The final version of this article is available on the publisher's website:
https://doi.org/10.1115/1.4046636

A pilot study to detect balance impairment in older adults using an instrumented one-leg stance test

Jennifer N.C. Bassement[1], Brajesh K. Shukla[2], Sandeep K. Yadav[2], Vivek Vijay[2], Arvind Mathur[3], David J. Hewson[4]

1. Centre Hospitalier de Valenciennes, France
2. Indian Institute of Technology Jodhpur, Jodhpur, India
3. Asian Centre for Medical Education, Research & Innovation, Jodhpur, India
4. Institute for Health Research, University of Bedfordshire, Luton, United Kingdom

SHORT TITLE

Instrumented OLS detection of balance impairment

FULL ADDRESS FOR CORRESPONDENCE

Professor David Hewson

Institute for Health Research

University of Bedfordshire

University Square

Luton

Bedfordshire LU1 3JU

Phone: +44 (0)7525616645

Email: david.hewson@beds.ac.uk

EMAIL ADDRESSES

Dr Jennifer Bassement	jennifer.bassement@uphf.fr
Brajesh Shukla	shukla.1@iitj.ac.in
Dr Sandeep Yadav	sy@iitj.ac.in
Dr Vivek Vijay	vivek@iitj.ac.in
Dr Arvind Mathur	mathurarvindju@gmail.com
Prof David Hewson	david.hewson@beds.ac.uk

ABSTRACT

The aim of this study was to investigate whether parameters from an instrumented one-leg stance (OLS) on a force plate could provide relevant information related to fall risk in older people. Forty-two community dwelling older people including 17 fallers and 25 non-fallers, and 25 young subjects performed a one-leg stance while standing on a force plate, with parameters related to transferring weight onto one leg and postural sway in singe-leg stance evaluated. No differences were observed between older fallers and non-fallers and the younger participants for any of the weight transfer parameters. The younger participants were able to reduce their postural sway during the OLS test after the first 0-2 second period, unlike older participants who swayed the same amount throughout the test. The older fallers swayed significantly more than both non-fallers and younger participants throughout the 10-seconds of OLS evaluated. When the tests were used to classify older participants as fallers, the instrumented OLS achieved 100% accuracy, compared to 69.0% classification accuracy for the five times sit-to-stand test, 61.9% for the standard OLS and 47.6% for the timed-up-and-go test. These findings suggest that the standard OLS test might not be suitable to detect fall risk. In contrast, an instrumented version of the OLS could provide valuable additional information that could identify older fallers. Future work will include a prospective study of the instrumented OLS in a larger population of older people.

Keywords

Balance, falls, functional screening.

INTRODUCTION

Falls typically occur in around 30% of older adults each year, with up to 20% of these falls resulting in injury, hospitalisation and even death [1, 2]. Falls place a substantial burden on all countries in terms of healthcare and economics, with the cost of a fall estimated at US$2000, rising to US$42,000 when there is a fall-related injury [3]. Given the healthcare and economic consequences of falls, interventions that decrease the incidence of falls are needed. Some studies have reported that interventions such as strength and balance training, and walking, can decrease both the incidence and severity of falls [4]. However, it is too costly to provide such interventions for all older people, making it necessary to identify older people at increased risk of falls, who can then be targeted for fall prevention. There are many risk factors for falls in older people, including a previous history of falls, gender, living alone, use of medication, and impaired balance and gait [5-7].

Several different clinical tools have been developed to identify fall risk, including questionnaires such as STRATIFY [8] and the self-rated fall-risk questionnaire [9] and functional tests such as the Berg Balance Test [10], Timed Up and Go Test (TUG) test [11], and the Five Times Sit to Stand Test (5STS) [12]. Another widely-used functional screening tool is the One Leg Stance (OLS) test, which requires the person being assessed to stand on one leg for as long as possible [13]. The OLS is cost effective, easy to administer, time efficient and does not require much equipment [7, 14, 15]. However, although the OLS has been found to be associated with an increased prevalence of fracture, a direct association with fall risk is not always clear [16]. One reason for this finding could be that the test uses only the time a person can balance on one leg and does not consider any information about the way in which a person maintains balance.

