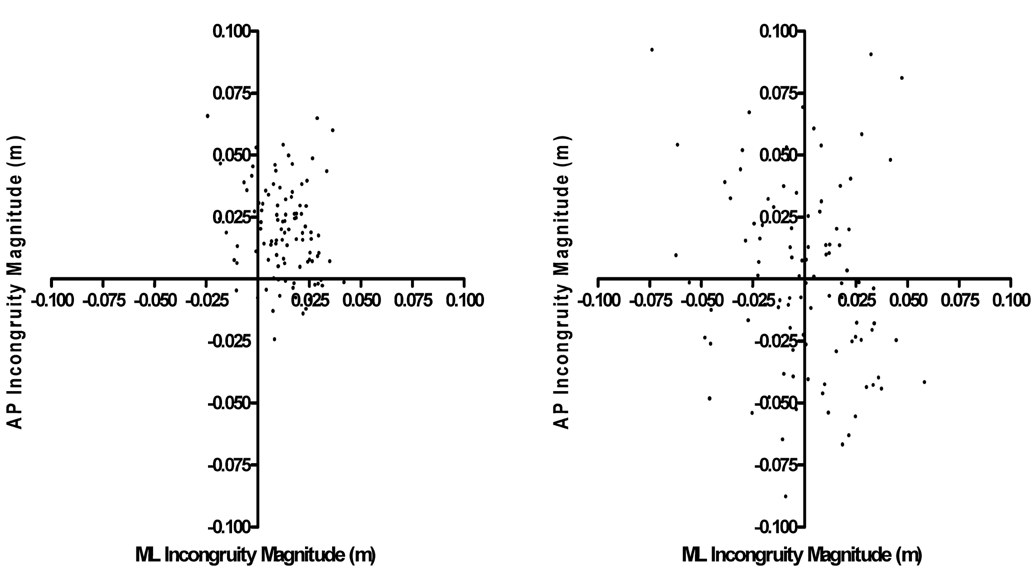


**Fig. 2.** Hypothetical centre of mass (COM) incongruity magnitudes (AP vs. ML) for all participant data for younger adults (left) and older adults (right). Positive values represent overshoot; negative values represent undershoot. *Note*: data points represent individual trials. For younger adults, data depict a bias towards overshoot (positive mean), with low trial-to-trial variability. For older adults, data depict no incongruity (zero mean), with high trial-to-trial variability.