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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 among 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 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 100m 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 were conducted, and a minimum rest period of 2 minutes 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 <20N. 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 men (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

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)

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 Figure 1). The mean head- trunk angle (Figure 2a) for those in the multiple fallers group is lower (mean difference of -5.1° and p-value of 0.018).

The peak (Figure 2b) and mean trunk to pelvis (Figure 2a) separation angles also appear to be lower for those in the multiple fallers group rather than those in the non fallers group (mean differences of -6.5 and -5.8 and *p*-values of 0.013 and <0.001 respectively).

Table 2: Results of t-tests comparing non-fallers with multiple fallers- difference in means (95% CI) with corresponding p-value; * p<0.05.

	Multiple fallers –Non-fallers Difference (95%CI)	p-value
Time (s)	0.27 (-1.45, 0.92)	0.644
Steps (n)	1.0 (-2.3, 0.2)	0.098
Trunk onset (s)	0.02 (-0.11, 0.08)	0.747
Pelvis onset (s)	-0.02 (0.01, 0.03)	0.002*
Foot onset (s)	0.07 (-0.17, 0.03)	0.170
Peak head-trunk (°)	-4.5 (-4.2, 13.4)	0.293
Mean head-trunk (°)	-5.1 (1.0, 9.2)	0.018*
Peak trunk-pelvis (°)	-6.6 (1.5, 11.5)	0.013*
Mean trunk-pelvis (°)	-5.7 (3.1, 8.5)	<0.001*
COP to head (s)	-0.08 (-0.07, 0.22)	0.304
COP to COM (s)	-0.01 (-0.07, 0.09)	0.755

The difference in the number of steps between the non-fallers and the multiple fallers appears to be greater for those in the multiple fallers group but this difference did not reach significance at the 5% level (mean difference of 1.05 and *p*-value of 0.098).

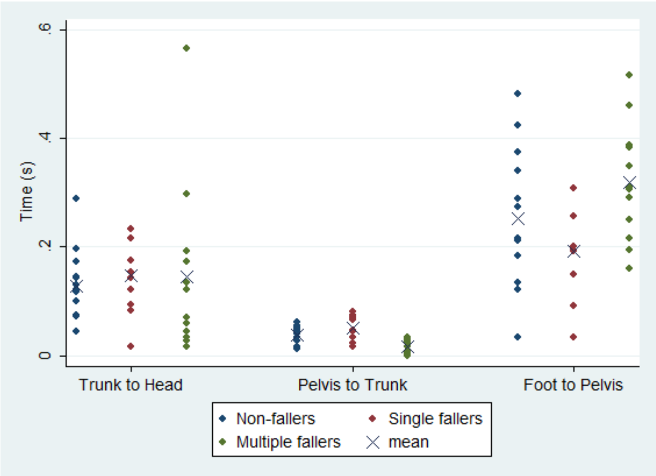

Figure 1. Dotplot of onset times of segments at turn initiation.

Due to 11 tests being conducted on this data, significant results may be found by chance. If we employ a conservative Bonferroni adjustment to the p-value, with α=0.05, the p-value for significance is 0.0045. At this adjusted significance level, the differences found between the non-fallers and the multiple fallers for pelvis onset and mean trunk to pelvis angle remain significant.

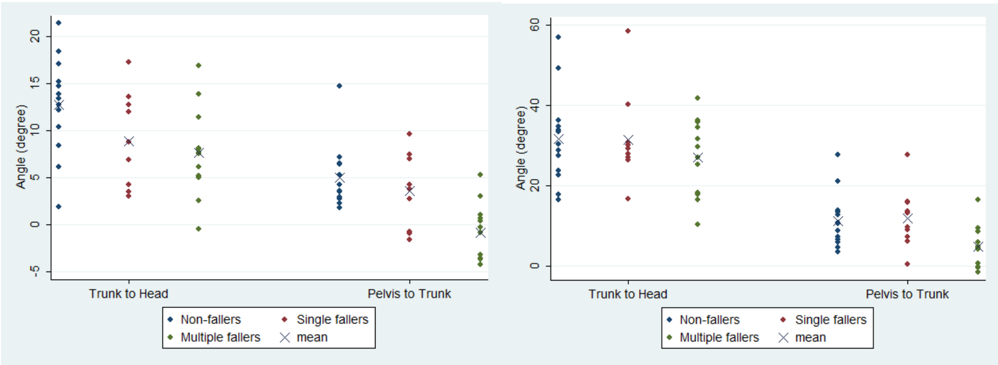

Figure 2. Dotplot of mean (a) and peak (b) segment separation in the transverse plane during the turn.

The first anticipatory movement in all participants was a slight shift in the frontal plane of the COP towards the first stepping foot (see Figure 3) followed by the COP shifting entirely to the supporting side for foot off. The first movement of the COM was also in the frontal plane of all participants. COM onset occurred just prior to head onset and shifted towards the supporting side. There were no differences between groups in either COP onset to COM onset time or COP onset to head onset time.

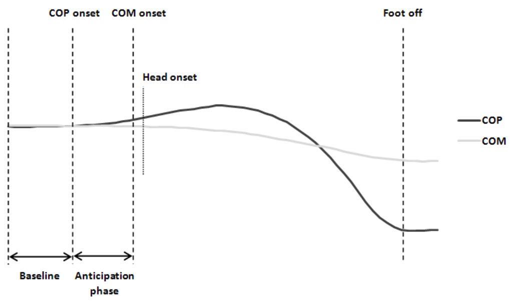

Figure 3. Illustration of the medio-lateral COP and COM displacements at turn initiation.

