Contribution of arm movements to recovery after a trip in older adults.

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Abstract

Falls are common in daily life, and our arms play an important role in recovering balance after a trip. Although older adults fall more often with more serious consequence, there is limited research into arm movements during falls in older adults. We investigated how older adults use their arms to recover from a trip and the difference between fallers and non-fallers.

Sixteen older participants walked along a walkway and were occasionally tripped using a custom tripping device. A biomechanical model used full-body marker and force-plate data to calculate the body rotation during the trip, and simulated the rotation without arms (Cut) and with transfer of the arms momentum to the body (Transfer & Cut). We only analysed the first trip, distinguishing fallers (n=5) from non-fallers (n=11).

Apart from an expected increase in forward body rotation at foot touchdown in fallers, we found no significant differences between fallers and non-fallers in the effects of arm movements on trip recovery. Like earlier studies in young participants, we found that arm movements had most favourable effect in the transversal plane: by delaying the transfer of angular momentum of the arms to the body, participants rotated the tripped leg more forward thereby allowing more room for a larger recovery step. Older adults that are prone to falling might improve their recovery from a trip by learning to [further] prolong ongoing arm movement.

Introduction

Falls are common in daily life, and a large proportion of these falls is caused by trips or slips (Talbot et al., 2005). The often-seen flailing of the arms after a perturbation makes one think that humans use their arms for balance recovery or protective purposes. Previous work has shown that arm swing during normal walking decreases stability (Bruijn et al., 2010; Meyns et al., 2013; Pijnappels et al., 2010), whereas extension of ongoing arm swing after a perturbation may be beneficial for balance recovery (Pijnappels et al., 2010).

After tripping, roughly two strategies can be observed; the elevating strategy, in which the tripped foot is placed over the obstacle, and the lowering strategy, in which the tripped foot is placed back on the ground before the obstacle (Eng et al., 1994). Pijnappels et al. (2010) showed that during the elevating strategy, young adults use their upper extremities to change their body orientation mainly in the transverse plane. Extension of the ongoing arm movement after obstacle impact delays the transfer of angular momentum from the arms to the body. This delay in momentum transfer leads to a more favourable body orientation with the tripped side being rotated more forward, which allows for a larger recovery step of the tripped foot.

So far, the role of the arms in recovering from a trip has mostly been studied in young adults, yet it is obvious that older adults suffer more from a poorly executed trip recovery. It has been suggested that older adults exhibit a more 'protective' recovery strategy, which could hamper their ‘preventive’ strategy

(Roos et al., 2008).It may be that elderly who fall after a trip, do so (partly) because of less adequate arm movements.

Thus, we investigated whether and how older adults use their arms to recover from an unexpected trip. Specifically, we evaluated the difference in the effects of arm movements in older adults who fell compared to those who did not.

Methods

Participants

16 older adults (11 males, 69.7±2.3 yr, 79±14 kg, 1.68±0.09 m) walked along a walkway, while in random trials they were tripped using a custom tripping device (Pijnappels et al., 2010). All participants were fit and had no orthopedic, neuromuscular, cardiac or visual problems. All participants signed informed consent, and the protocol was approved by the local ethical committee.

Procedure

First, participants were fitted with clusters of 3 infrared LED's for movement registration on the feet, calves, thighs, pelvis, thorax, upper and lower arms. Kinematics were sampled at 50 samples/second (Optotrak, Northern Digital, Waterloo, Ontario, Canada). Ground reaction forces were sampled at 1000 samples/second. In total, each subject walked on average 64 (SD 10) times along the walkway, in which they were randomly perturbed 7 (SD 2) times on the right leg

Calculations

A biomechanical human body model, was used to calculate whole body angular momentum, angular momenta of the separate segments, as well as a total body inertial tensor (Pijnappels et al., 2010). We then obtained whole body angular velocity at each time instant by dividing the angular momenta by the total body inertial tensor. These angular velocities were subsequently used to estimate the effects of arm movement at trip impact and during recovery phase (Pijnappels et al., 2010). In short, we calculated total body orientation (starting from 0º at trip impact) by integrating total body angular velocities over the course of a recovery until touchdown of the recovery foot (Actual). In addition, we calculated how the body would have rotated in a hypothetical situation in which the arms stop moving at the moment of the trip impact, i.e. when arm momentum is instantaneously transferred to the rest the body (Transfer & Cut, this calculation estimates the effect of ongoing arm swing at the instant of trip on body rotation after the trip). Third, we calculated how the body would have rotated in a hypothetical situation in which the arms do not transfer any momentum to the body (Cut). This calculation estimates the effects of arm movements executed during the trip. For mathematical details, see (Pijnappels et al., 2010).

