Age and Ageing 2007; 36: 532–537
doi:10.1093/ageing/afm068
Published electronically 1 June 2007

Application of the voluntary step execution test to identify elderly fallers

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Abstract

Objectives to assess the use of the Voluntary Step Execution Test to identify fallers.
Design cross-sectional retrospective.
Setting two self-care, residential facilities.
Participants a total of 100 healthy old volunteers (mean age = 78.4 ± 5.7).
Measurements the study investigated the use of the Voluntary Step Execution Test to identify fallers under single and dual-task conditions. Berg Balance Test (BBS) and Timed Get Up and Go (TUG) were used to assess balance and gait function.
Results there were no significant differences found between fallers and non-fallers in BBS and TUG (50.5 ± 4.6 versus 52.5 ± 3.4 and 9.4 ± 3.4 versus 7.98 ± 2.3 respectively). There were no statistically significant differences between non-fallers and fallers across all step execution parameters under the single-task condition. However, adding cognitive load to the Voluntary Step Execution Test revealed statistically significant increases in duration of the preparatory phase, swing time and the time to foot-contact ($P = 0.035$; $P = 0.033$ and $P = 0.037$, respectively). Based on the coefficients of the logistic regression model participants with dual-task step execution times of ≥1,100 ms had five times the risk of falling than participants with execution times of <1,100 ms.
Conclusions the study provides evidence that a simple, safe measure of step execution under dual-task conditions can identify elderly individuals at risk for falls.

Keywords: *ageing, balance, falls, postural control, step reaction times, elderly*

Introduction

Thirty percent of individuals over 65 years old, and almost 50% of individuals over 80 years old, experience at least one fall each year [1]. Although most falls do not end in death or result in significant physical injury, the psychological impact of a fall often results in an increasing self-restriction of activities and a decrease in quality of life [2].

Loss of balance (perturbation to posture) after slips, trips and pushes trigger automatic postural responses with a delay of about 100 milliseconds (ms), which act to restore equilibrium [3]. A rapid step is an important protective postural strategy since it can prevent a fall from occurring [4]. In addition, voluntary movements impose perturbation of posture and to compensate for these perturbations our voluntary movements are accompanied by so called associated postural adjustments (APA) [5]. Failure to compensate may cause falls during various daily activities, including walking or changing position [6] or when tripping or tangling of the feet [7]. Although a rapid voluntary step may prevent a fall, voluntary step reaction times during an attention-demanding task are increased dramatically in healthy elders as compared to the younger [8].

A few studies have examined effects of dual-tasking on balance [9] and gait in elderly fallers [10, 11], but the effects of dual-tasking on the ability to step rapidly, and its relation to falls in elderly persons are not well documented. Since most falls have been reported to occur during a dynamic task, and commonly under dual-task conditions [12], it was the goal of this study to retrospectively examine whether the Voluntary Step Execution Test during single- and dual-task conditions could identify elderly community-dwelling fallers.

We hypothesised that the Voluntary Step Execution Test would better identify fallers than some commonly used clinical balance function measures. We also hypothesised that the greatest performance differences between fallers and non-fallers for the Voluntary Step Execution Test would be present under attention-demanding dual-task conditions. An additional purpose was to determine whether Voluntary Step Execution Test parameters could improve the assessment of future fall risk as compared with clinical balance tests alone.

Method

A total of 100 healthy old volunteers, 65–91 years of age, were recruited from senior living facilities. The exclusion criteria were: (i) serious visual impairment; (ii) inability to ambulate independently; (iii) score less then 24 in Mini Mental State Examination.

Our sample size estimation was based on work by Brauer *et al.* [13] who showed a 365-ms difference in compensatory step time between healthy and balance-impaired older adults under dual-task conditions. For a conservative estimate we used a measure of standard deviation (314 ms) from our previous work on voluntary stepping [8], where variability typically is larger than for compensatory stepping. Using the above numbers for a two-sided estimate at a significance level of 0.05 and 80% power, a minimum of 13 subjects would be required. We decided to study multiple fallers since one fall can simply be a random event that not necessarily reflects a balance disorder, whereas two or more falls would be a more reliable indicator of impaired balance function [14]. Stalenhoef *et al.* [15] reported that recurrent falls occur in 19% of elders and Melzer *et al.* [16] found that 13% of community-dwelling elders had fallen at least twice in the past 6 months. Consequently, 100 elderly individuals were recruited for the study assuming that at least 13 of them would be multiple fallers. Furthermore, a high ratio of control subjects to experimental subjects (87/13) would increase the power of the test, or conversely, fewer fallers would be required to detect the given difference in step time.

