Comparison of balance and some other physical characteristics between elderly fallers and non-fallers

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Abstract

The present paper reports a retrospective study on differences between groups of elderly "fallers" (F) and "non-fallers" (NF). Participants (F: $n = 37$; NF: $n = 58$) were recruited among community dwelling home health care clients aged 65 or older. Participants were classified as "fallers" (F) and "non-fallers" (NF) based on their fall history. Static and dynamic balance tests were conducted using a force plate, complemented with Berg Balance Scale (BBS) test, visual gait analysis and leg strength measurements. Significant ($p \leq 0.05$) differences between the groups were found for medio-lateral sway while standing on foam, as well as for isometric leg-extension, body mass index (BMI) and body mass, fast-speed gait and for the four last items of the BBS test.

Introduction

Background

Inadvertent falls to the ground or the floor during standing, rising or walking pose considerable risks to the elderly because of the considerable probability of bone fractures and other traumas [1–3]. It is therefore of interest to screen people which might have an elevated risk of falling in order to be able to provide preventive measures [1, 4, 5], such as balance, agility and muscle strength training [6], or making the living environment safer. Balance platforms present convenient tools for investigating balance, and there are a few studies (for a review see [7]) which have shown that force platform measurements provide data that can predict to some degree whether a person belongs to the high risk group of fallers or not [8–11]. An interesting finding emerging from these studies is that the medio-lateral (M/L) sways during narrow stance seem to be a significant correlate with the fall risk. This phenomenon is confirmed by the present study also. As an exception we may mention the study [12] which found that the risk for falls indoor was correlated with the size of the anterior-posterior (A/P) sways; one may note that in that study they apparently did not standardize the foot position during quiet standing. A study [13] of Parkinson (PD) patients again found large M/L sways to be a significant distinguishing marker between PD (associated with impaired balance) and healthy participants. Sideways falls also increase the risks of hip fractures [14] compared to falls in other directions. Increasing response and reaction times with age have also been implied as fall risk factors [15]. Other potential factors are sensory ataxia, muscle weakness, syncope, medications, vestibular and cognitive losses [16–18]. It is therefore of interest to combine balance measurements with other types of measurements, such as force measurements, in order to get a fuller understanding of the factors contributing to raised fall risk. It is important not only to be able to assess the fall risks, but also to understand the reasons for increased fall risk in order to be able to plan and implement preventive measures.

Aims of the present study

There are several tests around (see Table 1) for a list) that have been used in fall risk assessments. The results are varying. For instance, a recent study [19] found that the Timed Up and Go Test (TUG) did not statistically correlate with the history of falls for women. It is thus of interest to distinguish the elements (if any) that contribute to an increasing fall risk. To this end we designed a comprehensive test battery including balance measurements, whose data was used in combination with the RAI-HC assessment report for background information [20]. The test battery was expected to reveal (sub)tests and parameters that are linked to a significant difference between the groups of fallers and non-fallers, and which can thus also form a basis for an abridged fall risk assessment protocol. In the present study the main emphasis is on tracking the differences between the fallers and non-fallers groups which may give further clues to why some have a higher or a lower fall risk than others. An information which in the end might be used in fall prevention. Thus the focus here is not on "fall prediction" as such (where a prospective study would have been preferable), for which taking the history of the patient may give sufficient information, but on the correlates of fall risk which may point to the causal factors involved.

Methods and materials

Participants

Participants (see Table 2 and Fig. 1) were community dwelling people selected from a RAI (Resident Assessment Instrument, www.interrai.org) home care (HC) database for the municipality of Kokkola (Ostrobothnia, Finland) and the surrounding covering a one year period. The assessments were performed by a team of care personnels led by a registered nurse and using computers and PDAs with specialized software (www.raisoft.com).

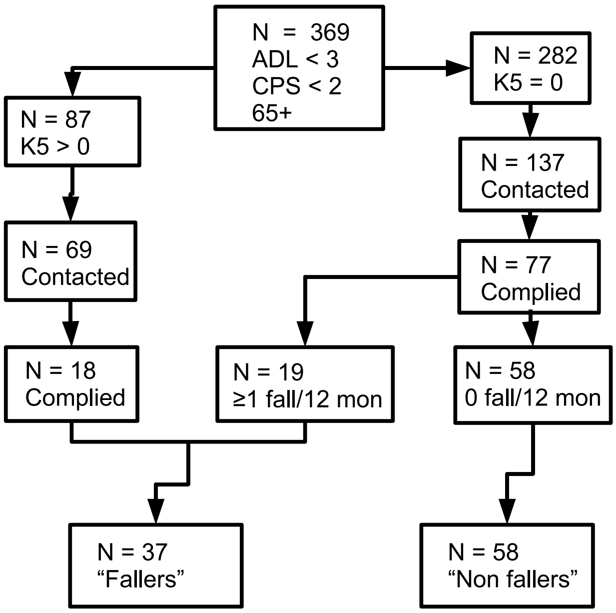

Figure 1: The participants selection process. K5 denotes the RAI-HC variable for the number of falls during the past 3 months at the assessment date.

The people receive home care services mainly because of a decline in IADL (Instrumental Activities in Daily Living [21]). The exclusion criteria were: diagnoses MS, PD; CPS (cognitive performance scale) > 2, where 2 means ”mild impairment” [22]. The CPS-criterion was used for practical reasons as the participants were expected to understand the test instructions. In the first screening we included all those who had CPS < 2 in some of the RAI-assessments. Seven persons of the participants had a change in the health status to CPS $= 2$ according to the most recent assessment but were able to take part in the test. The other basic inclusion criteria were: age 65 years or older, and the physical ability to participate in the test (the activity of daily living score, ADL ≤ 2, where 2 means "needs only limited assistance" [23]). (In fact only two of the participants had ADL greater than 0.) Thus the participants had to be able to stand unsupported and to walk 10 meters or more (possibly using a cane or with some assistance). This left us with 369 persons of which 206 were contacted by phone or visiting home care personnel. Of these persons 95 complied (participation rate 46 %). The target was to get, within the time limit of the study, about 100 participants in all with fallers and non-fallers fifty-fifty. In order to catch the "fallers" we used the K5 marker in the RAI-HC assessment which tells how many times the person has fallen during the past 3 months. Those with K5 > 0 were put on the "fallers" list and those with K5 $= 0$ on the preliminary "non-fallers" list. Since the RAI-HC assessments in Finland are typically conducted every 6 months, someone who has fallen during the past year may slip through the K5 criterion. Therefore at the interview everyone was queried about the fall history and specifically whether the person had fallen during the past 12 months. In this way we got additional 19 "fallers" from the K5 $= 0$ list satisfying the criterion of one or more falls during the 12 past months. For "fall" we have used the simple WHO definition as "an event, which results in a person coming to rest inadvertently on the ground or other lower level" [24]. In contrast to the "Kellogg" definition [25] we did not exclude falls due to a loss of consciousness (syncope). However, in the group of fallers we excluded falls due to slips on ice, and other external causes (such as being pushed) as they are not necessarily linked to balance impairments. Informed consent was obtained from each participant and the investigation was approved by the local Ethical Committee.

Test battery

Our test battery (Fig. 2) comprised the following parts: Interview, posture assessment, balance platform tests, reaction time, visual gait analysis, BBS test and force measurement (leg extension, hip abduction). The BBS test was included because it is one of the most comprehensive and widely used functional tests, and it has also been found to be significantly linked to laboratory measures of sway [26].

Interview and posture

In the interview (taking history) the participants were queried about pain, falls, fear of falls, physical activity, use of orthoses or supports for walking, dizziness, vision, medical conditions or old traumas, and medications. In connection with the posture assessment we recorded self selected foot position on a sheet of paper, and determined foot length and deformities if present (e.g. toe amputations, hallux valgus, etc).