Statistical analysis

We focused on the first trip, in line with previous studies as subsequent trips may contain habituation effects (Pijnappels et al., 2001). Tripping responses were manually classified by inspecting the data by two independent observers (LHS & SMB) into 1) lowering strategy, 2) successful elevating strategy, 3) unsuccessful elevating strategy. In the current study, we focused on the latter two. We tested differences between those participants that fell (‘fallers’, n=5) and those that did not (‘non-fallers’, n=11) during this first trial. We compared walking speed as well as time between impact and touchdown between these groups using an unpaired t-test. To test for differences in the effects of arm movements on body orientation at touchdown for each plane, we used a mixed model ANOVA, with Group (faller, non-faller) as between factor, and Calculation mode (Actual, Transfer & Cut, Cut) as within factor. Significant main effects were followed up by paired t-tests with Bonferroni correction. All analyses were performed in Matlab (R2019A, Nattick, Massachusetts: The MathWorks Inc.), and the level of significance was set at 0.05.

Table 1: Results of the statistical tests. Significant effects are displayed in **bold.**

	Calculation mode		Fallstatus		Calculation mode X Fallstatus	
	F(2,28)	p	F(F1,14)	p	F(2,28)	p
Sagittal	5.04	0.014	9.82	0.007	0.85	0.438
Frontal	16.74	<0.001	0.05	0.831	1.18	0.324
Transversal	67.34	<0.001	0.46	0.508	0.70	0.507

Results

The walking speed of the five fallers (1.48 m/s (SD 0.21)) was not significantly different from the non-fallers (1.43 m/s (SD 0.07), p=0.48). Also, the time between impact and recovery foot touchdown of fallers (464 ms (SD 84)) did not significantly differ from non-fallers (496 ms (SD 61), p=0.40). Thus, there were no differences in the time over which angular velocities were integrated between fallers and non-fallers.

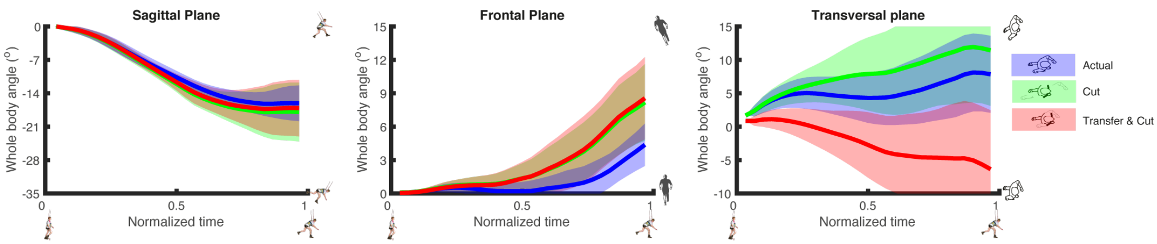

Figure 1: The effects of Calculation mode (different colours) on the total body orientation (y-axis) as a function of normalised time (x-axis, 0 = trip onset, 1.0=recovery touchdown) in the Sagittal (left), Frontal (middle), and Transversal (right) planes. Data represent the mean for the non-fallers. For each panel, the figures on the right illustrate what each orientation indicates. Shaded regions represent standard deviations.

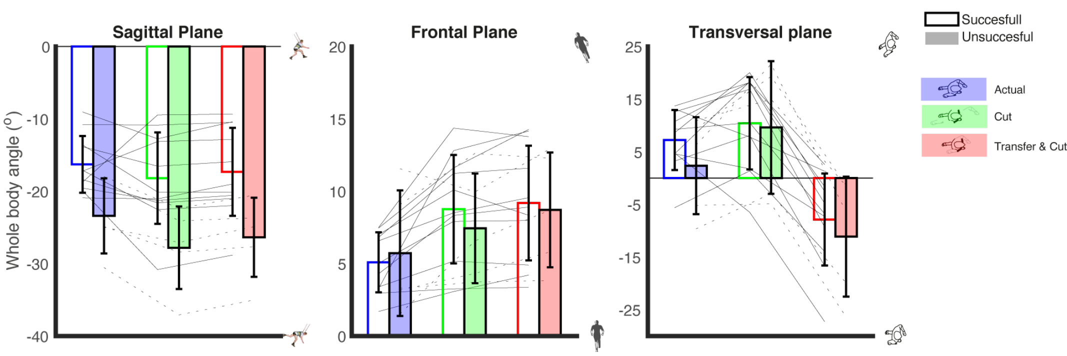

Figure2. Body orientation at touchdown for non-fallers (non-filled bars) and fallers (solid colours) as a function of Calculation mode (colours). Error bars represent standard deviations, and lines represent individual data.