Some studies have attempted to extract additional information from the OLS by requiring users to perform the test while standing on a force plate. These studies have used different balance parameters such as time to stabilisation (TTS) [17], the variability of the force developed [18], the amount of centre of pressure (CoP) displacement [19], and the CoP velocity and surface area [20]. In these studies, results were compared between different groups, with no comparison to other geriatric screening tools. The aim of this pilot study is to compare balance parameters extracted from an OLS, including CoP displacement and surface area with the TUG and 5STS screening tests to investigate whether balance parameters during single leg stance could provide relevant information related to fall risk in older people.

METHODS

Participants

Three groups of participants of were tested in Jodhpur, India. A group of 25 community-dwelling older people were included based on inclusion criteria of having not fallen in the previous two years, no medical conditions related to an increased fall risk, and not taking any medication known to increase fall risk. These older participants had a mean age of 70.9 ± 5.9 y (mean ± SD), a mean height of 1.66 ± 0.07 m, and a mean weight of 70.9 ± 12.4 kg. A second group of 17 community-dwelling older fallers were included, all of whom had fallen within the previous six months. These older participants had a mean age of 67.6 ± 6.8 y, a mean height of 1.57 ± 0.07 m, and a mean weight of 64.1 ± 11.6 kg. The third group of younger subjects consisted of 25 people living on the Indian Institute of Technology residential campus in Jodhpur, India. The younger participants had a mean age of 19.8 ± 1.2 y, a mean height of 171.8 ± 8.4 cm, and a mean weight of 66.3 ± 10.5 kg. Ethical approval was granted by the Ethics Committee of the Dr S.N Medical College of Jodhpur (Ethical approval: 1262/6419).

Testing protocol

Participants performed the OLS on their preferred leg with their eyes open for all tests. Participants performed the OLS three times when standing on a force plate (Bertec Corporation, Columbus, OH, USA; Model 4060-80). Participants were asked to step on the force plate, stabilise on two feet then perform the OLS on their preferred leg, with their best time taken as their OLS performance. Data was collected at 1000 Hz using Bertec's Digital Acquire software (Version 4.0). Immediately after the OLS test, participants performed two other functional screening tests, the Five Times Sit to Stand Test (5STS) [12] and the Timed Up and Go Test (TUG) test [11]. Older participants were classified as being at risk of falling if their performance did not meet one of the previously-established cut-offs of 15 seconds for the 5STS [21] and 13.5 seconds for the TUG [22].

Data analysis

All force plate data were analysed in Matlab (MathWorks Inc, Natick, Massachusetts, USA). Data were low pass filtered using a Butterworth filter with a cut-off of 10Hz and segmented into different phases.

The start of the signal was taken to be the instant when vertical force (Fz) exceeded the subject's body weight (T_{Start}), while the end of the signal was taken to be when vertical force (Fz) exceeded the subject's body weight, calculated backwards from the end of the signal (T_{Stop}). When the subject began to transfer their weight from two feet to one foot, a clear shift in mediolateral CoP displacement was visible (T_{Shift}), with the start of the OLS (T_{OLS1}) taken to be the moment the initial shift in CoP towards the single leg reversed (Figure 1). The end of the OLS (T_{OLS2}) was taken as 10 seconds, with all but three of the 67 participants achieving a 10 sec OLS in their best performance on the force plate.

Balance parameters were calculated for the OLS for the change from a two-foot to a single-foot stance (T_{Shift} to T_{OLS1}) and for static balance on one leg (T_{OLS1} to T_{OLS2}). The parameters used to quantify the weight transfer phase, when participants shifted their weight to one leg were the total excursion of the CoP (TOTEX), the mean velocity of the CoP (MVELO), and the range of the CoP (Range) [23]. All three parameters were calculated for both the mediolateral and anteroposterior axis displacement.

[Figure 1 here]

The amount of postural sway in the OLS was calculated as the surface area of a circle covering 95% of the CoP oscillation (Area) [23], with sway calculated for each 2-second interval across the ten seconds of the OLS retained for analysis. For the three participants who were unable to achieve a 10-second OLS, missing values for the missing 2-second sway intervals were imputed using multiple linear regression.