4. Discussion

This is the first prospective study to explore biomechanical differences between older community-dwelling fallers and non-fallers during a standing turning task, with differences detected between groups for measures of segmental orientation. The biomechanical assessment of turning is of particular importance as falls when turning have a higher likelihood of resulting in a sideways fall than a forward or backward fall [5]. A fall to the side is more likely to result in a hip fracture than a fall forward or backward [24], and falls when turning account for ~18% of hip fractures [25].

All of the participant groups demonstrated head yaw as the first movement in the initiation of a 360° turn. Head yaw has been shown as the first movement in studies involving different forms of turning such as walking a circular path [26], turning when walking[27, 28], and turning on the spot [13]. The head continued to lead the movement throughout the turn, demonstrated by the mean head to trunk angle, with the non-fallers demonstrating a significantly larger separation between the two body segments than the multiple fallers. Although eye movement was not measured in this current study, it is assumed that the head led the movement as a strategy by the participants to look where they were going. This gaze-centric control strategy has been demonstrated previously when turning, and suggests that aligning the head with the new travel direction prior to reorientation of the rest of the body is an important component of the steering strategy [28]. Previous research has found that older adults demonstrate an en-bloc head and trunk movement at turn initiation and then subsequently led the movement in the eyes open but not the eyes closed condition where the movement remained en-bloc[15]. This may be due to the turn being 90°, and it is possible that with the larger turn employed in the current study a higher priority was placed by the participants on looking where to turn.

The non-faller and single faller groups initiated movement at the trunk prior to movement at the pelvis, whereas the multiple faller group demonstrated significantly more en-bloc movement of these body segments during turn initiation. This trunk lead over the pelvis was maintained through the turn by the non-faller and single faller groups, albeit a small mean angular separation, whereas the multiple faller group exhibited less than 1° mean separation with the pelvis leading the movement of the trunk. The peak separation between trunk and pelvis was also significantly less for the multiple faller group, but this peak value was similar to the mean value of the other two groups demonstrating that the multiple faller group were able to generate the degree of separation displayed by the mean values of the non-faller and single faller groups but instead primarily used an en-bloc turning strategy. It is likely that these individuals are employing a strategy to simplify the movement to assist in balance control.

The clear cephalocaudal sequence demonstrated by the non-fallers and single fallers implies stabilisation of the head in space based on vestibular information with a descending temporal organisation of balance control [29]. This is in contrast to the en-bloc rotation, with the pelvis slightly leading the trunk, demonstrated by the multiple fallers which implies a pelvis stabilisation strategy where the destabilisation of the upper body induced by foot movement is counter-acted by locking the movement of the trunk to the pelvis and therefore the COM [29] . En-bloc rotations reduce the degrees of freedom to be controlled during the turning movement, and have been previously also been observed in patient groups [16, 17] as well as young children [30]. Therefore, the differences observed in trunk and pelvis motion in the multiple fallers, compared to the other groups, demonstrate the need for tighter control of movement in these individuals.

The multiple fallers took the longest time of the 3 groups to complete the 360° turn, however mean differences in turn duration were not statistically significant. Normal turning movement has been defined previously as the ability to complete a 360° turn in under 4 seconds [8], which is a faster turn time than for the mean times of all 3 groups in the current study. A turn time of greater than 9.1 seconds was correlated with recurrent falling [10], however none of the participants in the current study required 9 seconds to complete their turn despite some of them experiencing multiple falls in the follow-up period. The participants in this study by Lipsitz *et al* [10] were all classified as frail, were not community-dwelling and were older (mean age 87) than the participants in the current study (mean age 71). Therefore, time to turn may only be a predictor factor for falling in those who are frail and unable to live independently and is not sensitive enough measure to predict falling in community-dwelling older adults.

The multiple fallers and single fallers took on average an extra step to complete the turn than the non-fallers, but this was not significantly different, at the 5% level, between groups. However, the difference in this measure between the non fallers and the multiple faller was weighted significant at the 10% level, suggesting this variable may be useful in predicting those who might fall. This extra step employed by the single and multiple fallers may be a strategy to aid in trunk stability in these individuals.

Anticipatory COP and COM movements showed the same pattern amongst the participant groups and were similar to previous studies [18, 19]. No differences were observed between groups for the APA variables. This was surprising as increased APA time has been observed in faller groups for obstructed gait initiation [19]. However obstacle negotiation is a visually guided process, whereas the turning task was not visually guided by a target, therefore the obstacle task reported in the literature is likely to occur a higher attentional cost that the turning task in the current study. In addition, the obstacle task was initiated by a cue whilst the turning task was initiated by the participant, therefore reaction time could not be measured alongside APA time in the current study. Further research could investigate whether cued turning elicits differences in measures of APA in older faller and non-faller groups. Future research could also investigate COM and COP movements throughout the turn, which was beyond the scope of this study due to a tendency for participants to step off the force platforms during the turn, and how COM/COP profiles during turning are associated with a sequential or en-bloc movement strategy.

In the present study, all the participants were able to perform the turning task without stumbling or falling. However, the simplification of the movement displayed by the participants who subsequently experienced multiple falls suggests that the movement has to be simplified to assist with balance control during body rotation. Therefore, these individuals may be less able to react and adapt to situations during turning that requires a more complex movement or recovery from a perturbation. This might place these individuals at a higher risk of experiencing a fall.

5. Conclusions

Axial segmental reorientation was significantly more en-bloc during a 360° standing turn in community-dwelling older adults who fell two or more times during a prospective 12 month period. Other measures such as turn time and number of steps used to turn did not differ between the groups. These findings suggest that en-bloc axial segment reorientation during turning may be an indicator of compensating for decreased stability and therefore may be useful in identifying older adults at risk of falling.

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