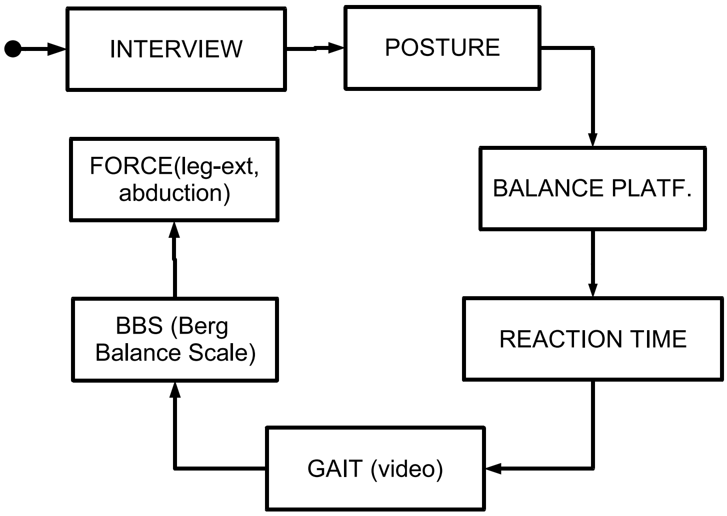

Figure 2: The test battery. Not everyone was able to complete the whole program.

Balance platform tests

The balance test protocol on the Balance platform (HurLabs Co, www.hurlabs.com) consisted of eight performances each of 30 second duration (EO = eyes open, EC = eyes closed, QS = quiet standing):

1. EO QS
2. EC QS
3. EO QS
4. EC QS
5. Foam EO
6. Autohead rotation EO
7. Autohead extension EO
8. Perturbation EO

The foot position was standardized [27] with a clearance (heel-to-heel distance) of 2 cm and a 30° splay (angle between medial sides of the feet). Arms were held at the side. The participants were allowed to rest between performances. For the EO condition there was a mark on the wall (3 m distance, height 1.5 m) for fixing the gaze. In the perturbation test the supervisor gave a nudge dorsally at the waist level. This nudge version was chosen instead of the mechanical perturbation version used in an earlier study [28] because of safety reasons. In autohead rotation the participant rotated head right-left-back (markers on the walls) once and in the extension test extended-flexed the head once (markers in the roof and on the floor). In the compliant surface test the participant stood on foam (2 cm PE-foam). Data sampling rate was set to 200 samples per second. For the analysis we used standard posturographic parameters derived from the COP (center-of-pressure): 90 % confidence ellipse area, **C90A**; trace length, **L5** (for data down sampled to 5 S/s); standard deviation of x (medio-lateral), **stdX**; and standard deviation of y (anterior-posterior), **stdY**; standard deviation of the "velocity" in the x- and y-direction, **stdVX**, **stdVY**. In the analysis of the balance data we excluded performances where the supervisor had to intervene in order to prevent a possible fall.

Reaction time

During the reaction time test the person was standing and wearing headphones and holding a switch, both connected to the computer. The quiet standing position was chosen as one might expect that balancing at the same time may effect the reaction time due to an increased cognitive burden for those with balance impairments. The participant was instructed to press the switch (which closed a circuit) as quickly as possible when hearing a load beep generated by the computer. The time between the onset of the beep and the voltage raise when the circuit closed was taken as the reaction time. After some rehearsals three measurements were performed. The best reaction time was used in the analysis. The sampling rate was set to 1000 S/s (using the LJ U12 data acquisition tool by Labjack Co, www.labjack.com).

Visual gait analysis

The walk line was 7 m of which the middle 4 meter section was used for timing gait speed manually. A standard web camera was mounted slightly off front for recording the walk on the computer for later visual gait analysis. Two performances were required: one free-speed walking and one fast walking. Gait speed and observations of gait pattern "anomalies" were entered into the database.

Berg Balance Scale, BBS

For BBS test [26, 29] (see Table 3) the version 2/2001 was employed (adapted to Finnish [30] by Jaana Paltamaa in consultation with Katherine Berg). The test consists of 14 items, each scored from 0 – 4. Note that for items 11, 13 and 14 the tests are performed in left/right version and the lowest score is recorded. During the test the participants had to take off their shoes (exceptions were made for those who needed shoes for orthotic support). In the analysis we found the reduced BBS score

$$\mathrm{BBS}_{11}^{14} = \mathrm{BBS}_{11} + \mathrm{BBS}_{12} + \mathrm{BBS}_{13} + \mathrm{BBS}_{14} \tag{1}$$

to be useful.

Force measurements

Isometric MVC leg-extension force was measured using Rehab Line Leg extension/curl device together with a digital Performance Recorder (Hur Co) which measures the maximum force in kg (kgf). For the leg-extension device the force F in kgf can be converted to torque M (about the knee joint) in Nm by $M = 1.11 \times F$. Three performance were recorded for right and left leg. The knee joint angle was 120° in the extension mode (180° corresponds to a straight leg). A similar abduction measurement procedure was repeated with the Adduction/Abduction device (Hur Co) with the difference that right and left are not measured separately but their combined effort. In case of the abduction device the force-torque relation is given by $M = 1.54 \times F$. The abduction angle was 10°. All the recorded force data were entered into the database. In the analysis we used the best effort of three (3 repetitions maximum, 3RM). One additional note is that, for leg-extension, the force measured does not include the contribution from the "gravitational torque" $T_{grav} = mgr\cos\phi$ (m = mass of lower leg+foot, $g \approx 9.81$ m s^{-2}, r = distance of the center the mass of lower leg + foot from the knee joint, ϕ = flexion angle). This contribution can be estimated from the body mass M and the height h using the standard estimations $m = 0.061 \times M$, and $r = 0.285 \times 0.606 \times h$ [31, pp. 60, 63].

Data analysis

All the collected data was transferred to a computer client-server database (based on Mysql, www.mysql.org). The basic approach adopted in the analysis of the data is to calculate averages for a selection of parameters for each group and then to check if there is a significant difference between the groups. First we computed the averages m_F, m_{NF} and the standard deviations s_F, s_{NF} (and the corresponding standard errors of the mean (S.E.M.) given by $\sqrt{s_i^2/n_i}$) for the two groups for any given measured parameter. The pooled standard deviation s was calculated as

$$s = \sqrt{\frac{(n_F - 1)s_F^2 + (n_{NF} - 1)s_{NF}^2}{n_F + n_{NF} - 2}}.$$

The p-value according to the t-statistics [32, p.490] was then calculated from

$$p = 2\left\{1 - F_t\left(\frac{|m_F - m_{NF}|}{s} \cdot \sqrt{\frac{n_N \cdot n_{NF}}{n_N + n_{NF}}}\right)\right\},$$

where F_t is the Student probability distribution for $n_F + n_{NF} - 2$ degrees of freedom. (These calculations along with regression analysis were programmed with the MATHCAD mathematics software, www.mathsoft.com, and partly by using the OPENOFFICE CALC program, www.openoffice.org.) We note that the data sizes n_N, n_{NF} could vary from test to test because not everyone completed all the tests (due to pain or fatigue). In case some subsamples of data contained less than 10 members we employed the Wilcoxon-Mann-Whitney Two Sample Test [32, p. 496] for evaluating the significance level (for an online calculator maintained by Rob van Son see [33]). Wilcoxon's method was also used for the total BBS score since it seems to be far from normally distributed. We have also made repeated use of analyzing data in terms of the cumulative relative frequency (c.r.f.). Given a parameter X then the c.r.f. $F_n(x)$ based on a data of n samples is defined by

$$F_n(x) \equiv \frac{\{\text{number of samples with} \quad X < x\}}{n}.$$

In practice we have calculated c.r.f. by first calculating the histogram and then used it to calculate the c.r.f. Here the number of bins – covering the range – used for the histogram will naturally determine the resolution of the c.r.f. computed from it. Whether two c.r.f.'s represent statistically different distributions can probed with the Kolmogorov-Smirnov test [34, p. 335] for which we used the online calculator maintained by T K Kirkman [35]. Throughout we have used the $p = 0.05$ as the significance level. For correlations and slopes we have computed the 95 % confidence intervals (CI) when applicable.