Statistical analyses were performed using SPSS version 25 (IBM Corp, Armonk, New York, USA). Data were assessed for normality using the Shapiro-Wilk test. All data was non-normal, therefore the bootstrap method was used to produce unbiased estimates of the confidence limits around the mean [24]. When the Kruskal-Wallis Test identified a significant effect of group, pairwise comparisons were performed, with effect sizes were calculated using the methods described by Fritz and colleagues [25] as:

$$abs(r) = \frac{Z}{\sqrt{N}}$$

where *r* is the effect size for the pairwise comparison, Z is the Z-score of the test, and N is the sample size. Comparisons were also made for postural sway within groups between the first time period and all other time periods. Owing to the post-hoc nature of this analysis, Bonferroni adjustments were made to p values for statistical significance. The descriptors for the magnitude of the effects of Hopkins and colleagues were used to describe the effects observed [26]. The fall-risk prediction performance of the functional tests and the instrumented OLS was compared using discriminant function analysis, with older participants classified as fallers or non-fallers using each test, and the leave-one-out method used for cross-validation.

RESULTS

Bootstrapped means and confidence limits for the performance of the two groups of non-falling older participants and the fallers in the three screening tests are shown in Table 1. There was no difference between fallers and non-fallers for TUG performance (r=0.14), however fallers were significantly worse at the 5STS test (r=0.53), which corresponds to a large effect. The number of older non-fallers classified as being at risk of falling using the cut-offs for the TUG and 5STS was 11 (44%), with five subjects were classified as being at risk of falls by both tests (20%), and six subjects classified as being at risk of falls by one of the tests (24%). The remaining 14 non-fallers were classified as having no risk of falling (56%). Four fallers were classified as having no risk of falling (23.5%), four fallers were classified as having a risk of falling by both tests (23.5%), while nine fallers were classified as being at risk of falls only by the 5STS (53%).

Table 1. Functional screening test results

Test	Non fallers	Fallers
TUG	11.9 (11.0-12.8)	11.1 (9.9-12.3)
5STS	13.4 (11.9-14.9)	17.4 (15.7-19.1)

Values are bootstrapped means and confidence limits

Weight Transfer Phase

There were no significant differences in the mean durations of the weight transfer phase for the three groups (H=3.195, p=0.202). The bootstrapped means and confidence intervals for the three groups were 0.8 sec (0.6-0.9 sec) for young, 1.1 sec (0.8-1.4 sec) for non-fallers, and 0.9 sec (0.7-1.2 sec) for fallers.

Bootstrapped means and standard deviations of the velocity of the CoP for both anteroposterior and mediolateral displacement are shown for all three groups of participants in Figure 2. There were no significant differences between the groups for either displacement direction based on the Kruskal-

Wallis test (Anteroposterior: H=0.682, p=0. 711; Mediolateral: H=2.622, p=0.270). Bootstrapped means and standard deviations of the total CoP displacement for both anteroposterior and mediolateral displacement are shown for all three groups of participants in Figure 3. There were no significant differences between the groups for either displacement direction based on the Kruskal-Wallis test (Anteroposterior: H=2.721, p=0.257; Mediolateral: H=0.367, p=0.832). Bootstrapped means and standard deviations of the range of CoP displacement for both anteroposterior and mediolateral displacement are shown for all three groups of participants in Figure 4. There were no significant differences between the groups for either displacement direction based on the Kruskal-Wallis test (Anteroposterior: H=0.105, p=0.949; Mediolateral: H=2.226, p=0.329).

[Figure 2 here]

[Figure 3 here]

[Figure 4 here]

One Leg Stance Phase

The amount of postural sway for the two groups of participants for each of the 2-second time periods is shown in Figure 5. There were significant effects of the group for each of the five time periods, as well as for the overall postural sway for the entire 10 seconds of the test. The pairwise effect sizes for the differences between the groups for each time-period are shown in Table 2. All the pairwise comparisons were significantly different, with the largest seen between the fallers and the other two groups.

Table 2. Effect sizes for differences in postural sway

Time Period	Kruskal-Wallis Test	Pairwise Comparisons		
		Young vs Non-fallers	Young vs Fallers	Non-fallers vs Fallers
0-2 sec	H=28.713, p<0.001	0.25	0.69*	0.69*
2-4 sec	H=36.866, p<0.001	0.35*	0.84*	073*
4-6 sec	H=42.718, p<0.001	0.56*	0.84*	0.73*
6-8 sec	H=38.864, p<0.001	0.48*	0.84*	0.69*
8-10 sec	H=39.291, p<0.001	0. 45*	0.84*	0.63*
0-10 sec	H=38.946, p<0.001	0.45*	0.84*	0.84*

Values are effect sizes for pairwise comparisons. * Significant difference in pairwise comparison using Bonferroni adjustments (p<0.05).

