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Differences in axial segment reorientation during standing turns predict multiple falls in older adults

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ABSTRACT

Background: The assessment of standing turning performance is proposed to predict fall risk in older adults. This study investigated differences in segmental coordination during a 360° standing turn task between older community-dwelling fallers and non-fallers.
Methods: Thirty-five older adults age mean (SD) of 71 (5.4) years performed 360° standing turns. Head, trunk and pelvis position relative to the laboratory and each other were recorded using a Vicon motion analysis system. Fall incidence was monitored by monthly questionnaire over the following 12 months and used to identify non-faller, single faller and multiple faller groups.
Results: Multiple fallers were found to have significantly different values, when compared to non-fallers, for pelvis onset ($p = 0.002$); mean angular separation in the transverse plane between the head and trunk ($p = 0.018$); peak angular separation in the transverse plane between the trunk and pelvis ($p = 0.013$); and mean angular separation between the trunk and pelvis ($p < 0.001$).
Conclusions: Older adults who subsequently experience multiple falls show a simplified turning pattern to assist in balance control. This may be a predictor for those at increased risk of falling.

1. Introduction

Falls and fall-related injuries are amongst the most serious and common medical problems experienced by the older population with approximately one-quarter of community-dwelling people aged 65 and over reporting at least one fall in a year [1]. Turning is one of the fundamental components of mobility, and is associated with 35–45% of steps in common everyday tasks [2]. Staggering when turning is a prominent characteristic of recurrent fallers [3], and those who are unsteady during turning are more likely to fall whilst turning [4]. If an individual does experience a fall during turning, they are eight times more likely to fracture their hip than if the fall occurred when walking in a straight line [5]. These findings suggest that turning could be a greater challenge to older people at risk of falling than walking straight ahead, and result in more serious consequences.

Assessment of standing turn performance is considered of value in predicting potential fall risk in older adults [6], and as a result has been included in many clinical tests. The 360° turn forms part of regularly used clinical assessment tools for assessing dynamic balance in older persons [7–9], with a longer turn time and a greater number of steps associated with an increased risk of falling [10] and loss of independence in activities of daily living [11]. Performance on the 360° turn is also strongly associated with walking speed and chair rise ability [12]. Therefore, the 360° turn is a useful measure of function in older adults.

During a turn, there is a clear temporal sequence in the initiation of axial segment reorientation. The movement is initiated in the yaw direction by the head, followed by the trunk and finally the feet in a cranio–caudal sequence [13]. Older adults have demonstrated less head on trunk rotation than young adults during a 130° turning task [14], which was suggested to be due to age-related decreases in cervical spine rotation. This reduced head on trunk rotation was partly compensated by increased trunk on pelvis rotation. However this is in contrast to a study of a 90° standing turn, which found that older adults started turning their head, trunk and pelvis simultaneously [15]. This en-bloc method of segmental reorientation may

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be adopted to simplify the control of the movement and to minimalise the risk of imbalance. This en-bloc strategy has also been demonstrated in patients groups such as turning in place in Parkinson's Disease [16] and online steering in stroke [17]. This en-bloc strategy may therefore be demonstrated in older adults who are at risk of experiencing a fall, and the 360° turn that is already utilised in clinical balance assessments may be suitable for identifying differences that may be present prior to falling.

Anticipatory postural adjustments (APAs) occur prior to a voluntary movement and have been observed in scenarios such as lateral stepping [18] and gait initiation [19]. In lateral stepping, the centre of pressure (COP) showed a small shift towards the swing side prior to the weight transfer to the support side [18]. This COP adjustment preceded a centre of mass (COM) adjustment. Longer APA time has been reported during obstructed gait initiation in older adults at high risk of falling compared to those at low risk, suggesting that those adults need a longer preparatory control time [19]. Therefore, it is likely that APAs will be detectable in standing turning.

Therefore, the purpose of this study was to investigate prospectively any differences in segmental coordination and APAs during a 360° standing turn task between older community-dwelling fallers and non-fallers. It was hypothesised that the fallers would display less segment-to-segment rotation during the turn, and demonstrate a longer APA time than the non-fallers.

2. Methods

2.1. Participants

Thirty-five older (23 women) adults (age mean (SD) of 71 (5.4) years; height mean (SD) 167.3 (9.9) cm; mass mean (SD) 71.2 (13.1) kg) were recruited through letters sent through community groups. All participants were able to walk at least 100 m without the use of a gait aid. None of the participants had experienced a fall, been injured or had surgery in the previous six months, and were free of known neurological or vestibular problems. All participants had normal or corrected to normal vision. Ethical approval for the research was granted through institutional procedures undertaken at departmental level, and all participants gave written informed consent prior to data collection.

2.2. Data collection

Whole body motion data using the Plug-In Gait (PiG) marker set [20,21] were collected at 60 Hz using a 14-camera Vicon MCam2 system (Vicon Peak, Oxford Metrics Ltd., UK). Ground reaction forces were collected by two force platforms (AMTI BP400600NC, Watertown, USA), embedded in the floor of the laboratory. These were placed in parallel in relation to the participant's starting position. The force platform data were captured at 120 Hz and time-synchronised to the motion capture system.