Results and discussion

Balance platform results

In Table 4 we have summarized the balance platform results. It shows the mean values of the parameters for both groups and all the tests. The significance values p for the differences between fallers (F) and non-fallers (NF) are included too. The quiet standing tests with no provocation or extra tasks show no significant difference between the groups. On the other hand, for the foam test and the dynamic (perturbation) tests the medio-lateral sway parameter stdX reveals a significant difference. This can also been seen from the cumulative frequency of the medio-lateral sway (Fig. 3) which for the faller group is shifted toward larger sways. A similar trend is also true for the area parameter C90A in the foam test, and for the medio-lateral sway velocity parameter stdVX in the nudge test. The importance of the medio-lateral sway as a distinguishing marker confirms earlier observations [7,8,10]. An inspection of Fig. 3 reveals for instance, that about 100 % - 59 % = 41 % of the fallers have a sway equal or larger than 10 mm while the corresponding figure for non-fallers is about 100 % - 87 % = 13 %. From this we may ("Bayesian" inference) infer that for a person x, coming from a similar population and who obtains a medio-lateral sway stdX equal or larger than 10 mm, the odds for being a "faller" (falling once or more during one year) is

$$\frac{\mathrm{Prob}(x \in F|\mathrm{stdX} \geq 10)}{\mathrm{Prob}(x \in NF|\mathrm{stdX} \geq 10)} = \frac{\mathrm{Prob}(\mathrm{stdX} \geq 10|F)}{\mathrm{Prob}(\mathrm{stdX} \geq 10|NF)} \times \frac{\mathrm{Prob}(F)}{\mathrm{Prob}(NF)}$$
$$= \frac{0.41}{0.13} \times \frac{\mathrm{Prob}(F)}{\mathrm{Prob}(NF)} \approx 3.2 \times \frac{\mathrm{Prob}(F)}{\mathrm{Prob}(NF)},$$

where $\mathrm{Prob}(F)$ ($\mathrm{Prob}(NF)$) is the proportion of fallers (non-fallers) in the population. Thus if $\mathrm{Prob}(F) \approx \mathrm{Prob}(NF)$ then the odds for x to be a faller in this case would be 3.2 to 1, or a probability of $3.2/(1 + 3.2) \times 100\ \% \approx 76\ \%$. This interpretation of the probablitiy requires the assumption that the fallers have not undergone significant long term physiological or behavioral changes due to the fall(s).

Force data

The force measurement data is summarized in Table 5. In has been necessary to separate female and male data because it is well known that gender influences strength. There is a significant difference between the female F and NF groups both for leg-extension strength. If the force is normalized with respect to the body weight (BW) the difference is no longer significant. In terms of body weight normalized torque the average (F+NF) knee extension torque becomes 1.01 (± 0.05) Nm kg^{-1} for women, and 1.09 (± 0.09) Nm kg^{-1} for men; for normalized abduction torque we get 0.95 (± 0.04) Nm kg^{-1} for women and 1.05 (± 0.09) Nm kg^{-1} for men. Note that the above force values are not "gravity corrected" for the weight of the leg. Taking this into account then e.g. we have to add about 5.4 Nm (4.9 kgf) to the women's leg-extension results which amounts to a correction by around 10 %. (Thus, due to the weight differene between the female F- and NF-groups, the gravity correction augments the leg-extension difference a bit: To the measured difference (weaker leg) of 12.1 Nm we would have to add a correction of about 0.7 Nm due to

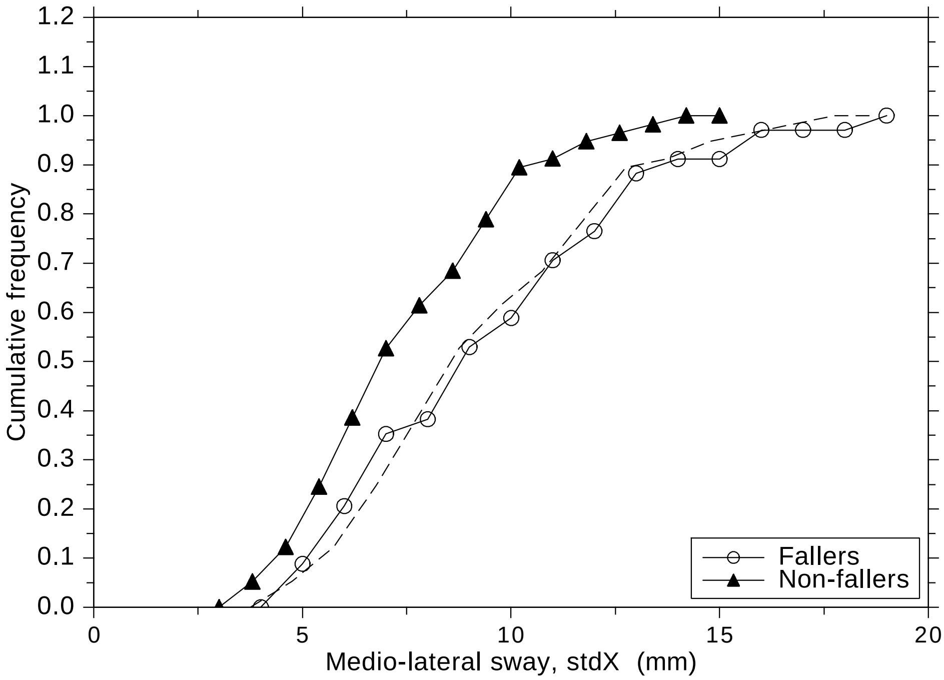

Figure 3: Cumulative frequency for medio-lateral sway stdX for the foam test. Curve with filled symbols based on non-faller data ($n = 57$), curve with non-filled symbols based on faller data ($n = 34$). The dashed line is the scaled version $F_{nf}(k \cdot x)$ ($k = 1.25$) of the non-fallers distribution curve, and demonstrates that the fallers have on the average a lateral sway about 25 % bigger than for non-fallers: $F_f(x) \approx F_{nf}(k \cdot x)$.

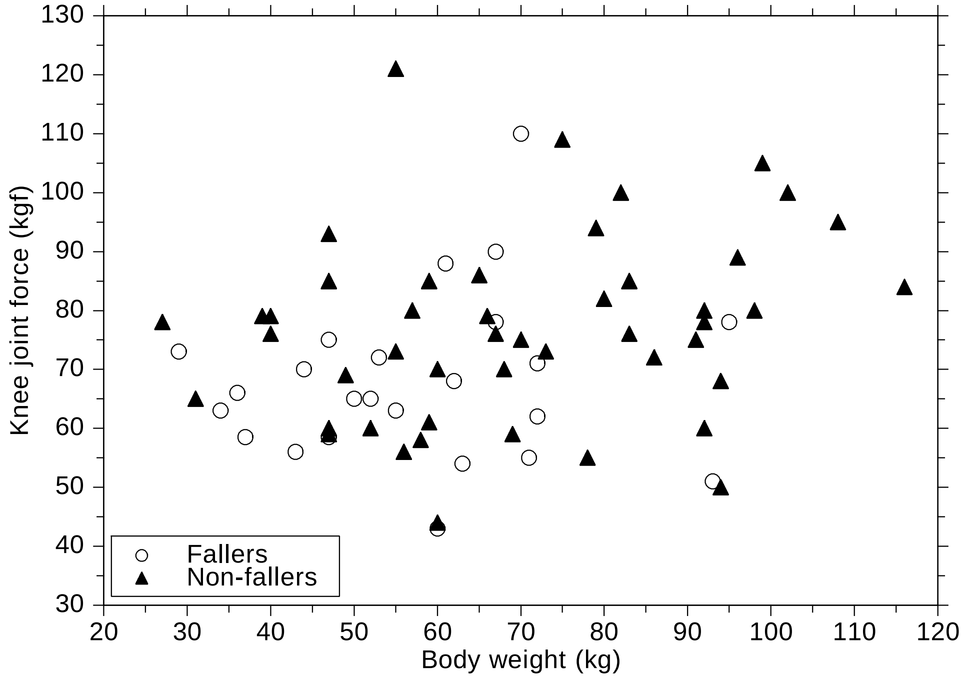

Figure 4: Leg (stronger leg) extension force (kgf) vs body weight (kg). Filled symbols for non-fallers (n = 47), and non-filled symbols for fallers (n = 24). Correlations: 0.13 fallers; 0.23 non-fallers.

gravity correction, which amounts to a circa 5 % correction to the measured difference.)

