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# Aging effect on step adjustments and stability control in visually perturbed gait initiation

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ABSTRACT

Gait adaptability is essential for fall avoidance during locomotion. It requires the ability to rapidly inhibit original motor planning, select and execute alternative motor commands, while also maintaining the stability of locomotion. This study investigated the aging effect on gait adaptability and dynamic stability control during a visually perturbed gait initiation task. A novel approach was used such that the anticipatory postural adjustment (APA) during gait initiation were used to trigger the unpredictable relocation of a foot-size stepping target. Participants (10 young adults and 10 older adults) completed visually perturbed gait initiation in three adjustment timing conditions (early, intermediate, late; all extracted from the stereotypical APA pattern) and two adjustment direction conditions (medial, lateral). Stepping accuracy, foot rotation at landing, and Margin of Dynamic Stability (MDS) were analyzed and compared across test conditions and groups using a linear mixed model. Stepping accuracy decreased as a function of adjustment timing as well as stepping direction, with older subjects exhibited a significantly greater undershoot in foot placement to late lateral stepping. Late adjustment also elicited a reaching-like movement (i.e. foot rotation prior to landing in order to step on the target), regardless of stepping direction. MDS measures in the medial-lateral and anterior-posterior direction revealed both young and older adults exhibited reduced stability in the adjustment step and subsequent steps. However, young adults returned to stable gait faster than older adults. These findings could be useful for future study of screening deficits in gait adaptability and preventing falls.

## 1. Introduction

In daily walking, one often has to suppress preplanned step and adjust foot placements in response to environmental perturbations (uneven surface, obstacles, pets, etc.). The ability to make quick step adjustments is essential for maintaining locomotion stability, whereas limited capacity to adapt gait might contribute to tripping and falling [1]. In suddenly perturbed locomotion, the inhibition of original motor planning, the selection of alternative foot placement [2], and the postural stability control during rapid limb adjustments [3] all need to be executed in a timely manner.

With increased age, limited sensorimotor and cognitive function may lead to poor gait adaptability [1,4]. More specifically, in response to sudden perturbations, the deficits of older adults in making rapid step adjustments may be caused by decline in musculoskeletal function to generate muscle power [5], reductions in joint range of motion [6], delayed perception of environmental changes [4], and impaired executive function [1].

Previous studies on step adjustments to sudden shifts in stepping targets have been primarily conducted in discrete step initiation [7–10] and continuous walking scenarios [2–4,11–13], but not in gait initiation task, which is also a challenge to the balance control system as the body moves from stable static balance to continuous unstable gait [14]. Gait initiation has also been proposed as a natural but deliberately destabilizing task that can be a valid instrument in assessing the balance ability of aging, frail or neurological impaired subjects [15,16]. One hallmark of gait initiation is anticipatory postural adjustment (APA), which involves a sequence of weight shifting to propel the body mass forward and towards single stance limb before foot lift [17–19]. The APA, although named as anticipatory in nature, has also been associated with online postural control, as demonstrated by the correction of error during choice reaction stepping [19,20]. Therefore, APA may be critical for making rapid step adjustments during perturbed gait initiation. Moreover, previous studies on step adjustments often used fixed delay intervals (ranges from 100 ms to 650 ms) [4,9,21] to trigger stepping adjustments, which might not be sensitive to individual

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differences in reaction time and motor execution time.

Given the goal of a successful adaptive gait is not only controlling the foot trajectory for alternative placement, but also maintaining balance during and after the step adjustment [3,13], understanding how humans maintain and control stability when exposed to perturbations is crucial to determine the risk of falling [22]. In order to quantify the dynamic process of locomotion stability control, Hof et al. [23] introduced the measure of margin of dynamic stability (MDS), which was then widely applied in numerous locomotion research [3,22,24]. MDS was defined as the distance between the velocity extrapolated center of mass (XCoM) position and the edge of the base of support (BOS), and a stable gait was achieved as long as the XCoM remains within the BOS.

In the present study, we investigated the aging effect on step adjustments at gait initiation utilizing projected stepping-target perturbations. A novel method was used to trigger the stepping target relocation during gait initiation based on the subject's APA weight shift pattern prior to foot lifting, so that the available response time was adjusted for each individual. The stepping accuracy, the foot landing rotation, as well as the MDS at and after the step adjustment were chosen as the primary outcome measures. We hypothesized that older adults would have decreased stepping accuracy as well as decreased stability, especially in more challenging condition (i.e., with increased time pressure).

## 2. Method

### *2.1. Participants*

Ten healthy college students (21.5 ± 1.9 years, 4 female) and ten healthy community dwelling older adults (68.0 ± 4.1 years, 6 female) participated in this study. None of the participants had a history of neurological, musculoskeletal disorder, or other conditions that limit mobility at the time of participation. All participants had normal or corrected to normal vision. The Mini-Mental Status Examination (MMSE) [25] and Timed Up and Go (TUG) test [26] were conducted for screening of cognitive and mobility deficits. All participants had a MMSE score above 27, and a TUG score below 14 s. The study was approved by the Institutional Review Board of Indiana University Bloomington. All participants gave informed consent prior to participation in the study.