Stabilisation was taken to be a decrease in postural sway when compared to the first time-period. The young group stabilised quickly, with all time periods from the second onwards having significantly less sway than the first time-period (Figure 5). However, neither of the two groups of older participants decreased postural sway during the OLS.

[Figure 5 here]

Discriminant function analysis to classify older participants as fallers and non-fallers achieved only 47.6% accuracy using the TUG (Wilk's Lambda = 0.997, F=0.114, p=0.737). The use of OLS time produced slightly better classification results, with 61.9% of participants classified correctly (Wilk's Lambda = 0.845, F = 7.337, p=0.010), as did the 5STS, which successfully classified 69.0% of participants (Wilk's Lambda 0.720, F=15.574, p<0.001). In contrast, when total postural sway for the 10-sec instrumented OLS parameters was used, 100% classification accuracy was achieved (Wilk's Lambda = 0.172, F=191.361, p<0.000).

DISCUSSION

The findings of this pilot study offer evidence that an instrumented version of the OLS could provide additional information related to fall risk in older people when compared to the standard OLS test. The analysis addressed both the weight transfer and the single leg stance phases of the test. With respect to weight transfer, no differences were visible between the groups. Such a lack of differences could be due to the large variability in the duration of the weight transfer phase for all groups of participants, with each group having large 95% confidence intervals of the bootstrapped means. This would indicate that there were varying strategies employed by the participants to step onto one leg, from performing the movement as quickly as possible, to taking a slower precautionary approach. The variation in the duration of the weight transfer phase would also influence the parameters calculated during this phase.

With respect to postural sway, not surprisingly, younger subjects swayed less than both groups of older participants for total sway during the 10-second OLS. When the individual epochs were compared, there was no difference between the younger subjects and the older non-fallers for the first two seconds after weight transfer. Thereafter, older non-fallers swayed more than the younger participants, suggesting the difference in sway was due to the ability of the younger subjects to stabilise their posture. When older participants were compared, the fallers swayed much more the non-fallers, with large to very large effect sizes observed [26]. Interestingly, despite swaying more than non-fallers, all fallers passed the OLS test for fall risk, which has a five-second cut-off [13]. This finding throws some doubt on the suitability of OLS as a test of fall risk, unless additional information about the way in which they perform the test is available. Such information could be provided by an instrumented version of the test.

Although there have been other studies in which an instrumented version of the OLS has been used, such studies have compared younger and older subjects, but no comparison has been made to fall risk [19, 20]. In these studies, differences between older and younger subjects varied over time, with older subjects taking more time to regain standing balance after the weight transfer. Similar results were observed in the present study, with younger participants immediately decreasing their postural sway after the first two-second time-period. However, none of the older participants were able to decrease their postural sway after beginning the OLS, regardless of whether they were fallers or non-fallers.

When the performance of functional tests to identify fallers was compared, the instrumented OLS performed much better than any of the other tests, including the standard OLS. The TUG was unable to identify fallers, while the OLS and 5STS were able to classify around two thirds of participants successfully. In contrast, postural sway from the instrumented OLS was able to classify all participants correctly as fallers or non-fallers. This finding suggests that an instrumented version of the OLS would be worth investigating in a larger study.

There are some limitations in the present study. Firstly, all participants were able to pass the fall-risk threshold for the OLS. This means that the findings of the study might not apply to people unable to maintain the OLS for five seconds. In addition, a larger sample size than 25 older non-fallers and 17 older fallers would have strengthened the results of this pilot study. Despite these limitations, there were clear differences in postural sway during the OLS between fallers and non-fallers. The instrumented OLS was able to discriminate between fallers and non-fallers based on the amount of sway when standing on one leg, unlike other functional tests. Future work will include prospective fall risk using falls diaries, with a larger participant group that would ideally include some participants who fail the standard OLS test. Future work could also use a lower-cost, portable device such as the Wii Balance Board or the Balance Quality Tester, which is an intelligent bathroom scale that can measure balance remotely.

Disclosure statement

The authors certify that they have no conflict of interest in the subject matter discussed in this manuscript.

Ethical approval

Ethical approval was granted by the Ethics Committee of the Dr S.N Medical College of Jodhpur (Ethical approval: 1262/6419). All participants read an information sheet and gave their informed consent. None of the subjects had any known musculoskeletal or neurological disorders nor had fallen in the previous twelve months.