Figure 4 displays the leg extension strength (stronger leg) versus body weight. It reveals that the fallers tend to cluster toward smaller leg strength and smaller body weight. It is also evident that there is no direct relation between leg strength and body weight though there is a positive correlation (0.13/fallers, 0.23/non-fallers).

BBS results

The Table 6 summarizes the results of the Berg Balance Scale test and shows both the total BBS score and the reduced BBS_{11}^{14} score (1). Most ambulatory people do quite well on the first part of the BBS test and the total BBS score tend therefore to saturate. However the final four items of the BBS test seem to be especially relevant for assessing balance and the corresponding reduced BBS_{11}^{14} score does indeed reveal a significant difference between the fallers and non-fallers groups. This can be compared to the result of the study [9] by Lajoie and Gallagher where the last BBS item, BBS_{14}, was singled out as the third "most significant predictor" of falls in their test battery. The relevance of the 4 last BBS items is demonstrated by summing only 10 first items yielding a truncated BBS score we may denote BBS_1^{10}. Then we obtain for the groups (women only) the average BBS_1^{10}-values 36.73 ± 0.80 (fallers), and 37.68 ± 0.48 (non-fallers) and the difference is no longer significant ($p = 0.334/0.263^{\star}$ – the starred p-value due to the Wilcoxon test).

Note that the male subgroup has lower mean BBS-values than the female subgroup. The males are fewer in number than the females which may be an indication that they are more impaired in general than the females in this age group. Figure 5 shows the difference in cumulative relative frequencies for the reduced BBS score (1) for fallers and non-fallers, women. It demonstrates how the non-fallers tend to have a higher BBS_{11}^{14} score.

The figures 6, 7 display the leg extension strength versus BBS_{11}^{14} for women (male data left out for reasons indicated above). As can been seen the fallers tend to cluster toward weaker leg strength and smaller BBS_{11}^{14}. For fallers there is a weak negative correlation (-0.18) between leg strength and BBS_{11}^{14} while there is a stronger and *positive* correlation (0.41) for non-fallers. Fig. 6 suggests that this result may have to do with an apparent threshold around $\mathrm{BBS}_{11}^{14} = 8$; participants with $\mathrm{BBS}_{11}^{14} \geq 8$ tend to be stronger compared to those with $\mathrm{BBS}_{11}^{14} < 8$.

Finally we also find a significant negative correlation between sway parameters and the BBS-score in line with results reported by Berg et al. [26]. Correlations for the total BBS score BBS_1^{14} vs sway parameters tend to be a bit stronger than for the reduced score BBS_{11}^{14}. Calculating the correlations for all the sway parameters with BBS_1^{14} we find the correlations to be in the ranges (F: -0.67, -0.03) and (NF: -0.80, -0.07), with the weakest correlations found for the nudge condition.

Gait speed, reaction time, posture

It might be a bit surprising that we found no significant difference in reaction time, free-speed and the normal stance width between the groups (see Table 7). We believe that our reaction time test was not challenging enough compared to the one used by Lajoie and Gallagher [9] where the participants had to give a verbal response. This apparently involves a more demanding cognitive task than just pressing-a-button response. This seems to be indicated by the longer average reaction times (around 450

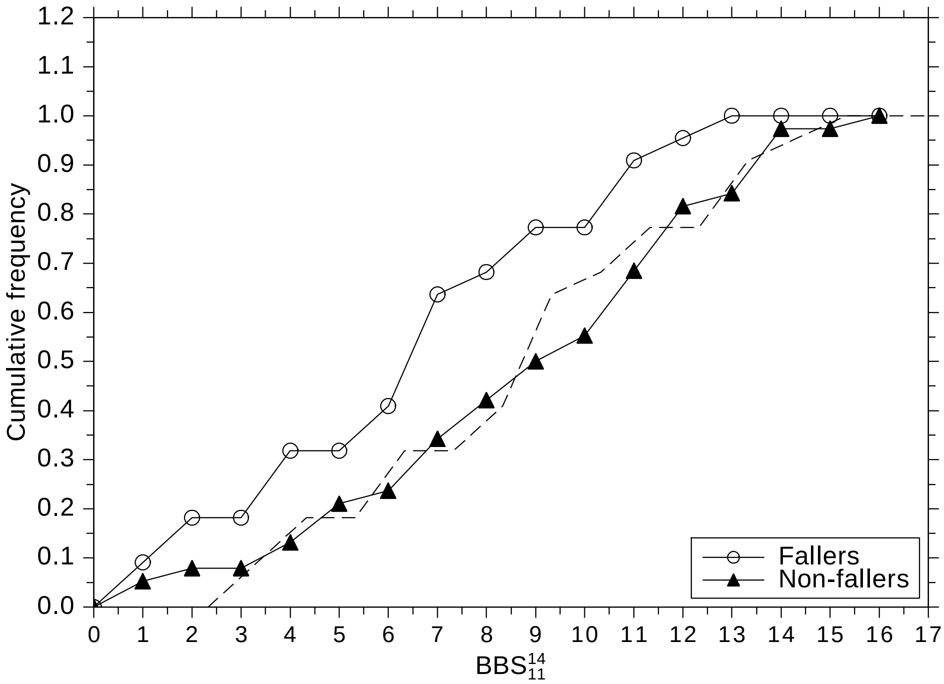

Figure 5: Cumulative frequency for the reduced BBS score BBS_{11}^{14} for fallers (n = 22) and non-fallers (n = 38), women. The dashed line presents the faller cumulative frequency shifted by 2.33 points along the x-axis. This amount corresponds to the average difference in BBS_{11}^{14} between the two groups.

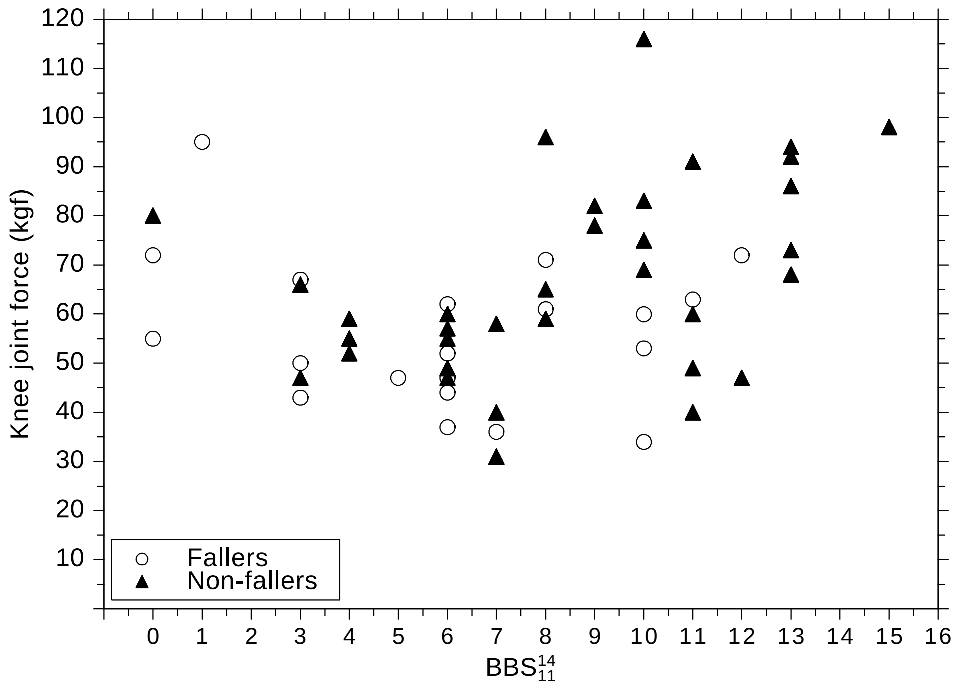

Figure 6: Leg extension force, stronger leg, versus BBS_{11}^{14} for women. Correlations: -0.18 fallers (n = 20); 0.43 non-fallers (n = 34).