Participants provided informed consent, in accordance with approved procedures by the Helsinki ethics committee. After eligibility was determined, subjects were instructed to stand upright and barefoot on a force platform and to step as quickly as possible following a tap cue on the heel provided manually by the experimenter [8]. Centre of pressure (COP) and ground reaction force data during step execution tests were collected with a Kistler 9287 force platform (Kistler Instrument Corp, Winterthur, Switzerland). The force platform data were sampled at a frequency of 100 Hz. Step execution trials were 30 centimetres long and were always performed with the dominant leg as chosen by the subject. A total of nine trials were conducted for each of the two test conditions, forward, sideways and backward (three trials in each direction) for a total of 18 step trials. The test was performed under two different conditions. For the single task, subjects were viewing an **'X'** displayed on a screen 3 metres in front of them. During the dual task, they were viewing the same screen while performing a modified Stroop task and awaiting the somatosensory cue [8, 17].

Elderly persons enrolled in the study also underwent clinical gait and balance measures: The Berg Balance Test (BBS) with a test-retest reliability correlation coefficient of 0.98, [18]; and Timed Get up and Go test (TUG), found to be correlated with gait speed ($r = -0.61$) and Barthel Index ($r = -0.78$) [19, 20].

Data and statistical analyses

The analysis of step execution data extracted specific temporal events using a program written in MatLab (Math Works Inc, Cambridge, MA, USA). There were no significant differences in times between step directions, so the average across all directions was used for statistical analysis. The following events were extracted from the ground reaction force data (Figure 1): (i) The tap cue was detected as a spike in the anterior-posterior direction (shear ground reaction forces greater then 15N and less than 25N); (ii) The step initiation was detected as the first medio-lateral deviation of the COP towards the swing leg (COP excursion greater than 4 mm away from baseline sway following the tap); (iii) Time to Foot-off (FO) was defined as the sudden change in the slope of COP towards the stance leg in the medio-lateral direction; (iv) A successful Foot contact (FC) or step execution time was determined from the onset of unloading in vertical force seen when the foot of the step leg contacted the ground outside the force platform; (v) Preparatory phase was calculated as the time from step initiation to FO; (vi) Swing phase was calculated as the time from FO to FC. Similar procedures have previously been described in detail [8]. For each parameter, the mean dependent variables were calculated with SPSS (Chicago, IL) using a two-way analysis of variance (ANOVA) that included groups (fallers–non-fallers) as the between-subjects factor with repeated measures on the within-subjects factors of task (single–dual).

Student's t-test for independent measures was used to evaluate the differences between fallers and non-fallers in the BBS, TUG ($P<0.05$) and overall effect of the dual task (the average value across all three directions in the dual task normalised to a single task within each group) on step initiation phase, preparatory and swing phases. A full Bonferroni correction for uncorrelated measures was used ($P<0.017$) for each of the three t-tests to achieve an overall significance level of 0.05.

To assess the predictive abilities of the balance measures, a backwards logistic regression models was used with fallers