REFERENCES

[1] Rubenstein, L. Z., 2006, "Falls in older people: epidemiology, risk factors and strategies for prevention," Age and Ageing, 35(suppl 2), pp. ii37-ii41.

[2] Korhonen, N., Kannus, P., Niemi, S., Palvanen, M., and Parkkari, J., 2013, "Fall-induced deaths among older adults: nationwide statistics in Finland between 1971 and 2009 and prediction for the future," Injury, 44(6), pp. 867-871.

[3] Heinrich, S., Rapp, K., Rissmann, U., Becker, C., and König, H. H., 2010, "Cost of falls in old age: a systematic review," Osteoporosis International, 21(6), pp. 891-902.

[4] Robertson, M. C., Campbell, A. J., Gardner, M. M., and Devlin, N., 2002, "Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data," J Am Geriatr Soc, 50(5), pp. 905-911.

[5] Todd, C., and Skelton, D., 2004, "What are the main risk factors for falls among older people and what are the most effective interventions to prevent these falls?," World Health Organisation Regional Office for Europe, Copenhagen, Denmark.

[6] Tinetti, M. E., Doucette, J. T., and Claus, E. B., 1995, "The Contribution of Predisposing and Situational Risk Factors to Serious Fall Injuries," Journal of the American Geriatrics Society, 43(11), pp. 1207-1213.

[7] Fuller, G. F., 2000, "Falls in the elderly," Am Fam Physician, pp. 2159-2168, 2173-2154.

[8] Oliver, D., Britton, M., Seed, P., Martin, F. C., and Hopper, A. H., 1997, "Development and evaluation of evidence based risk assessment tool (STRATIFY) to predict which elderly inpatients will fall: case-control and cohort studies," Bmj-British Medical Journal, 315(7115), pp. 1049-1053.

[9] Rubenstein, L. Z., Vivrette, R., Harker, J. O., Stevens, J. A., and Kramer, B. J., 2011, "Validating an evidence-based, self-rated fall risk questionnaire (FRQ) for older adults," Journal of Safety Research, 42(6), pp. 493-499.

[10] Berg, K., and Norman, K. E., 1996, "Functional assessment of balance and gait," Clinics in Geriatric Medicine, 12(4), pp. 705-723.

[11] Podsiadlo, D., and Richardson, S., 1991, "The timed "Up & Go": a test of basic functional mobility for frail elderly persons," J Am Geriatr Soc, 39(2), pp. 142-148.

[12] Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., Scherr, P. A., and Wallace, R. B., 1994, "A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission," J Gerontol, 49(2), pp. M85-M94.

[13] Vellas, B. J., Wayne, S. J., Romero, L., Baumgartner, R. N., Rubenstein, L. Z., and Garry, P. J., 1997, "One-leg balance is an important predictor of injurious falls in older persons," J Am Geriatr Soc, 45(6), pp. 735-738.

[14] Waldron, N., Hill, A., and Barker, A., 2012, "Falls prevention in older adults Assessment and management," Australian Family Physician, The Royal Australian College of General Practitioners (RACGP), pp. 930-935.

[15] Persad, C. C., Cook, S., and Giordani, B., 2010, "Assessing falls in the elderly: should we use simple screening tests or a comprehensive fall risk evaluation?," Eur J Phys Rehabil Med, pp. 249-259.

[16] Michikawa, T., Nishiwaki, Y., Takebayashi, T., and Toyama, Y., 2009, "One-leg standing test for elderly populations," Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association, 14(5), pp. 675-685.

[17] Dingenen, B., Staes, F. F., and Janssens, L., 2013, "A new method to analyze postural stability during a transition task from double-leg stance to single-leg stance," J Biomech, 46(13), pp. 2213-2219.

[18] Jonsson, E., Seiger, A., and Hirschfeld, H., 2004, "One-leg stance in healthy young and elderly adults: a measure of postural steadiness?," Clinical Biomechanics, 19(7), pp. 688-694.

[19] Parreira, R. B., Boer, M. C., Rabello, L., Costa, V. D. P., de Oliveira, E., and da Silva, R. A., 2013, "Age-related differences in center of pressure measures during one-leg stance are time dependent," J Appl Biomech, 29(3), pp. 312-316.