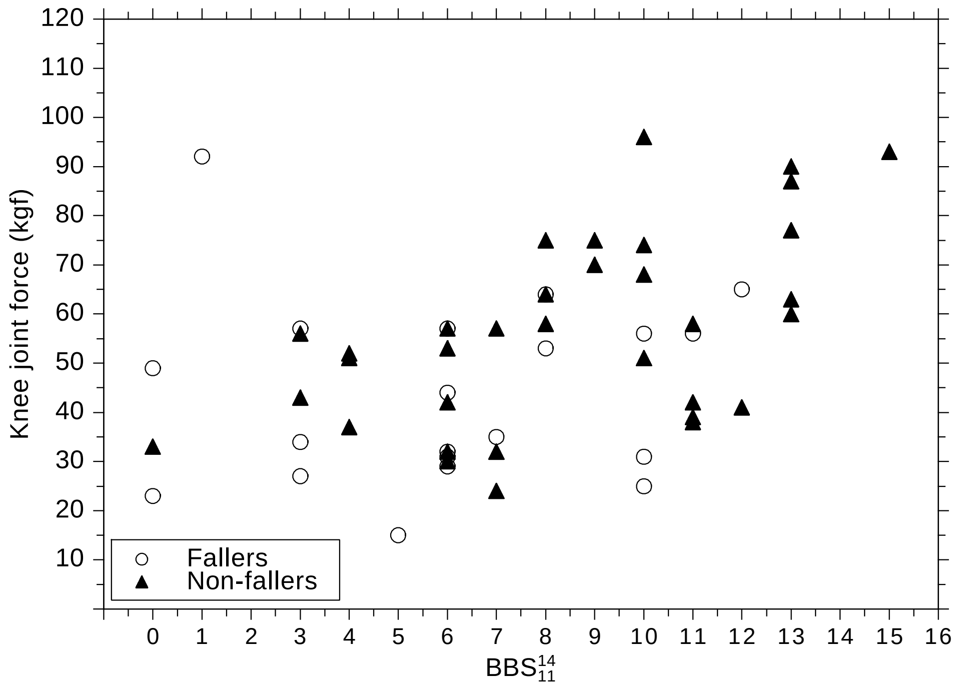

Figure 7: Leg extension force, weaker leg, versus BBS$^{14}_{11}$ for women. Correlation 0.06, fallers ($n = 20$); correlation 0.55, non-fallers ($n = 34$).

ms) obtained in the experiments by Lajoie and Gallagher. Our "null-result" emphasizes the importance of using adequately challenging attention demanding tasks in order to bring forth the differentiating factors if present. We note that in the non-fallers group we had on "outlier" with reaction time 1138 ms. In fact the non-fallers group has a smaller median reaction time of 226 ms compared to 243 ms for the fallers group. However the difference is not statistically significant.

Another perhaps surprising result is that here is no significant difference in stance width (measured as clearance) between fallers and non-fallers (Table 5). The median clearance was 7.5 cm for fallers and 5.5 cm for non-fallers with upper ranges about 21 cm. The results underline the need to standardize the foot position in balance tests. If the participants were allowed to adopt their usual stances during balance tests this would probably make a comparison of the results impossible.

Analyzing average gait speeds we obtain a significant difference in case of fast-speed. For free-speed we obtain a difference that is on the border of being statistically significant (p = 0.056). In fact the cumulative frequencies (Fig. 8) seem markedly different. The Kolmogorov-Smirnov Two Sample Test gives $p = 0.053$. There is an apparent agreement up to a velocity about 0.5 m s^{-1} above which the distributions diverge. We believe this may reflect the fact people in quite poor condition may become categorized as non-faller because they move very little (or use extra supports) and thus reduce the risk of falling. Clearly one who e.g. moves in a wheelchair, or is a very sedentary person and only occasionally make transfers using legs, may have a smaller fall risk compared to a more mobile person. If we compare the subgroups of fallers and non-fallers who have a walking free-speed ≥ 0.5 m s^{-1} then we obtain a significant difference (p = 0.01) for the mean gait speed between the groups: 0.70 $\pm$ 0.03 m s^{-1} (fallers, n = 20), and 0.88 $\pm$ 0.04 m s^{-1} (non-fallers, n = 37). One may interpret these results as there being a threshold value near 0.5 m s^{-1} such that a gait speed below this implies a relative reduction in the fall risk (despite e.g. weaker leg muscles) because of a decreased mobility and activity (less "risky" behaviour). One interesting feature seen in Figure 8 is that the fast-speed distribution for fallers almost coincides with the free-speed distribution for non-fallers if we restrict the range to speeds above 0.6 m s^{-1}.

Finally we have made a comparison between gait speed and leg-extension force of the *weaker* leg (Fig. 9). The force of the weaker leg was used because it is likely that the weaker leg limits the gait speed. Indeed, using the force of the stronger leg we obtained somewhat smaller correlations between force and gait speed compared to using force of the weaker leg – see Table 8. The correlations using force of the stronger leg were 0.01 (fallers), 0.70 (non-fallers) for free-speed, and 0.10 (fallers), 0.69 (non-fallers) for fast-speed to be compared with correlation for the weak leg: 0.33 (free speed) and 0.44 (fast speed) for fallers, and 0.74 (free speed) and 0.71 (fast speed) for non-fallers. The lower correlations for fallers is in part explained by the smaller gait speed range in the group. The median velocities were 0.80 m s^{-1} (non-fallers) and 0.63 m s^{-1} (fallers) to be compared with the reported lower 95 % range of 0.80 m s^{-1} for females aged 65 – 80 yr (value quoted by Whittle [36, p. 223]). Bohannon [37] reports a mean value (± S.D.) of 1.27 ± 0.13 m s^{-1} for apparently healthy women in the seventh decade (70 – 79 yr) which would correspond to a 95 % lower range of ca 1.0 m s^{-1}. These relative high lower-end ranges compared to the median values obtained for our groups probably reflect that our participants come from a more impaired population (frailer) which is e.g. suggested by the high number of drugs they use. Our non-fallers values are somewhat closer to those recently published by Hardy et al. [38] who obtained an average (± S.D.) free-speed of 0.88 ± 0.24 m s^{-1} for community-dwelling persons aged 65 and older recruited from two U.S. metropolitan primary care clinics ($n = 439$). (One notes though that only people with gait speed ≤ 1.3 m s^{-1} and ≥ 0.2 m s^{-1} were included in their study which will affect the average value.)

Discussion

In this study ”fallers” included those who had fallen once or more during the previous 12 months. If the chance of falling during a given period of time were completely due to variation in external factors we would hardly expect to find physiological differences between the groups. However, we have in the present case obtained significant differences in a number of characteristics for these groups. The differences thus found may be assumed to point to a distinct ”physiological profile” [4] for people with an increased fall-risk. For example, the risk for falls and consequent injuries seem to increase with lower BMI. In a parallel investigation of 28 elderly hip fracture patients admitted to the regional hospital we found an average (premorbid) BMI value of 24.0 ± 0.8 compared to our present fallers group value of 27.1 ± 0.8, and 30.0 ± 0.9 for the non-fallers group.