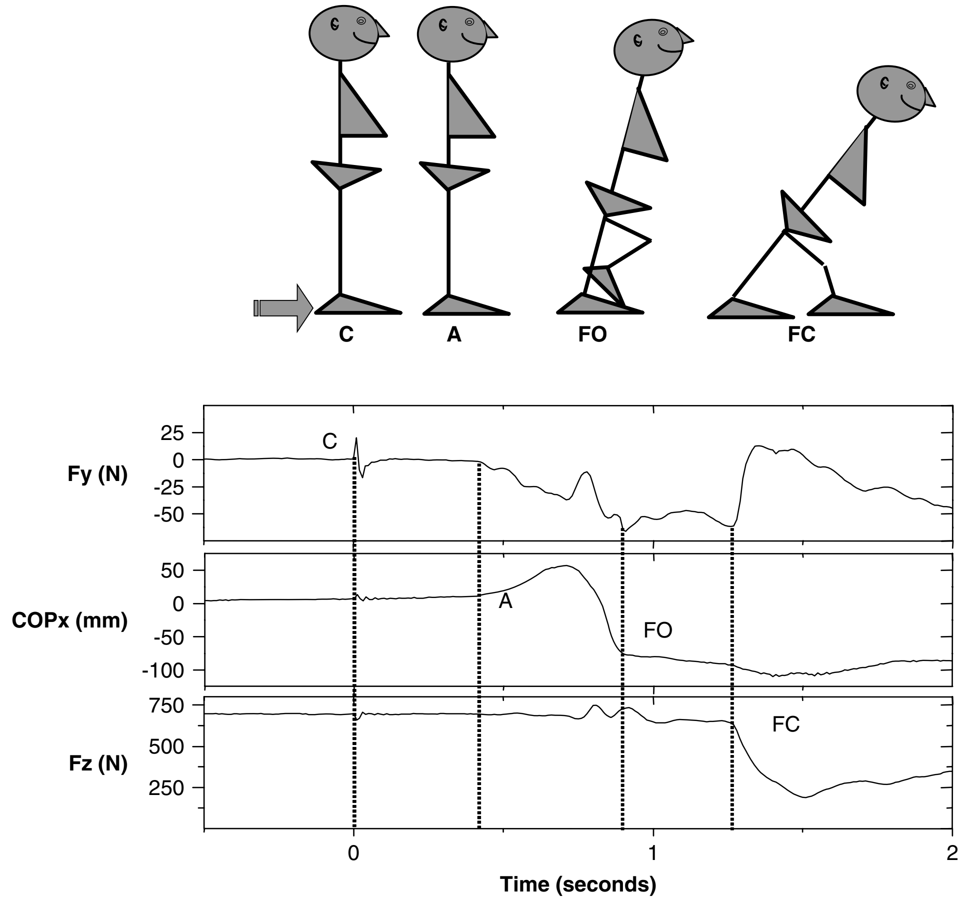

Figure 1. An example of forward step execution data. The following events are marked; Tap cue (C); Initial lateral deviation of centre of pressure towards the swinging foot (A); Foot-off (FO); Foot contact (FC) with the ground completing the step. Fy = Ground reaction forces (shear forces) in antero-posterior direction. Fz = Vertical ground reaction forces, COPx = Medio-lateral centre of pressure, N = Newton, mm = Millimetre.

and non-fallers as the dependent variable. Based on the coefficients of the logistic regression model we developed a score that used a weighted sum of the predictors for falls (BBS, TUG, Single and Dual Step). For each predictor, the antilog of the coefficient was multiplied by the predictor to create a weighted score in which the contribution of each predictor is based on its actual contribution to the log likelihood of falling. Then the area under the receiver operating characteristic (ROC) curve calculated. Sensitivity and specificity were calculated based on the ROC curve. The sensitivity of the model was defined as the percentage of fallers who were correctly identified by the test as compared with their reported falls in the last year. Multiple fallers were defined as fallers in the model. Alternately, specificity was defined as the percentage of non-fallers that were correctly identified. The sum of sensitivity and specificity defined as the validity of the dual task test (area under the curve), as compared with the single-task test and a combined score.

Results

Subject characteristics

Of the 100 aged 65–91 years old who participated in the study, 11 were multiple fallers (2 or more falls), 71 non-fallers, and 18 elderly persons fell only once during the past half year. Table 1 describes the physical, mental and performance characteristics of the 82 participants, and the differences in performance test scores between fallers and non-fallers. There were significant age differences between fallers and non-fallers, surprisingly, as fallers were younger 74.7 ± 5.1 than non-fallers 78.9 ± 5.5 ($P = 0.019$) suggesting that biological age is a more important variant than chronological age. Table 1 shows no significant differences in BBS and TUG (50.5 ± 4.6 versus 52.5 ± 3.4 and 9.4 ± 3.4 versus 7.98 ± 2.3 respectively), in mini mental state examination score, number of medications taken and physical characteristics.

Step reaction times

There were no statistically significant differences between non-fallers and fallers across all step execution parameters

Table 1. Subject characteristics for both groups of subjects. *P*-value compares baseline means ±1SD in the two groups and, unless otherwise indicated, are based on *t*-test or chi-square ([a])

Characteristic, mean ± SD	Fallers $n = 11$	Non-fallers $n = 71$	*P*-value
Age (years)	74.7 ± 5.1	78.9 ± 5.5	0.019
Gender (% males)	18.18%	33.9%	0.61[a]
Mini mental test score	29.4 ± 0.7	28.9 ± 1.0	0.17
No. of medications	5.9 ± 3.5	4.8 ± 2.9	0.29
Weight, kg	67.5 ± 6.1	66.6 ± 12.4	0.81
Berg Balance test	50.5 ± 4.6	52.5 ± 3.4	0.079
Timed Get up and Go, s	9.4 ± 3.4	7.98 ± 2.3	0.089

during the single-task condition (Figure 2(A)). The average step initiation times during the single-task condition were 262 ms for fallers and 220 ms for non-fallers ($P = 0.06$). The FC times were not significantly different between fallers and non-fallers (1,113 ms versus 986 ms). The preparatory phase and swing phase durations under single-task condition, were also not significantly different between groups (483 ms versus 443 ms and 367 ms versus 324 ms respectively).