The time courses of the body rotation for the different Calculation modes for non-fallers are displayed in figure 1. In the sagittal plane, fallers had a more forward rotated body configuration at touchdown than non-fallers (see figure 2, table1). Moreover, the Cut calculation led to small, although significant more forward body orientation than the Transfer & Cut calculation in both fallers and non-fallers. There was no significant interaction effect. These findings suggest that in the sagittal plane, it may be undesirable to delay transfer of angular momentum from the arms to the body, as this would lead to a less favourable body orientation (as seen in the Cut calculation). However, it should be noted that this difference between Calculation modes was very small (~1°).

In the frontal plane, there was no effect of Fall status, nor was there an interaction effect. However, the Actual calculation had a smaller rotation to the tripped side than both the Cut and Transfer & Cut calculations. This indicates that participants were able to fully cancel all angular momentum that was present at trip onset (i.e. the Transfer & Cut calculation), and even could transfer angular momentum from the body to the arms (since the actual orientation of the body was rotated even less than the Cut calculation.

In the transversal plane, there was also no effect of Fall status, nor was there an interaction effect. However, the Actual calculation showed an orientation with the tripped side less rotated forward than the Cut calculation, yet more rotated than the Transfer & Cut calculation. This indicates that in the transversal plane, participants significantly benefitted from delaying transfer of angular momentum from the arms to their body, so much even, that would they not do so, their body orientation at right recovery touchdown would be rotated backward at the right side. Still, participants did not manage to delay transfer of all arm angular momentum, as indicated by a significantly difference between Actual and Cut calculations

Discussion

We studied the effects of arm movements on recovery after a trip in older fallers and non-fallers. Apart from an expected larger forward rotation of the body in fallers compared to non-fallers at touchdown, we found no significant differences between fallers and non-fallers. Similar to earlier studies in young adults, we found that arm movements had most effect in the transversal plane, where older adults delayed the transfer of angular momentum of the arms to the body (i.e. behaved like the Cut calculation), thereby gaining a more favourable body orientation, with the tripped right leg rotated more forward.

Interestingly, these arm movements in the transverse plane, which may lengthen the recovery step, were not significantly different between fallers and non-fallers. Yet, in a post-hoc analysis, we found that fallers took significantly shorter recovery steps than non-fallers (0.56m (SD 0.14) for fallers, 0.82m (SD 0.11) for non-fallers, $p<0.01$). Thus, falling after a trip indeed seems to be related to problems with lengthening the step, but this is most likely not related to arm movements. Nevertheless, we measured only a limited number of participants, and the number of participants that fell during the first trip was small. Hence, it may be that there are meaningful differences that we could not detect due to low statistical power. Although another study suggested that older adults use a protective arm strategy of both arms limiting impact in case of a fall, which contributes to destabilizing(Roos et al., 2008), we did not observe such strategies in our fallers or non-fallers. Furthermore, earlier work strongly suggests that problems in rate of change in hip, knee and ankle moment that can be generated during push-off may be a more crucial in successful recovery from a trip than the contribution of arm movement (Pijnappels et al., 2005).

Another approach of understanding the potential importance of arm movements to falls in older adults is to compare the body rotation of them to earlier reported findings for young adults. In the sagittal plane, calculated body rotation at recovery foot touchdown in our older on-fallers was more upright than for young adults (-20º forward rotation in (Pijnappels et al., 2010), compared to ~16º in our study). While this could indicate that older adults were better at recovering from a trip, it could also be related to the fact that they generally walked slower, thus carrying less momentum (1.54 m/s in (Pijnappels et al., 2010), 1.48 m/s in ours).

The frontal plane body rotations at touchdown in older non-fallers were similar to the young adults in Pijnappels et al. (2010). However, in the older non-fallers, both the Transfer & Cut and Cut calculations led to significantly more rotation towards the tripped side. Thus, our results suggest that in the frontal plane, older non-fallers not only were able to cancel the angular momentum of the arms at the instant of a trip fully, but most likely were able to transfer some of the (hindering) angular momentum in this plane from the body to the arms. How they were able to do so is an interesting topic for further investigation.