Perhaps a more intriguing indicator is the greater lateral sway for the group of fallers during foam and perturbation balance tests compared to the non-fallers group. One may hypothesize that ”lateral instability” is particularly endangering because it may be generally harder to correct sidewise stumbling than a forward stumbling. In the neuromotor control loop of balance problems may arise either due to loss of sensory input, loss of motor output, loss of muscular strength, or the lack of coordination of these

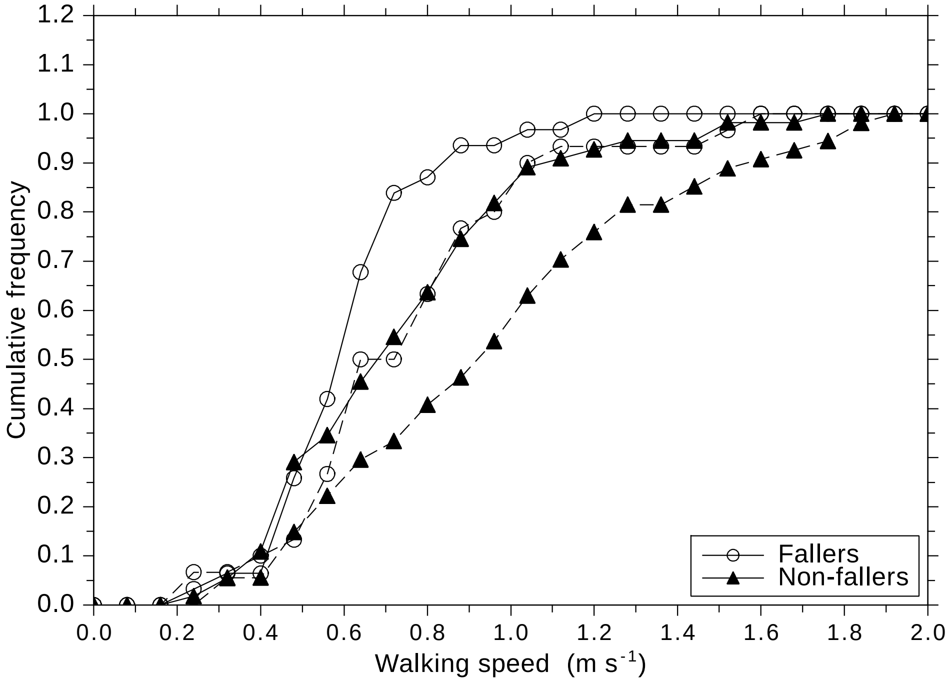

Figure 8: Cumulative frequencies of gait free-speed and fast-speed (dashed line) for fallers (n = 31/free, 24/fast) and non-fallers (n = 55/free, 46/fast).

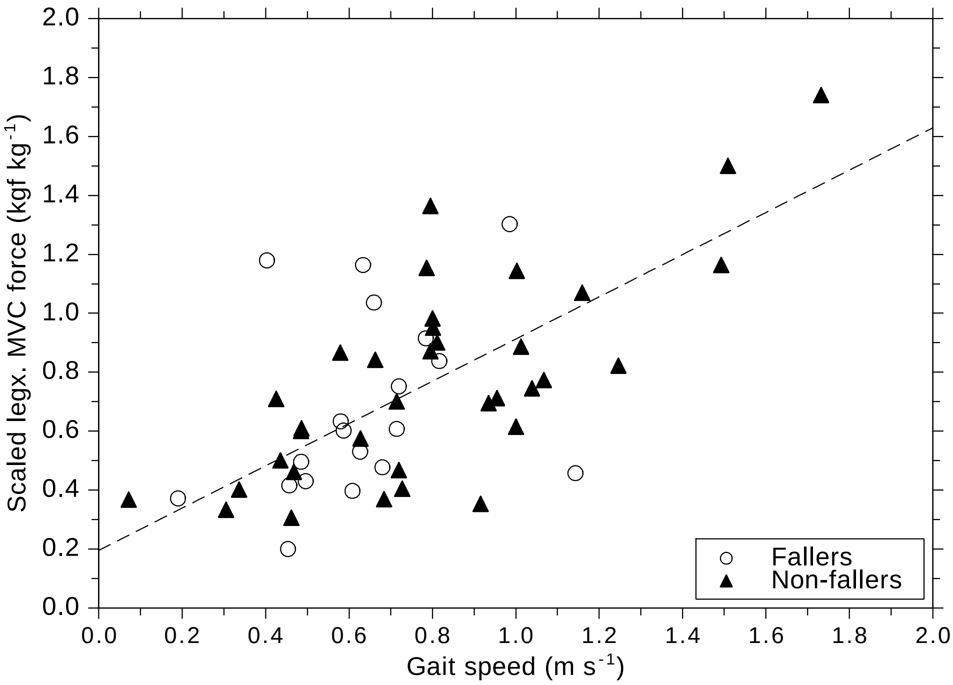

Figure 9: Normalized leg-extension force of the weaker leg versus gait free-speed for fallers ($n = 19$) and non-fallers ($n = 35$), women. The dashed line represents the best linear fit to the non-fallers data (correlation $= 0.74$, slope $= 0.72$).

subsystems (impaired motor programs).

It was found that the four last BBS items and their sum BBS_{11}^{14} explained the main part of the difference in the BBS score between the fallers and non-fallers. The lower BBS score for the fallers group can therefore be seen as an indication of balance problems associated with shifting the weight between the legs. This is supported by the negative correlation between the lateral sway velocity (foam), stdVX, and the BBS score. There was no correlation between BBS_{11}^{14} and leg-extension force for fallers but a moderate positive correlation for non-fallers. This can be interpreted as combination of threshold effect (not enough strength) and an inability to fully utilize the available strength for effective postural controll.

The fast-speed gait was generally lower for fallers. There might be again a threshold effect involved; that is, a minimum strength level is needed for walking, and it takes a further step to "shift gears" and walk faster. There is only a weak correlation between free-speed and leg-extension force for fallers but a much stronger correlation in case of non-fallers. This indicates that the fallers cannot effectively use their strength for propulsion.

When muscular strength is intact the risk of falling may be related to e.g. neuropathy, hypotension, syncope, vestibular dysfunction, or dizziness (where medication can be involved). In fact, based on the interview part where we asked about the circumstance of the most recent fall (which also included those "non-fallers" who had fallen more than 12 months ago) we estimated that about 24 % of the falls were associated with these syndroms. Furthermore, though momentary muscular strength may be adequate, the risk for falling may arise because of fatiguability (e.g. due to respiration problems such as COPD). Secondary effects due diabetes have also to be recognized as possible fall risk enhancers (fatigue, syncope, foot deformities, sensory losses). Some of these risk factors have been mapped in a broad ($N = 2304$) Canadian survey using the RAI Home Care instrument [39].

If we assume that there is an inherent propensity for falling, which is not determined by external circumstance but by the accumulation of physiological impairments due to aging, then the total risk of falling will be a function of this inherent risk and factors due to activity (risky behaviour ?) and external circumstances (slippery floor ?). If the inherent risk accumulates during aging it might be related to how frailty (quantified by various frailty indexes, FI) in general is thought to accumulate [40–42]. From the point of view of biomechanics, standing and walking involve complex neuro-muscular control systems which have a certain degree of redundancy. For instance, when the proprioceptive input is degraded then this can be partially compensated for by relying more on visual, auditory and haptic inputs. However, with an increasing number of deficits the resiliency of the balancing systems decreases. The ”safety margin” becomes thus smaller, and moderate ”stressors” may already put the person at risk of falling. This aspect was revealed in the balance platform tests where no significant difference was found between the fallers and non-fallers groups in the ordinary static tests, but when adding ”stressors”, such as in the form of a compliant surface, or a nudge, the difference became significant (for lateral sway). The degree of challenge must therefore be adequate in order for tests to be able to differentiate potential fallers.

Conclusion

In this study we have presented a test battery with the purpose to highlight some of the multifarious aspects of fall risk. Lowered BMI, increased lateral sway on compliant surfaces, slow fast-speed gait, low muscle strength, and low BBS-scores are some of the indicators of fall risk that may be included in advanced assessments. These changes seem related to the degree of frailty and a vulnerability to stressors. This emphasizes the need of a comprehensive test battery in order to capture physiological risk factors of falls.

Competing interests

Frank Borg and Gerd Laxåback have occasionally acted as technical and scientific advisors for Hur Co. Before joining the Chydenius Institute Laxåback worked as a geriatric physiotherapist at Medirex Co. Magnus Björkgren is a founding member of RAIsoft Co.

Authors' contributions

FB: study design, writing, analysis of data. GL: study design, measurements and interviews, contacting the participants. MB: study concept and design, contribution to manuscript preparation.

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Figures

Figure 1 - Participants selection

The participants selection process. K5 denotes the RAI-HC variable for the number of falls during the past 3 months at the assessment date.

Figure 2 - Test battery

The test battery.