Statistically, significant differences between fallers and non-fallers were found when an attention-demanding task was added to the Voluntary Step Execution Test (Figure 2(B)). The preparatory phase duration was 17.5% longer ($P = 0.037$) in fallers compared with non-fallers (515 ms versus 441 ms). Swing times were 27% longer ($P = 0.033$) in fallers (448 ms versus 351 ms), and time to FC (duration of step execution), was also significantly different, 1,414 ms for fallers versus 1,168 ms for non-fallers ($P = 0.037$). The step initiation phase under the dual task condition, were not significantly different between fallers and non-fallers (451 ms versus 376 ms, $P = 0.3$).

A ratio between dual- and single-task test conditions for each phase of the stepping task for the two groups were made. A statistically significant increase in the duration of the initiation phase that was of similar magnitude for both groups was found (170% and 173% for fallers and non-fallers, respectively, not statistically different between groups). Fairly similar statistically non-significant between-groups increases in preparatory phase (106% and 98%) and swing phase durations (122 and 109%) were also seen.

Results of the TUG, BBS, single and dual Step Execution Test were entered into a backwards stepwise regression model. Dual-task step execution time was the only independent variable that remained in the final step of the regression model. Participants with time to FC of ≥1,100 ms had five times the risk of falling than participants with time to FC of <1,100 ms. The *P*-value of the omnibus test for the final model was 0.026, −2 log likelihood ratio = 58.8. The goodness-of-fit of the model was improved when BBS, TUG, and Single Step Execution Test were included in the model (although their coefficient did not reach a significance level), therefore, we assessed the AUC of a combined score of these measurements. ROC curve demonstrated a higher area under the curve (AUC) for dual task stepping (0.67, $P = 0.06$) than for single-task stepping (0.63, $P = 0.17$) while a combined score has even higher AUC (0.72, $P = 0.02$). It was found that 9 of the 11 fallers had step execution times that were longer than 1,100 ms (range from 1,180 ms to 2,170 ms). The two remaining fallers had step execution times that were longer than 1,000 ms.

Discussion

The present findings are consistent with other reports demonstrating that performance of an attention-demanding

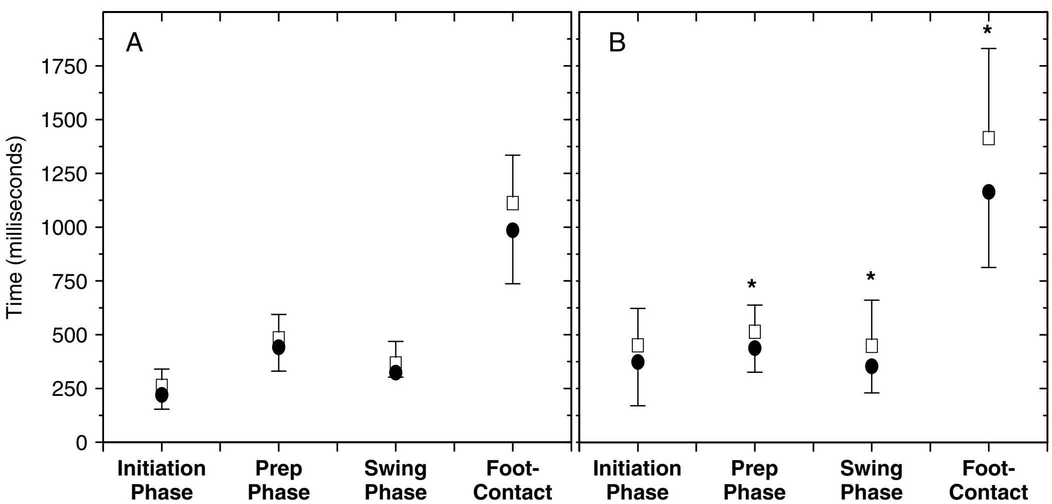

Figure 2. Average voluntary step execution parameters for both groups of subjects in both task conditions: (A) single task condition; and (B) dual task condition. Open squares represent Fallers and filled circles represent Non-fallers. Placement of symbols indicate mean values in milliseconds and the whiskers of each plot indicate ±1 standard deviation of the mean. *Indicates significant differences between groups ($P<0.05$).

dual task has a destabilising effect on the postural control of elderly fallers [21, 22]. Previous studies measured balance performance during standing or walking [11, 12, 15], whereas the current study investigated the application of the Voluntary Step Execution Test to retrospectively identify elderly fallers with the assumption that a quick step execution is a skill that can serve to alter the base of support and prevent a fall [8]. Such an indicator would allow identification of those elders who had previously fallen, as well as those at risk of future falls, allowing preventive measures to be implemented. It was previously suggested that a fast response time is the most important factor for successful balance recovery [4]. Cognitive loading leads to marked deteriorations in postural performance, suggesting that such 'dual tasking' is difficult for elderly even under relatively simple conditions [8, 22–24]. In fact, results of the current study show that a delayed completion of a voluntary step during a dual attention-demanding task may well be a marker for an increased risk of falling. The ability to quick-step during the execution of an attention-demanding task was significantly impaired in elderly fallers, with no statistical differences during single-task stepping.

