Gait & Posture 41 (2015) 894–898

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

The posterior shift anticipatory postural adjustment in choice reaction step initiation

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ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form 8 February 2015
Accepted 18 March 2015

Keywords:
Step initiation
Choice reaction stepping
Anticipatory postural adjustment
Falls
Motor control

ABSTRACT

The ability to step quickly in response to a perturbation has been shown to be critical for prevention of falls. The cognitive processing, weight shifting, and locomotion must be well timed to execute a successful step. The purpose of this study was to compare the response preparation and response execution processes between a simple (SRST) and a choice reaction stepping task (CRST). Nine healthy young subjects were recruited to participate in this study. Subjects were required to stand on a forceplate and maintain their balance, and step forward on a second forceplate with either the left or right foot after hearing an auditory tone. The center of pressure (COP) was analyzed to determine the types of anticipatory postural adjustment (APA) prior to a step. The APA phase and stepping phase timing was calculated based on the COP trajectory. Findings showed that reaction time (RT), APA phase and overall stepping latency were slower for CRST than for SRST. We also identified an intermediate type of APA response (posterior shift APA) in addition to the correct and error APA response, and found the posterior shift APA response had the fastest execution time for CRST, and may be beneficial for falls prevention.

Published by Elsevier B.V.

1. Introduction

Falls are a major source of injury and death among the elderly population [1–5]. Rapid postural adjustment to restore center of mass (COM) equilibrium after loss of balance (slip, trips, etc.) is critical for the prevention of falls [2,3,6,7]. The most common approach for compensation of a postural perturbation is to initiate a step to increase the base of support as well as decelerate the speed of COM movement [8]. The speed of voluntary step initiation has been shown as an important predictor for fall detection among the elderly population [2,6,7,9]. To minimize the risk of falling, the cognitive processing, weight transfer, and locomotion components of a step must be timed and executed appropriately [2,10,11]. Thus, the aforementioned components during step initiation were studied to investigate the cognitive processing to prepare and execute a step.

Step initiation can be divided into 5 stages (see Fig. 1): (1) the RT lasts from the stimulus delivery to the onset of center of pressure (COP) deviation; (2) the release phase lasts from the COP onset until the furthest point of postero-lateral COP (MaxCOP); (3) the unloading phase lasts from the MaxCOP to the swing foot toe off the ground (SWTO); (4) the single support phase (SSP) or swing phase lasts from the SWTO to the swing foot initial contact (SWIC); and (5) the double support phase (DSP) lasts from the SWIC to the stance foot toe off ground (STTO). Stages 2 and 3 combined are defined as the APA phase, while stages 4 and 5 combined are defined as the stepping phase [8,11–13].

Previous studies have identified anticipatory postural adjustment (APA) as a marker of preparatory movement during step initiation [3,11]. The APA is defined as lateral weight transfer toward the swing foot preceding a step. It is believed to stabilize posture and generate the initial momentum needed to begin walking [13]. Multiple studies report that errors [3,4,11] in the initial weight transfer, which is defined as APA error, lead to slow choice step execution due to additional time for error correction before a step can safely take place.

The present study examined the effects of choice on the temporal characteristic of step initiation. The study also aimed to investigate the impact of APA on step characteristics. Previous studies on APA error were limited to a binary choice situation in which APAs were either correct or incorrect based on the shift direction in weight transfer [3–5,11]. According to decision theory [14–16], human behavior tends to reflect a compromise effect in which subjects add an intermediate alternative that lies between the two competing extreme options in the original choice set. Therefore, we hypothesized that by analyzing the COP trajectory, we could identify the compromise effect during the reaction and APA phase of step initiation.

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http://dx.doi.org/10.1016/j.gaitpost.2015.03.010
0966-6362/Published by Elsevier B.V.

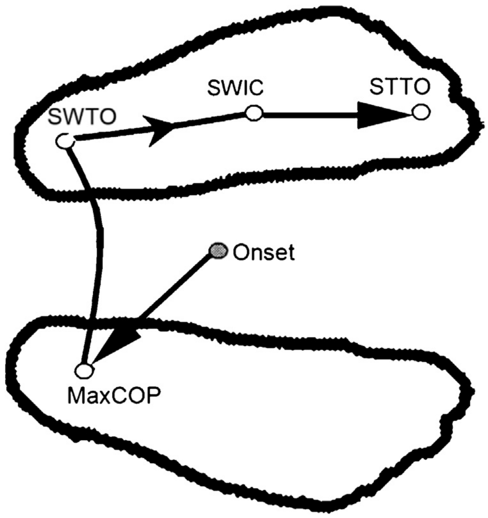

Fig. 1. COP displacement pattern during step initiation. During the release phase the COP moves from onset to the furthest point of posterolateral COP movement (MaxCOP). During the unloading phase the COP moves across from MaxCOP to the stance foot, ending at swing toe off (SWTO). The forward COP displacement from SWTO to stance toe off (STTO) marks the stepping phase (SSP and DSP).

2. Method

2.1. Participants

Nine healthy young subjects (six females, three males, $M = 21.9 \pm 1.3$ years old, right leg dominant according to self-report) participated in this study. None of the participants had a history of orthopedic injury, musculoskeletal, vestibular, neurological disorders or stroke according to self-report. All participants gave informed consent prior to participation in the study. The study was approved by the Institutional Review Board of Indiana University.