### *2.2. Experimental setup*

The experimental setup (Fig. 1A) included a custom-built 5 m walkway with two embedded forceplates (AMTI OR6-7-1000, Advanced Mechanical Technology, Inc., Watertown, MA) and a DLP projector (Mitsubishi XD490U, 3000 lumens, 1024*768, 60 Hz). The visual stimuli were generated from a customized MATLAB (MathWorks, Inc., Natick, MA) program with Psychophysics Toolbox extensions [27]. Real-time force data was analyzed by a customized microcontroller (Arduino.cc, sampled at 1000 Hz) to trigger the visual cueing with small delay latency (~30 ms). The first forceplate (FP1) was placed at the start of the walkway, where subject stood and initiated forward walking. A second forceplate (FP2) was placed directly in front of FP1 to record the landing kinetics of the first step.

### *2.3. Protocol*

Subjects stood upright without shoes on FP1 with their feet 10 cm apart. The perimeter of participants' feet was marked with tape to ensure a consistent starting stance throughout the experiment. Subjects were instructed to look at the fixation mark displayed at the center of walkway during standing, and initiate forward walking with the right foot as quickly as possible upon the disappearance of the fixation. Ten target-free gait initiation trials were first performed to determine individual's preferred initial step length/width for stepping target generation (by calculating the average landing location of the right heel marker). Subjects then performed 10 baseline trials of fixed target gait initiation, in which they were instructed to step on a projected foot sized visual target (30 cm × 10 cm rectangular, bright white color) located at the preferred initial landing position, and continue walking to the end of the walkway. Ten practice trials were performed before the target-free and the baseline trials.

After completion of the baseline fixed target trials, subjects then performed 90 randomized adjustment trials, in which the stepping target was first displayed at the preferred location upon fixation disappearance, and then could be relocated laterally or medially by 10 cm after varied delayed intervals. The timing of target relocation was categorized as Early/Intermediate/Late, based on real-time force analysis of subjects' weight distribution during the gait initiation cycle (APA event timing). For the exact criteria for the timing of the target relocation, please refer to the data collection and analysis section. The adjustment trials consisted of 30 trials of medial target relocation (10 trials per timing condition), 30 trials of lateral target relocation (10 trials per timing condition) and 30 trials of unchanged catch trials. These trials were divided as 5 blocks of 18 trials. To prevent fatigue, participants sat and rested for 5 min between testing blocks. Thirty-six practice trials were performed prior to data collection (4 practice trials per adjustment condition).

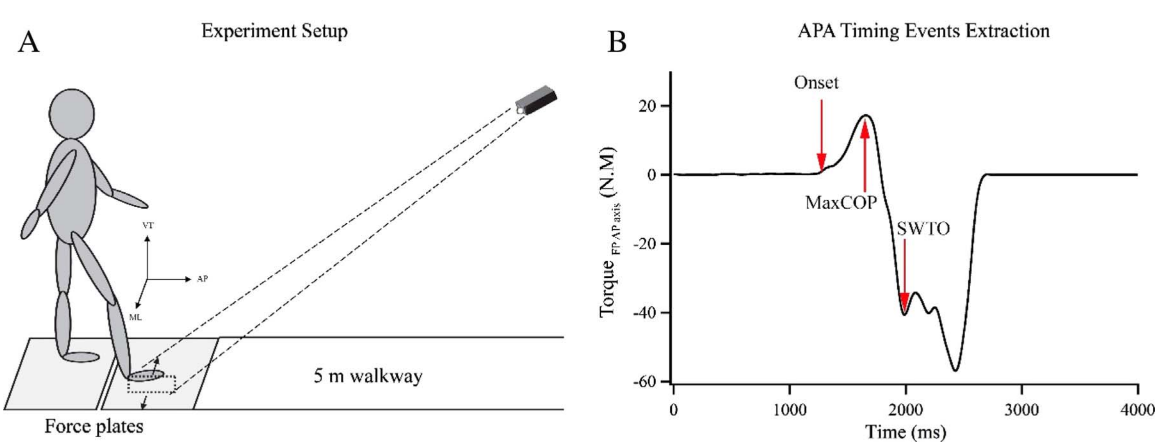


**Fig. 1.** A) Illustration of the experimental setup. A DLP projector displayed a foot sized target (dashed line rectangular) on the ground at subject's preferred foot landing position. The target could be randomly shifted 10 cm medially or laterally to trigger foot adjustments. B) Sample torque waveform about the AP axis of FP1 for a right-foot gait initiation. Red arrows marked the extracted timing events of APA (Onset, MaxCOP and SWTO). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)