Tideiksaar [25] suggested that falls in balance-impaired older adults commonly occur during walking and simultaneously performing a secondary task. It was hypothesised that these falls are due to the inability to effectively allocate attention to balance function in multi-task conditions [24, 25]. Toulotte *et al.* [26] found no significant difference in gait parameters between fallers and non-fallers during single-task conditions, however there was a significant difference under dual-task conditions. A recent study by Springer *et al.* [11] indicated that dual tasking can destabilise gait in elderly fallers and that this effect was accompanied by a decrease in executive function. Brauer *et al.* [27] found that balance-impaired older adults take longer to establish a stable position using a feet-in-place strategy when performing a second task. Similarly, Morris *et al.* [28] found that a concurrent task produced a significant deterioration in performance for the step test for patients of Parkinson's disease who were fallers.

We divided step execution into three phases: (i) the step initiation phase, (ii) the preparatory phase and (iii) the swing phase [8]. Each of these phases are dominated, although not exclusively, by different physiological processes. The step initiation phase is mainly dependent on peripheral sensory detection and afferent nerve conduction time followed by central neural processing and efferent nerve conduction time. During the preparatory phase, APA are executed. Finally, the swing phase is mainly dependent on neuromotor mechanisms related to the build-up of muscle force and power to execute the step. Since there were no significant differences in step initiation phase between fallers and non-fallers it seems that sensory detection thresholds, nerve conduction and velocities were similar between the two groups (Figure 2(A) and (B)). The similar dual- to single-task time ratios for fallers and non-fallers suggested similar increases in attentional demand for the two groups when performing dual-task stepping. Yet, significant changes in preparatory and swing phase durations were found during dual-task conditions (Figure 2(B)) suggesting that APA and power to execute the step during dual-task stepping were more attentionally demanding for fallers, and that dual-task stepping test be sensitive to changes in physical function, something single-task measures did not do as well, but only dual-task stepping was able to distinguish fallers from non-fallers. This illustrates that elderly fallers may be at a considerably greater risk of falling during an attention-demanding task.

The results from the present study add to a growing body of evidence showing that central processing factors and attentional capacity are important limitations for balance function. Results of the present study indicate that rapid dual-task stepping is taxing for the available cognitive resources in elderly fallers. Our evidence suggests that impaired ability to multi-task was associated with a fivefold increase in risk of sustaining a fall in daily life.

In conclusion, our evidence indicates that the dual-task paradigm Voluntary Step Execution Test may be a sensitive tool in the assessment of fall-prone individuals and could be a simple and inexpensive test to detect severity of balance impairments and to identify elders who are at risk of falling. These findings give some insight into the complexity of performing attention-demanding tasks while balancing and accentuate the need for multi-factorial, personalised specific intervention strategies, to prevent decline in dual-task performance in this fall-prone population. The ability to rapidly execute a step is a skill that can be improved by training [29] implying that such tasks should be part of a balance rehabilitation program for elderly individuals. Furthermore, results of the present study support the view that elderly persons should receive balance training under multi-task conditions. This notion was also supported by Silsupadol *et al.* [30] who found that older adults are able to improve their balance under dual-task conditions following specific dual-task balance training.

Key points

- There were no statistically significant differences between non-fallers and fallers in the Voluntary Step Execution Test under the single-task condition.
- Adding cognitive load to the Voluntary Step Execution Test revealed statistically significant differences between non-fallers and fallers.
- Participants with dual-task step execution times of $\geq$1,100 ms had five times the risk of falling than participants with execution times of $<$1,100 ms.
- The evidence indicates that the dual-task paradigm Step Execution Test may be a safe measure and sensitive tool in the assessment of fall-prone individuals.

Acknowledgement

This study was supported by a grant from the Sapir Research Foundation of 'Mifal H'apais' and by Ben-Gurion University Internal Research Support Fund.

Conflicts of interest

None

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Received 17 September 2006; accepted in revised form 27 March 2007