Figure 3 - Medio-lateral sway

Cumulative frequency for medio-lateral sway stdX for the foam test. Curve with filled symbols based on non-faller data (n = 57), curve with non-filled symbols based on faller data (n = 34). The dashed line is the scaled version $F_{nf}(k \cdot x)$ ($k = 1.25$) of the non-fallers distribution curve, and demonstrates that the fallers have on the average a lateral sway about 25 % bigger than for non-fallers: $F_f(x) \approx F_{nf}(k \cdot x)$.

Figure 4 - Leg extension force vs body weight

Leg extension force (kgf) vs body weight (kg). Filled symbols for non-fallers (n = 47), and non-filled symbols for fallers (n = 24). Correlations: 0.13 fallers; 0.23 non-fallers.

Figure 5 - Reduced BBS score

Cumulative frequency for the reduced BBS score BBS_{11}^{14} for fallers (n = 22) and non-fallers (n = 38), women. The dashed line presents the faller cumulative frequency shifted by 2.33 points along the x-axis. This amount corresponds to the average difference in BBS_{11}^{14} between the two groups.

Figure 6 - Leg extension force (stronger leg) vs BBS

Leg extension force, stronger leg, versus BBS_{11}^{14} for women. Correlations: -0.18 fallers (n = 20); 0.43 non-fallers (n = 34).

Figure 7 - Leg extension force (weaker leg) vs BBS

Leg extension force, weaker leg, versus BBS_{11}^{14} for women. Correlation 0.06, fallers (n = 20); correlation 0.55, non-fallers (n = 34).

Figure 8 - Gait, free-speed

Cumulative frequencies of gait free-speed and fast-speed (dashed line) for fallers (n = 31/free, 24/fast) and non-fallers (n = 55/free, 46/fast).

Figure 9 - Normalized knee-joint force vs gait speed

Normalized leg-extension force of the weaker leg versus gait free-speed for fallers ($n = 19$) and non-fallers ($n = 35$), women. The dashed line represents the best linear fit to the non-fallers data (correlation = 0.74, slope = 0.72).

Tables

Table 1 - Common balance tests

List of common balance tests. For detailed references see [43, 44].

Balance test	Main author, year
Berg Balance Scale, BBS	Berg 1990
Functional Reach Test, FRT	Duncan 1990
Lateral Reach Test, LRT	Brauer 1999
Timed Get Up & Go Test, TGUG	Podsiadlo 1991
Modified Figure Eight, MFE	Johansson 1991
Tinetti Test, TT	Tinetti 1986
Falls Related Efficiency Scale, FES	Tinetti 1990
Activities-specific Balance Confidence, ABC	Powell 1995
One Legged Stance, OLS	Vellas 1997
Sensory Organization Test, SOT	Shumway-Cook 1986
Postural Stress Test, PSTW	Wolfson 1986
Minimum Motor Test, TMM	Mourey 2005
Step-Up Test, SUT	Hill 1996
Short Physical Performance Battery, SPPB	Guralnik 1994

Table 2 - Participant characteristics

Some characteristic data about the participants. The third and fourth columns show averages, and standard error of the mean, and range (in parenthesis). The last column shows the significance values (p) of the differences. Values $p \leq 0.05$ are boxed. Note that the apparent "significant" difference in height for fallers and non-fallers is just an effect of combining female and male data. BMI = body mass index.

		Fallers	Non-fallers	p
Number	Female	31	43	—
	Male	6	15	—
	All	37	68	—
Age	Female	83.4 (1.0, 74–97)	79.8 (1.0, 64–91)	$\boxed{0.008}$
	Male	77.3 (2.9, 68–87)	80.3 (1.6, 67–88)	0.174
	All	82.4 (1.0, 68–97)	79.9 (0.8, 64–91)	$\boxed{0.027}$
Weight (kg)	Female	65.8 (2.3, 43–90)	74.5 (2.4, 44–121)	$\boxed{0.014}$
	Male	78.8 (7.1, 51–110)	83.1 (3.0, 67–105)	0.514
	All	67.9 (2.4, 43–110)	76.9 (2.0, 44–121)	$\boxed{0.005}$
Height (cm)	Female	155.8 (1.1, 145–169)	157.2 (0.8, 142-167)	0.147
	Male	170.0 (2.2, 160–177)	170.8 (1.3, 163-182)	0.375
	All	158.1 (1.3, 145–177)	161.0 (1.0, 142–182)	$\boxed{0.039}$
BMI (kg m^{-2})	Female	27.1 (0.9, 17.7–37.6)	30.0 (0.9, 20.8–46.1)	$\boxed{0.030}$
	Male	27.0 (1.9, 19.9–35.1)	28.5 (1.1, 23.7–36.8)	0.486
	All	27.1 (0.8, 17.7–37.6)	29.6 (0.7, 20.8–46.1)	$\boxed{0.023}$
Nr of drugs	Female	9.9 (0.8, 3–20)	9.4 (0.6, 2–18)	0.611
	Male	10.7 (1.4, 3–15)	8.9 (1.2, 1–21)	0.403
	All	10.1 (0.7, 3–20)	9.2 (0.5, 1–21)	0.938
Pain level	Female	2.3 (0.2, 0–4)	2.3 (0.2, 0–4)	1.000
	Male	1.0 (0.5, 0–3)	1.9 (0.4, 0–4)	0.221
	All	2.1 (0.2, 0–4)	2.2 (0.2, 0–4)	0.737

Table 3 - BBS test

Items of the Berg Balance Scale test. Each item is scored in the range 0–4. For items 11–14 the *lower* score of the right/left subtest is recorded.

Item	Comment
01. Sitting to standing	
02. Standing unsupported	
03. Sitting unsupported	
04. Standing to sitting	
05. Transfers	
06. Standing with eyes closed	
07. Standing with feet together	
08. Reaching forward while standing	
09. Retrieving objects from floor	
10. Turning trunk (feet fixed)	
11. Turning 360 degrees	Full score if is able to turn 360 degrees safely in 4 seconds or less in both directions.
12. Stool stepping	Uses a 20 cm step. Full score if able to stand independently and safely and complete 8 steps in 20 seconds.
13. Tandem standing	Tested alternately with left/right foot in front. Lowest score is recorded. Full score if able to place foot tandem independently and hold 30 seconds.
14. Standing on one leg	Tested standing on left and right leg alternately. Lowest score is recorded. Full score if able to lift leg independently and hold for 10 seconds or longer.

Table 4 - Posturographic parameters

The group mean values for the posturographic parameters. The standard error of the mean (S.E.M.) given in parenthesis. Significance levels (p) for differences between fallers (F) and non-fallers (NF) group according to t-statistics. Values $p \leq 0.05$ have been marked by boxes. Rows represent different balance tests, columns represent the set of posturographic parameters. EC/EO = eyes close/open, QS = quiet standing.