[20] Roemer, K., and Raisbeck, L., 2015, "Temporal dependency of sway during single leg stance changes with age," Clin Biomech, 30(1), pp. 66-70.
[21] Buatois, S., Miljkovic, D., Manckoundia, P., Gueguen, R., Miget, P., Vancon, G., Perrin, P., and Benetos, A., 2008, "Five times sit to stand test is a predictor of recurrent falls in healthy community-living subjects aged 65 and older," Journal of the American Geriatrics Society, 56(8), pp. 1575-1577.
[22] Shumway-Cook, A., Brauer, S., and Woollacott, M., 2000, "Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test," Phys Ther, 80(9), pp. 896-903.
[23] Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., and Myklebust, B. M., 1996, "Measures of postural steadiness: differences between healthy young and elderly adults," Biomedical Engineering, IEEE Transactions on, 43(9), pp. 956-966.
[24] Kelley, K., 2005, "The effects of nonnormal distributions on confidence intervals around the standardized mean difference: bootstrap and parametric confidence intervals," Educ Psychol Meas, 65(1), pp. 51-69.
[25] Fritz, C. O., Morris, P. E., and Richler, J. J., 2012, "Effect size estimates: Current use, calculations, and interpretation," Journal of Experimental Psychology: General, 141(1), pp. 2-18.
[26] Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J., 2009, "Progressive statistics for studies in sports medicine and exercise science," Medicine and Science in Sports and Exercise, 41(1), pp. 3-12.

