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Older adults who have previously fallen due to a trip walk differently than those who have fallen due to a slip

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ABSTRACT

Studying the relationships between centre of mass (COM) and centre of pressure (COP) during walking has been shown to be useful in determining movement stability. The aim of the current study was to compare COM–COP separation measures during walking between groups of older adults with no history of falling, and a history of falling due to tripping or slipping. Any differences between individuals who have fallen due to a slip and those who have fallen due to a trip in measures of dynamic balance could potentially indicate differences in the mechanisms responsible for falls. Forty older adults were allocated into groups based on their self-reported fall history during walking. The non-faller group had not experienced a fall in at least the previous year. Participants who had experienced a fall were split into two groups based on whether a trip or slip resulted in the fall(s). A Vicon system was used to collect full body kinematic trajectories. Two force platforms were used to measure ground reaction forces. The COM was significantly further ahead of the COP at heel strike for the trip (14.3 ± 2.7 cm) and slip (15.3 ± 1.1 cm) groups compared to the non-fallers (12.0 ± 2.7 cm). COM was significantly further behind the COP at foot flat for the slip group (-14.9 ± 3.6 cm) compared to the non-fallers (-10.3 ± 3.9 cm). At mid-swing, the COM of the trip group was ahead of the COP (0.9 ± 1.6 cm), whereas for the slip group the COM was behind the COP (-1.2 ± 2.2 cm). These results show identifiable differences in dynamic balance control of walking between older adults with a history of tripping or slipping and non-fallers.

1. Introduction

Falls and fall-related injuries are among the most serious and common medical problems experienced by the older population with approximately 28% of community-dwelling older adults experiencing at least one fall a year [1]. The majority of falls (over 60%) in this age group are in the forward direction [2], and 53% of falls [3] and 20% of hip fractures [4] are reported as the result of a trip. In non-fatal falls, almost half of all fallers are unable to get up without help [5], and nearly one-third of falls in community dwelling older adults have been reported to produce pain lasting for 2 or more days [6]. As most falls occur during locomotion [7], it is important to develop a greater understanding of gait and the underlying control mechanisms that govern stability during movement.

Slips and trips are associated with different phases of the gait cycle. Slips are most likely to occur shortly after heel strike when only the edge of the heel is in contact with the ground or during toe off when only the forepart of the shoe is in contact with the ground [8]. Of these occurrences, forward slips occurring at heel strike are the most challenging type of slip for both young and older adults to recover from and avert a fall [9]. Trips occur during the swing phase of the gait cycle, and the recovery mechanism employed varies with the timing of the perturbation. An elevating strategy occurs in early to mid-swing, where the perturbed limb is lifted over the obstacle, whereas a lowering strategy occurs in late swing where the perturbed limb is placed prior to the obstacle and the contralateral limb is lifted over. Some older adults use a lowering rather than an elevating strategy when perturbed in the mid swing phase [10], suggesting that a less appropriate response for trip recovery is employed in these individuals at the phase of the gait

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cycle [11]. It has also been observed that trip perturbations during late-mid and late swing are most likely to result in falls in older adults [11].

Previous studies have demonstrated the usefulness of the centre of mass-centre of pressure (COM–COP) interaction as a measure of stability during locomotion [12,13]. The COM is in a state of dynamic balance during walking, with the COP moving behind and then ahead of the COM in the sagittal plane, resulting in the total body gravity force vector passing forward through the COP four times in one gait cycle [12]. Peak anterior COM–COP separation was decreased in older people compared with young adults [13] possibly indicating a conservative strategy to reduce the mechanical load on the supporting limb. However, anterior COM–COP separation increased in hemiparetic patients when the stance limb was on the affected side [14], suggesting that maintaining balance on the affected side was a greater challenge to stability. A recent study suggests that incorrect weight shifting resulting in the COM being moved beyond their base of support was the main reason for falling in care home residents [15]. Investigating COM–COP separation at points in the gait cycle associated with slips and trips may provide further information on postural stability during walking in older adults. Any differences between individuals who have tripped and those who have slipped in measures of dynamic balance could potentially indicate differences in the mechanisms responsible for falls. The aim of this study was to investigate differences in COM–COP separation measures during walking in groups of older adults without a history of falling and with a history of tripping or slipping resulting in a fall.