In the transverse plane, older non-fallers rotated their tripped side forward by only 6.5º versus an average of 18º reported for young adults (Pijnappels et al. (2010), which indicates a substantially less favourable body orientation. Like in young adults, arm motions in older adults contributed to this rotation compared to no arm movements. However, there was also a slight but significant difference between the Actual and Cut calculations, implying that older adults did not cancel all momentum of the arms at the instant of a trip. Thus, older adults could perhaps improve their recovery to a trip by further prolonging the ongoing movements of the arms, thereby delaying the transfer of the angular momentum from the arms to the legs, achieving more forward rotation of the tripped side and potentially increasing recovery step length.

Conclusion

Arm movements during tripping in older adults help to move the body in a more favourable orientation for balance recovery after a trip, in particular in the transverse plane. While the recovery step was smaller in fallers, we found only minor differences in body rotation between fallers and non-fallers. This suggests that arm movements are not the main factor differentiating fallers from non-fallers.

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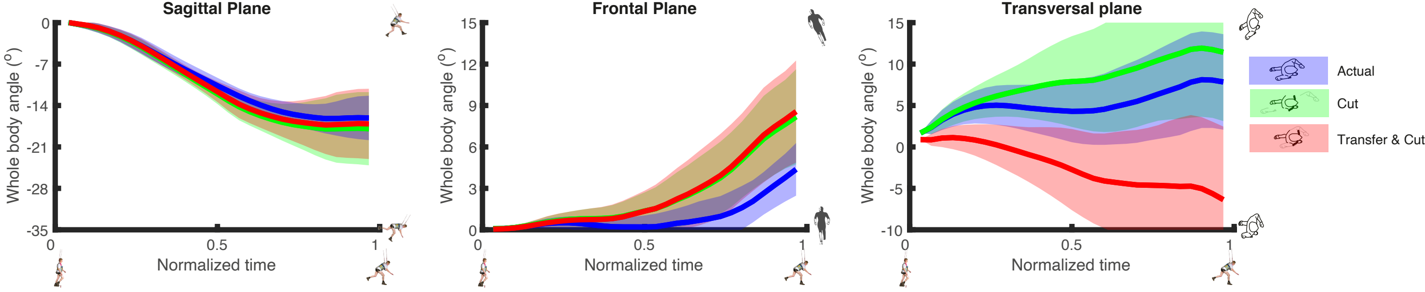
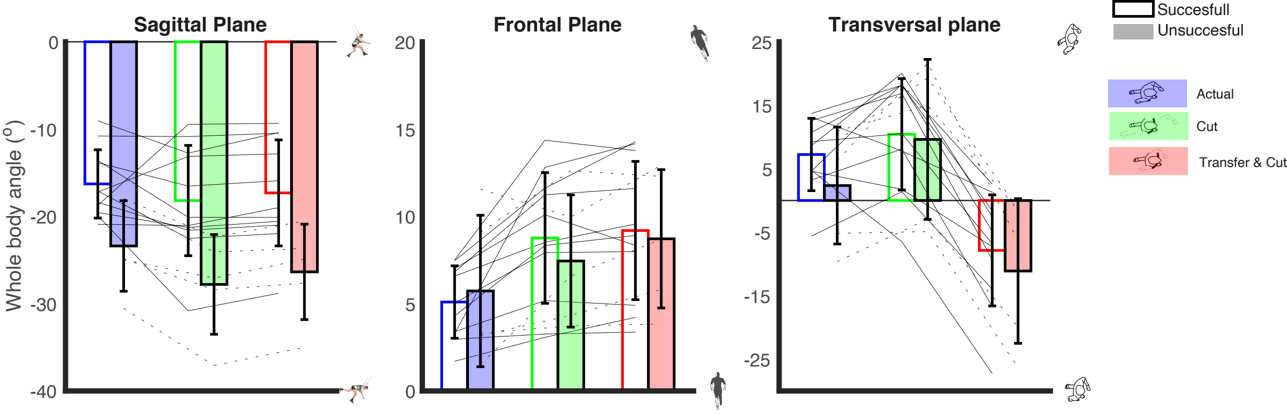


Sagittal Plane
Frontal Plane
Transversal plane
Whole body angle (°)
0
-7
-14
-21
-28
-35
15
12
9
6
3
10
5
-5
-10
0.5
1
Normalized time
Actual
Cut
Transfer & Cut


Sagittal Plane
Frontal Plane
Transversal plane
Succesfull
Unsuccesful
Actual
Cut
Transfer & Cut
Whole body angle (°)
0
-10
-20
-30
-40
20
15
10
5
0
25
15
5
-5
-15
-25