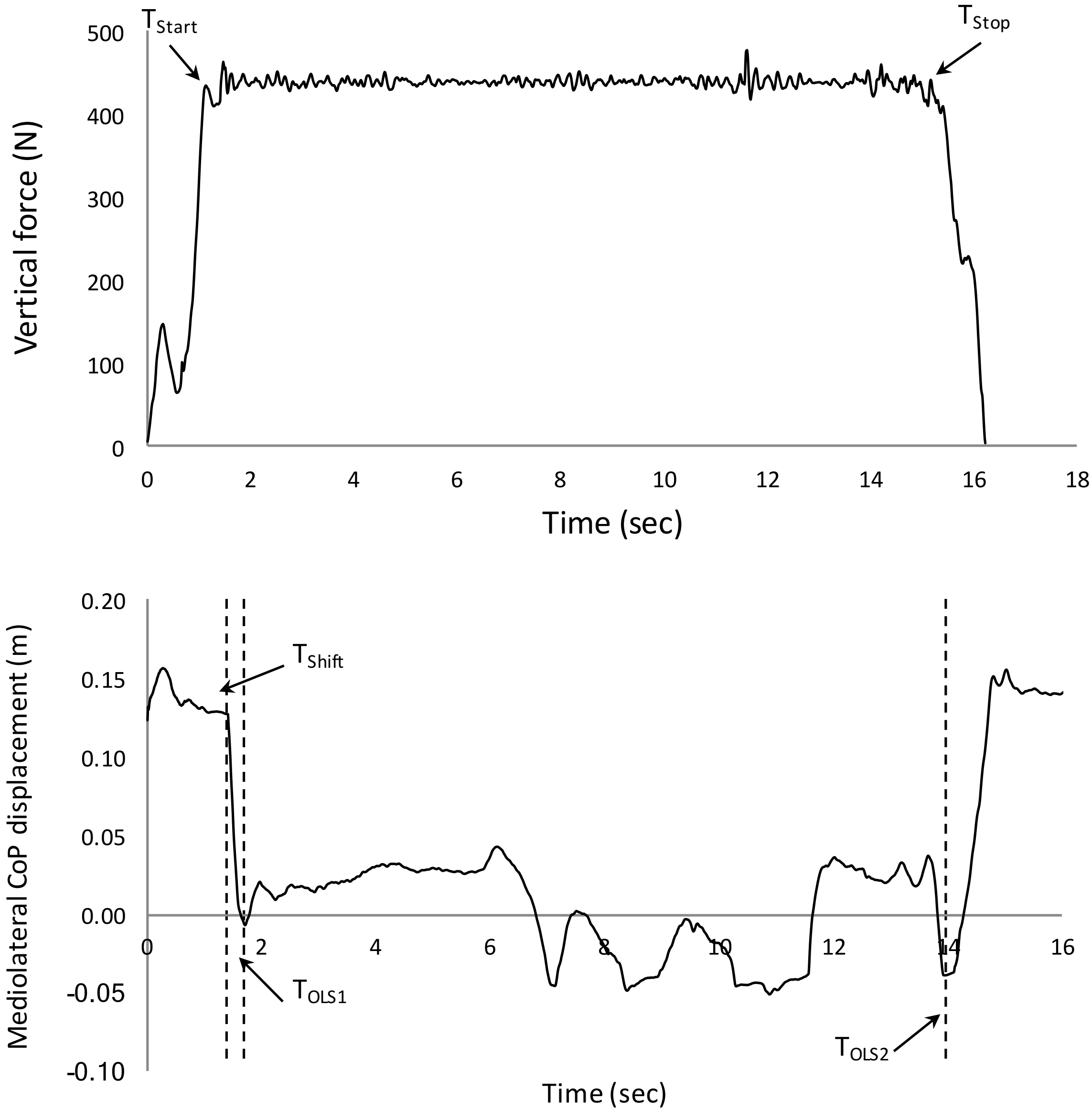

Figure 1. Example of a typical segmentation for the OLS signal using the mediolateral centre of pressure.

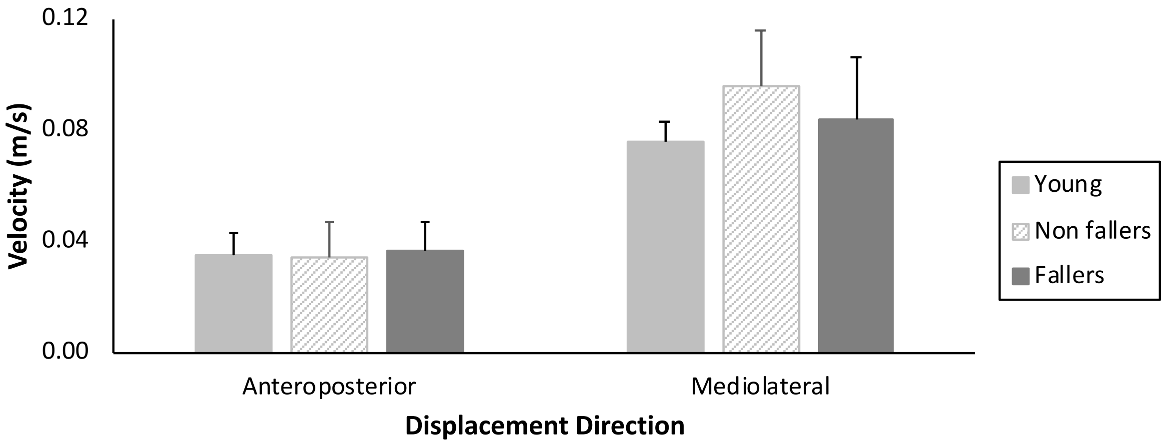

Figure 2: Velocity of centre of pressure displacement for older and younger participants. Data are bootstrapped means; error bars are 95% confidence intervals of the means.

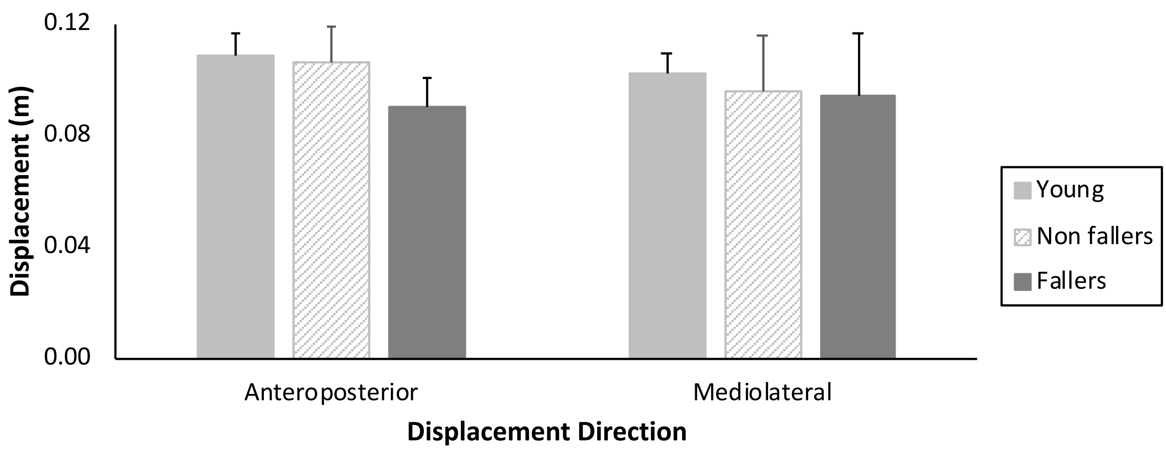

Figure 3: Total centre of pressure displacement for older and younger participants. Data are bootstrapped means; error bars are 95% confidence intervals of the means.