2.2. Task and design

Subjects were instructed to stand upright and barefoot on a force platform, with their feet 20 cm apart. The perimeter of participants' feet was marked with tape to ensure consistent stance throughout the experiment. Subjects looked straight ahead during the entire trial, with eyes open, fixating on a target placed 3 m ahead at eye level. After a warning signal and a random foreperiod between 2 and 5 s, subjects received an auditory cue and initiated a forward step onto a second force platform as quickly as possible. Subjects stepped forward with the foot corresponding to the pitch of the auditory cue, and then brought the stance foot next to the stepping foot. The two sound pitches were 250 Hz (low pitch) for left leg stepping, and 500 Hz (high pitch) for right leg stepping. In the SRST condition, participants were informed that the auditory cue would signal either the left (SRST-L) or right (SRST-R) leg stepping for the entire block of trails. In the CRST condition, participants were informed that the auditory cue was equally likely to signal left (CRST-L) or right (CRST-R) leg stepping. The SRST condition was blocked and counterbalanced with every participant completing 10 trials in the SRST-L and SRST-R conditions. To prevent subject anticipation and movement preprogramming, the CRST consisted of 25 trials with at least 10 trials stepping with left or right leg. Catch trials (1000 Hz sound buzzer) in which subjects were required to abort stepping were included in all testing blocks at a rate of 20% of total number of trials. Subjects sat and rested for 5 min between trial blocks.

2.3. Data recording and analysis

A Tekscan HR MAT Pressure Mat (Tekscan Inc.) was mounted on top of a forceplate (AMTI). The HR MAT allowed the experimenter to monitor and maintain the participant's weight distribution under both feet evenly (with no more than 51% of weight on either foot) before starting the trial [3]. Ground reaction forces (GRFs) and moments were collected from the forceplate at 1000 Hz. The COP was derived from the forces and moments.

The auditory stimuli (250 Hz/500 Hz/1000 Hz, 85 dB, 100 ms) were generated from a customized LABVIEW program (National Instruments). Tones were presented via 2 loudspeakers (<1 ms rise time) located at 2 m height and 2 m away bilaterally from the participant. The stimulus intensities were measured using a sound level meter. All analog signals were synced and recorded with the motion analysis system (Qualisys AB, Sweden) through a 64 channel A/D board, and sampled at 1000 Hz.

Step initiation event timings were calculated for each trial from the COP data, as well as vertical velocity of toe and heel markers [8] (sampled at 100 Hz) recorded by the Qualisys system. Specific temporal events were extracted from the step initiation data using a customized program written in MATLAB (MathWorks Inc.). The movement onset was identified as when COP velocity was greater than 3 standard deviations from the baseline value calculated from a 0.5 s window before stimulus onset [12]. The point of maximum postural lateral COP displacement (MaxCOP) was identified as the end of COP mediolateral shift toward the swing leg (absolute COP velocity <100 mm/s). Swing Toe Off (SWTO) was defined as the end of the COP mediolateral shift toward the stance leg [1]. Swing Leg Initial Contact (SWIC) was determined using the sudden increase of GRF on the second force platform. Stance Leg Toe Off (STTO) was determined as the point when GRF under the 1st forceplate dropped to below 10 N level.

2.4. Statistical analysis

Before analyzing data, we excluded trials on which participants (1) initiated an APA sooner than 80 ms after the audio cue [3,17], (2) failed to step within 2 s after the audio cue, and (3) stepped with the wrong foot. This left 347 trials (171 SRST, 176 CRST), on average 39 trials per subject. For analysis, a two-way repeated measures analysis of variance (ANOVA) was first performed, in which stepping task (SRST vs CRST) and stepping leg (left vs right) were used as the fixed factors and subjects as the random factor. To determine how APA responses affected the timing of each step initiation phase (RT, Release, Unloading, SSP, DSP), a secondary analysis was performed on CRST data using a linear mixed model with APA types (correct, error and posterior shift) and stepping leg as fixed factors and participant as a random factor. We used post hoc testing (Tukey HSD) to further investigate the role of APA response type. Alpha was set at .05 for all tests. COP sway path length, and its correlation with the duration in each step initiation stage was calculated.

3. Results

Examples of one subject's COP spatial evolution during choice reaction stepping trials are shown in Fig. 2. Three types of APA response were classified based on the COP velocity profile in the M/L and A/P direction during release phase: (1) correct APA (COP shifts postero-laterally toward the swing leg); (2) error APA (COP shifts postero-laterally toward the stance leg, and then turning back to the swing leg); (3) posterior shift (PS) APA (COP shifts in the posterior direction before turning toward the swing leg). In the PS APA trials, the posterior COP velocity increased above 3 SD from its static baseline value at least 50 ms prior to lateral COP velocity onset. In the correct and error APA trials, the lateral and posterior COP velocity onset latency was within 50 ms. All SRST trials were determined as correct APA trials. In the CRST condition, there were 51 correct APA trials, 65 error APA trials, and 60 PS APA trials. Mean and SD of the duration in each stepping stage are summarized in Table 1.