2. Methods

2.1. Participants

Forty community-dwelling older adults were recruited to the study from the local area through links with retirement groups. Ethical approval for the research was granted through institutional procedures conducted at departmental level. All participants gave written informed consent prior to data collection, and the study was carried out in accordance with the principles laid down by the Declaration of Helsinki. All of the older participants were able to walk at least 100 m without the use of a gait aid, and reported themselves free of any neurological disease, head trauma, musculoskeletal impairment and visual impairment not correctable by lenses. A falls questionnaire was completed which asked participants whether they had experienced a fall, which was defined as a loss of balance resulting in the body, or part of the body, coming to rest on the ground [16] and how many times this occurred. Participants were also asked to indicate how they fell on each occasion by ticking a box next to the categories: trip, slip, unsure, felt faint/dizzy. Participants were then interviewed about each fall prior to testing. Examples of response recorded were "I caught my toe on the pavement" for a trip and "my foot slid forward" for a slip. Participants were generally very clear about whether they thought they had slipped or tripped. Each report of a fall was discussed at the lab testing session prior to data collection starting in which we also checked if any falls had occurred between questionnaire completion and data collection. Of the "slip" group, four participants reported one fall and six participants reported two falls in the year before testing. Of the "trip" group, seven participants reported one fall, six reported two falls and one participant reported three falls. Any participant who could not clearly recollect details of the fall or reported both a slip and a trip were excluded from the study.

This manuscript presents retrospective analysis of data collected as part of a larger study investigating the relationships between lifelong physical activity and biomechanical measures of stability in a group of older adults. Therefore the number of participants in each group was randomly determined. The participants were split into three groups based on their self-reported previous fall history during walking. The non-faller group ($n = 16$, 10 female, age 72 ± 5 years, height 166.6 ± 8.2 cm, mass 68.1 ± 9.4 kg) had not experienced a fall in at least the 12 month period prior to testing. Participants who had experienced at least one fall in the 12 months prior to testing were split into two groups based on whether a trip ($n = 14$, 10 female, age 71 ± 6 years, height 164.9 ± 9.6 cm, mass 71.5 ± 14.0 kg) or slip ($n = 10$, 6 female, age 68 ± 5 years, height 169.8 ± 9.3 cm, mass 76.0 ± 18.2 kg) had resulted in the fall.

2.2. Data collection

Whole body motion data were collected at 60 Hz using a 14-camera Vicon MCam2 system (Vicon Peak, Oxford Metrics Ltd., UK) set up in a large (17 m × 12 m × 4.5 m) gait laboratory. The full-body Vicon Plug-in Gait (PiG) marker set was used. Ground reaction forces were collected by two force platforms (AMTI BP400600NC, Watertown, USA), placed in series and embedded in the floor of the laboratory with their top surface flush with the laboratory floor. The force platforms were situated in the centre of the laboratory, therefore were in the middle of the walkway used during testing. The force platform data were captured at 120 Hz and time-synchronised to the motion capture system.

Participants were instructed to walk at their self-selected velocity across the laboratory. The participants were not given instructions on foot placement across the force platforms, so that they would not alter their stride pattern to strike the force platforms. Walking trials were conducted until there were three trials with clean foot strikes on both force platforms. Most participants achieved this within three or four trials: the maximum number of trials needed was six.

2.3. Data analysis

Vicon Workstation software (Vicon Peak, Oxford Metrics Ltd., UK) was used to reconstruct the data from each camera into three-dimensional trajectories. Data were filtered using a 2nd order, multi-pass Butterworth filter with a cut-off frequency of 10 Hz. The first and last strides were not included in analysis since we were interested in studying steady state walking rather than gait initiation and termination.

The position of the whole body COM was computed in Vicon Bodybuilder software (Vicon Peak, Oxford Metrics Ltd., UK) using a model based on Vicon's Golem model. Whole body COM was the weighted sum of each body segment's COM using a 13-link biomechanical model. COP data were combined from both force platforms to provide a single COP:

$$\mathrm{COP} = \mathrm{COP}_1 \frac{Fz_1}{Fz_2 + Fz_1} + \mathrm{COP}_2 \frac{Fz_2}{Fz_1 + Fz_2}$$

where COP_1 and COP_2 are the COPs on the 2 separate force platforms and Fz_1 and Fz_2 are the vertical ground reaction forces on force platform 1 and force platform 2.

The horizontal distance between COM and COP was calculated for in both the antero-posterior (A/P) and medio-lateral (M/L) directions. A/P and M/L COM velocity were also calculated. Values were determined for 5 points across the gait cycle (GC): heel strike, foot flat, toe off, mid-swing and late swing. Foot flat was defined as the instant where the toe marker reached its first minimum vertical position after heel strike [8]. Mid-swing was defined as 50% and late swing as 90% of the swing phase. Peak braking force and peak propulsive force were calculated from the A/P component of