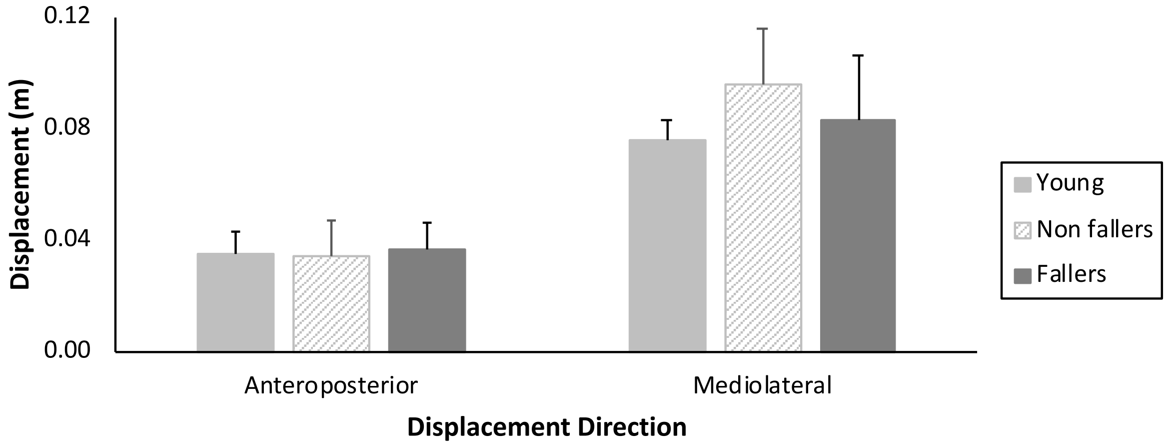

Figure 4: Range of centre of pressure displacement for older and younger participants. Data are bootstrapped means; error bars are 95% confidence intervals of the means.

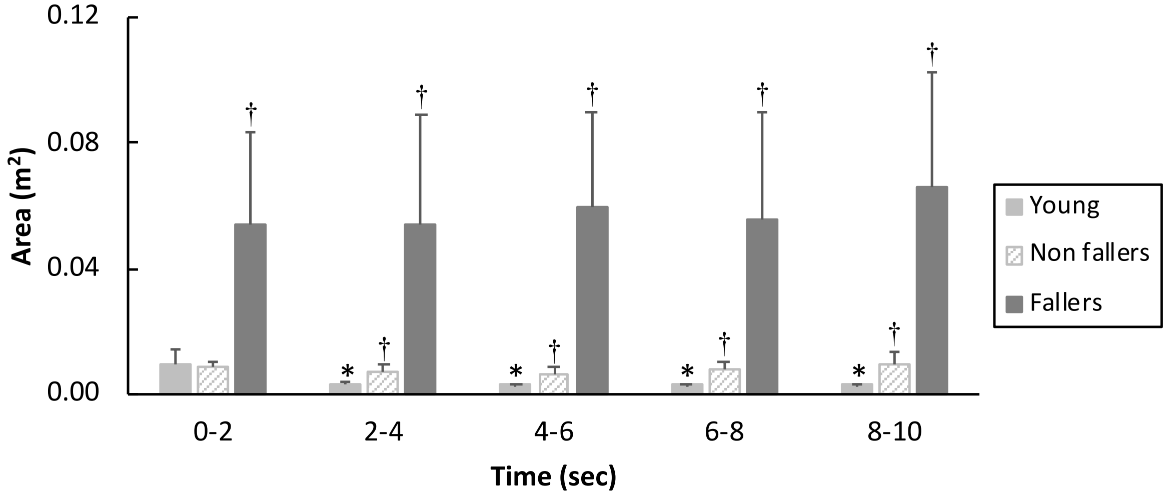

Figure 5: Sway area of the OLS for fall risk and no fall risk participants. Data are bootstrapped means; error bars are 95% confidence intervals of the means. *Significant difference from time period 0-2 sec ($p<0.05$); † Significant difference from young group ($p<0.05$).