		C90A (mm^2)	L5 (mm)	stdX (mm)	stdY (mm)	stdVX (mm s^{-1})	stdVY (mm s^{-1})
EO QS	F	545.7 (75.1)	530.6 (34.5)	5.6 (0.4)	6.2 (0.4)	11.4 (0.8)	17.7 (1.3)
	NF	612.1 (79.4)	608.0 (48.8)	5.6 (0.4)	6.7 (0.4)	13.0 (1.2)	20.6 (1.7)
	p	0.574	0.260	0.923	0.448	0.316	0.233
EC QS	F	823.3 (111.2)	816.7 (74.9)	6.6 (0.5)	7.8 (0.6)	17.2 (1.8)	28.0 (2.6)
	NF	925.8 (142.6)	796.5 (71.7)	6.3 (0.5)	8.2 (0.5)	16.7 (1.9)	27.4 (2.4)
	p	0.613	0.853	0.679	0.630	0.836	0.877
EO QS	F	535.3 (80.0)	531.1 (37.4)	5.4 (0.5)	6.2 (0.4)	11.1 (1.0)	18.1 (1.4)
	NF	518.0 (74.5)	576.7 (57.2)	5.0 (0.4)	6.2 (0.4)	12.6 (1.8)	19.9 (2.0)
	p	0.880	0.565	0.543	0.888	0.548	0.520
EC QS	F	891.2 (132.1)	833.0 (78.2)	7.0 (0.7)	8.0 (0.5)	17.0 (2.1)	28.8 (2.7)
	NF	767.9 (112.8)	737.3 (73.2)	5.8 (0.4)	7.9 (0.5)	15.0 (1.7)	25.8 (2.6)
	p	0.488	0.393	0.112	0.842	0.466	0.440
Foam	F	1322.0 (143.6)	766.0 (48.7)	9.2 (0.6)	9.3 (0.5)	18.5 (1.3)	24.3 (1.7)
	NF	930.7 (75.8)	718.1 (50.0)	7.3 (0.3)	8.4 (0.3)	15.8 (1.1)	23.7 (1.8)
	p	$\boxed{0.010}$	0.523	$\boxed{0.004}$	0.132	0.119	0.804
Head rot.	F	700.4 (80.0)	674.8 (39.8)	6.6 (0.5)	7.0 (0.4)	14.6 (1.0)	23.0 (1.5)
	NF	561.7 (48.8)	656.1 (46.2)	5.5 (0.3)	6.8 (0.3)	13.7 (0.9)	23.2 (1.7)
	p	0.120	0.781	$\boxed{0.027}$	0.706	0.542	0.949
Head ext.	F	722.1 (112.4)	618.4 (39.3)	6.2 (0.6)	7.5 (0.4)	12.5 (0.9)	22.0 (1.6)
	NF	530.2 (51.2)	599.9 (51.5)	4.8 (0.3)	7.2 (0.3)	10.6 (0.8)	22.4 (2.1)
	p	0.084	0.799	$\boxed{0.016}$	0.639	0.127	0.915
Nudge	F	966.8 (116.5)	758.5 (51.0)	6.5 (0.5)	9.7 (0.4)	18.4 (2.9)	36.4 (2.2)
	NF	807.7 (54.5)	698.5 (43.6)	5.4 (0.3)	10.2 (0.3)	12.7 (0.8)	35.3 (1.6)
	p	0.165	0.389	$\boxed{0.045}$	0.314	$\boxed{0.025}$	0.693

Table 5 - Isometric leg-extension and abduction forces

Isometric leg-extension and abduction MVC force results. Starred p-values based on Wilcoxon's Two Sample Test which is used for small samples (sample sizes indicated in the second column in parentheses).

		Fallers	Non-fallers	p
Force legx. (kgf), stronger leg	Female (22/37)	56.1 (3.3)	65.4 (3.3)	0.071
	Male (4/12)	64.8 (11.5)	86.4 (5.8)	$0.125^{\star}$
Force legx. per BW (kgf kg^{-1}), stronger leg	Female (22/37)	0.87 (0.06)	0.92 (0.05)	0.562
	Male (4/12)	0.93 (0.27)	1.01 (0.06)	$0.317^{\star}$
Force legx. (kgf), weaker leg	Female (22/37)	43.8 (4.1)	54.7 (3.2)	$\boxed{0.043}$
	Male (4/12)	58.8 (12.7)	68.7 (6.9)	$0.521^{\star}$
Force legx. per BW (kgf kg^{-1}), weaker leg	Female (22/37)	0.70 (0.07)	0.77 (0.05)	0.306
	Male (4/12)	0.86 (0.29)	0.82 (0.09)	$0.521^{\star}$
Force abd. (kgf)	Female (16/33)	36.8 (2.2)	44.2 (2.5)	0.062
	Male (4/11)	46.3 (4.8)	58.6 (4.7)	$0.097^{\star}$
Force abd. per BW (kgf kg^{-1})	Female (16/33)	0.58 (0.04)	0.62 (0.04)	0.492
	Male (4/11)	0.63 (0.10)	0.71 (0.06)	$0.556^{\star}$

Table 6 - BBS scores

The table shows total BBS scores and the reduced BBS_{11}^{14} score, and correlations and slopes (with confidence intervals) for BBS_{11}^{14} vs lateral sway stdX and total BBS-score vs lateral sway velocity stdVX. Balance platform data for the foam test. Starred *p*-values according to Wilcoxon's method.

		Fallers	Non-fallers	p / α
BBS Total	Female (22/38)	42.50 (1.35)	45.68 (1.03)	0.067/ $\boxed{0.038^\star}$
	Male (5/11)	37.40 (0.74)	37.91 (3.32)	$0.562^\star$
	All (27/49)	41.56 (1.24)	43.93 (1.19)	0.201/ $\boxed{0.037^\star}$
BBS_{11}^{14}	Female (22/38)	5.77 (0.74)	8.11 (0.62)	$\boxed{0.023/0.025^\star}$
	Male (5/11)	2.60 (0.83)	5.45 (1.39)	$0.392^\star$
	All (27/49)	5.19 (0.67)	7.51 (0.60)	$\boxed{0.016}$
BBS_{11}^{14} vs lateral sway stdX, all (26/49)	Correlation	$\boxed{-0.44\ (-0.67, -0.13)}$	$\boxed{-0.48\ (-0.65, -0.28)}$	95 %
	Slope	-0.40 (-0.64, -0.06)	-0.29 (-0.44, -0.13)	95 %
Total BBS vs lateral sway velocity stdVX, all (26/49)	Correlation	$\boxed{-0.56\ (-0.75, -0.29)}$	$\boxed{-0.69\ (-0.80, -0.54)}$	95 %
	Slope	-0.63 (-1.01, -0.24)	-0.74 (-0.97, -0.51)	95 %

Table 7 - Reaction time, speed, clearance

Average reaction time, gait speed and medial foot clearance (S.E.M. and range in parentheses) for fallers and non-fallers (women + men). The large range in reaction time for the non-fallers is due to an outlier. The clearance is measured when the participant is standing comfortably.

	Fallers	Non-fallers	p
Reaction time (29/46), ms	255 (16, 146-484)	273 (24, 144-1138)	0.590
Gait free-speed (31/55), m s^{-1}	0.60 (0.04, 0.19-1.14)	0.72 (0.04, 0.24-1.73)	0.056
Gait fast-speed (24/46), m s^{-1}	0.73 (0.06, 0.18-1.58)	0.94 (0.06, 0.25-1.89)	$\boxed{0.021}$
Clearance (37/57), heel-to-heel, cm	7.73 (0.66, 0.5-21.3)	6.97 (0.22, 0.0-21.0)	$0.401/0.279^\star$

Table 8 - Gait speeds

Average velocities (S.E.M. and range in parenthesis) for gait speed, together with correlations and slopes (with 95 % confidence intervals in parenthesis) with respect to normalized leg-extension force of the weaker leg, and for age vs speed. The calculations are for fast-speed and free-speed walking modes and for the subgroup of women who did complete *both* the force and gait tests.

	Mode	Fallers	Non-fallers	p / α
Average speed (m s^{-1})	Free (19/35)	0.63 (0.05, 0.19-1.14)	0.80 (0.06, 0.07-1.73)	0.061
	Fast (18/34)	0.78 (0.07, 0.18-1.58)	1.07 (0.07, 0.32-1.89)	$\boxed{0.012}$
Correl.: speed vs normalized force	Free (19/35)	0.33 (-0.07, 0.64)	$\boxed{0.74\ (0.58, 0.85)}$	95 %
	Fast (18/34)	$\boxed{0.44\ (0.05, 0.72)}$	$\boxed{0.71\ (0.53, 0.83)}$	95 %
Slope: speed vs normalized force	Free (19/35)	0.49 (-0.22, 1.21)	0.72 (0.51, 0.92)	95 %
	Fast (18/34)	0.44 (-0.04, 0.85)	0.58 (0.34, 0.82)	95 %
Correl.: age vs speed	Free (19/35)	-0.29 (-0.61, 0.11)	-0.13 (-0.40, 0.16)	95 %
	Fast (18/34)	$\boxed{-0.41\ (-0.70, -0.02)}$	-0.27 (-0.52, 0.02)	95 %
Slope: age (yr) vs speed (m s^{-1})	Free (19/35)	-0.012 (-0.032, 0.080)	-0.007 (-0.027, 0.013)	95 %
	Fast (18/34)	-0.025 (-0.054, 0.004)	-0.018 (-0.041, 0.005)	95 %