The participants were instructed to start with one foot placed on each of the two force platforms in a side-by-side stance. They were then asked to turn 360° at their own speed when ready to do so (self-initiated) and in their preferred turning direction. After the opportunity to practice was given, a minimum of 3 trials was conducted, and a minimum rest period of 2 min was given in between trials.

2.3. Data processing

The head, thorax and pelvis were modelled as segments using the PiG model, and whole body COM was calculated using a 13-link biomechanical model [22]. Each segment was defined by 4 markers placed in accordance with the PiG marker set, and segment angles were calculated relative to the global coordinate system of the laboratory and to each other. The velocities of the segments in the yaw direction were calculated and were used to define the start and finish of the turn. The turn was defined as a single, continuous, rotational movement in one direction. The turn was identified as the point where the rotational velocity of the first of the three measured body segments crossed zero and continued to increase until the point when the rotational velocity of the last of those segments returned to zero. Foot off was identified from the force platform data as the point where the loading under the stepping leg decreased to <20 N. The force platform data also assisted in counting the number of steps required to turn. COP data was combined from both force platforms to provide a single COP. The onset of COP and COM movements was defined as the point where the amplitude exceeded 2 SDs of the quiet standing amplitude. The time from COP onset to head onset, and from COP onset to COM onset were calculated.

2.4. Fall assessment

At the end of testing, participants completed a written monthly fall assessment for the following 12 months. A fall was defined as an unexpected event in which the participants came to rest on the ground, floor, or other lower level [23]. If a report was not returned or completed incorrectly, the participant was contacted by an investigator.

2.5. Statistical analysis

Data was collected for eleven turning variables: time to turn, number of steps, head onset to trunk onset time, trunk onset to pelvis onset time, pelvis onset to foot off time, peak head–trunk angle, peak trunk–pelvis angle, mean head–trunk angle, mean trunk–pelvis angle (all angles in the transverse plane), COP onset to head onset time and COP onset to COM onset time. The means and corresponding 95% confidence intervals were calculated, for each fall category, for each of the turning variables. *t*-Tests were used to test for differences between the non-fallers and the multiple fallers for each of the 11 recorded variables. As multiple testing was conducted, a Bonferroni correction was investigated to allow for this.

3. Results

3.1. Fall occurrence

Thirteen (9 women, age mean (SD) 70 (5.0) years, height mean (SD) 164.4 (9.1) cm, mass mean (SD) 69.4 (10.3) kg) participants did not fall during the follow-up 12 months and were classed as non-fallers. Ten (7 women, age mean (SD) 74 (4.7) years, height mean (SD) 168.0 (8.7) cm, mass mean (SD) 65.0 (8.0) kg) participants experienced one fall during the follow-up and were classified as single fallers. Twelve (7 women, age mean (SD) 70 (6.1) years, height mean (SD) 169.7 (11.5) cm, mass mean (SD) 78.2 (16.3) kg) participants fell more than once during the follow-up and were classed as multiple fallers.

3.2. Turning

Means and 95% confidence intervals by falling group, for the turning variables are displayed in Table 1.

The mean pelvis onset time appears to be less for those in the multiple fallers group than the non fallers group (mean difference of −0.02 s and *p*-value of 0.002, see Table 2 and Fig. 1). The mean

Table 1
Characteristics of turning between groups; mean (95% CI).

	Non-fallers ($n=13$)	Single fallers ($n=10$)	Multiple fallers ($n=12$)
Time (s)	4.83 (4.16, 5.49)	5.01 (4.20, 5.81)	5.09 (4.00, 6.19)
Steps (n)	7.2 (6.3, 8.0)	7.9 (7.2, 8.5)	8.2 (7.2, 9.3)
Trunk onset (s)	0.13 (0.09, 0.17)	0.15 (0.10, 0.20)	0.14 (0.04, 0.24)
Pelvis onset (s)	0.04 (0.03, 0.05)	0.05 (0.03, 0.07)	0.02 (0.01, 0.03)
Foot onset (s)	0.25 (0.17, 0.33)	0.19 (0.13, 0.26)	0.32 (0.25, 0.39)
Peak head–trunk (°)	31.7 (24.8, 38.7)	31.5 (23.6, 39.5)	27.2 (21.0, 33.3)
Mean head–trunk (°)	12.7 (9.6, 15.9)	8.9 (5.4, 12.3)	7.6 (4.6, 10.6)
Peak trunk–pelvis (°)	11.4 (7.2, 15.5)	12.0 (6.7, 17.3)	4.8 (1.6, 8.0)
Mean trunk–pelvis (°)	4.9 (2.9, 7.0)	3.6 (0.8, 6.3)	−0.8 (−2.8, 1.1)
COP to head (s)	0.37 (0.27, 0.48)	0.36 (0.30, 0.43)	0.30 (0.18, 0.42)
COP to COM (s)	0.19 (0.15, 0.24)	0.20 (0.12, 0.27)	0.18 (0.11, 0.25)