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FUNCTIONAL BALANCE TESTS IN 76-YEAR-OLDS IN RELATION TO PERFORMANCE, ACTIVITIES OF DAILY LIVING AND PLATFORM TESTS

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ABSTRACT. Functional balance was studied in a sample of 98 women and 75 men from a population study. Tests used were one-legged stance and walking in a figure of eight. The results revealed that both static and dynamic functional balance were significantly correlated to isometric knee extensor strength, walking speed and stair-climbing capacity, while the association with activities of daily living (ADL) was modest in this sample of relatively healthy elderly persons. A sub-sample of 17 women and 10 men also performed balance tests on a force plate. Velocity of the sway path with both open and closed eyes was significantly correlated to the functional balance tests. Mean sway in the anterior–posterior direction and area tested with closed eyes were significantly correlated to the functional static balance test. There were no significant associations between the platform variables and the results in the performance tests. The study demonstrated differences between the sexes in that males were able to stand for a longer time on one leg, while they swayed more than females on the platform.

Key words: balance, elderly, posture, measurement, functional, activities of daily living.

INTRODUCTION

The three sensory systems involved in postural control, the vestibular, the visual and the somatosensory systems, are used to monitor the relationship between the position of the body in space and the forces acting upon it. The ability to activate appropriately organized postural muscle response synergies, to use adaptive mechanisms to shift the dominant sensory input controlling posture and to activate postural muscles with sufficient force to correct for threats to balance, all contribute to balance control (34). Both cutaneous vibratory sensation and joint sensation deteriorate in the elderly, and a 40% reduction in sensory cells within the vestibular system has been demonstrated in subjects above 70 years of age (34). Elderly persons also seem to depend more on visual input than other sensory inputs when controlling balance (23, 34). In a review article, Berg (2) states that the ability to maintain one's equilibrium is a complex motor skill, which can be studied from biomechanical and neurophysiological aspects, but that balance can also be viewed as a prerequisite to functional capabilities.

A great variety of methods for measuring balance have been described in the literature, and they can be divided into laboratory or functional methods. Force plates have been used to measure static balance (10, 11, 18, 25), and subjects have been exposed to different kinds of perturbation such as varying sensory inputs, tilting of the platform and the like (11, 23, 24, 33).

The 'get-up and go' test (21) and the timed version of this test (22), the sharpened Romberg test (16, 19) and various walking manoeuvres (17, 19) are examples of functional methods. Stones & Kozma (27) have demonstrated that one-leg stance with open eyes is a reliable and valid measure of postural control. Tinetti (29) has presented a performance-oriented assessment of balance and gait, which includes direct observation of the component manoeuvres as well as careful evaluation of the contributing characteristics, a reliable instrument that reflects the positional changes and gait manoeuvres used during normal daily activities. A similar instrument has been developed by Berg et al. (3), a scale consisting of 14 movements common in everyday life. It can be expected that balance function plays an essential role for the fulfilment of daily life activities.

It is of great importance to develop adequate and simple methods that can detect changes in different types of subjects. Johansson & Jarnlo (17) found that one of their tests, which was used to evaluate the effect of a training programme in healthy 70-year-old women, was too easy (walking on a beam), while another test developed by them ('the eight' described below under Methods) was more suitable for their group.

Berg (2) argues that situations requiring balance can be divided into three general classifications: maintenance of position, postural adjustment to voluntary movements, and reactions to external stresses. The purpose of the present study was to consider the first two of these situations, here called static and dynamic balance, in order to describe the balance function in 76-year-old women and men, and to create a reference material. We also wished to investigate the relation between functional balance tests and platform tests, to relate certain performance variables to both functional and platform variables and to relate daily life activities (ADL) to functional balance tests.

MATERIAL AND METHODS

Population

The subjects included in the present study derive from the third longitudinal population study of 70-year-old people in Göteborg, the IVEG study (InterVention of Elderly people in Göteborg) (13). At the age of 76, the response rate was 77% out of the 844 subjects then eligible for the follow-up.

The balance tests (see Methods) crucial for the present study were added to the investigation after the start of the examinations at age 76. Of the 185 subjects who were consecutively asked to perform the functional balance tests, 12 were unable to participate due to: joint problems, 3; dependence on walking aids, 2; severe dizziness, 2; hemiparesis, 2; dementia, 2; or blindness, 1.

One hundred and seventy-three subjects, 98 women and 75 men, consequently constitute the material of the present study. 60% of the women and 27% of the men lived alone. Among women, 15% lived in private homes and 85% in apartments, while among men 20% lived in private homes, 77% in apartments and 3% in sheltered accommodation. Their mean body height was 1.59 m (SD 0.05) in women and 1.72 m (SD 0.06) in men and the mean body weight 65.3 kg (SD 11.3) in women and 74.6 kg (SD 10.2) in men. A comparison with the subjects who participated in all performance tests (14) showed no significant difference regarding the variables mentioned above. In addition, a subgroup of 17 women and 10 men of those who had taken part in the functional balance tests was randomly selected to perform a platform balance test.

The study has been approved by the Ethical Committee of the Faculty of Medicine at Göteborg University.

Methods

Functional balance tests. For static balance, the ability of subjects to stand on one leg (right as well as left) without shoes for a maximum of 30 s, hands behind their back and looking straight ahead, was tested. The subjects were free to choose which leg to start with. The hip joint of the non-weightbearing leg was in a neutral position and the knee flexed to approximately 90°. The test was interrupted if the subject moved from the standardized position, and three attempts were allowed. A comparison between the first and the second attempt among those who did not achieve 30 s revealed a significant difference in favour of the second attempt for the right leg ($p \leq 0.05$) in both women and men, but not between the second and third attempts. There was no significant difference between the three attempts for the left leg. Consequently, the analysis is based on the best value of each leg, and for the analysis of associations only the result from the better leg has been used.

For the dynamic test, the subjects were asked to walk in a figure of eight, a method developed by Johansson & Jarnlo (17). 'The figure eight' consists of 2 sets of 2 circles, the inner with a diameter of 1.50 m, the outer with a diameter of 1.65 m, and the subject was instructed to walk in the space between these circles without touching them. The ability to walk (without shoes) twice through 'the eight' without stopping was tested, and the number of oversteps or touches was recorded. The subjects were asked to walk at a comfortable speed. In 98 subjects (55 women and 43 men) the test was repeated twice, and there was a significant difference between the mean values of the two trials in favour of the second: 21.7 (SD 11.0)–17.9 (SD 11.3) in women, $p \leq 0.001$, and 23.1 (SD 11.7)–20.7 (SD 13.2) in men, $p \leq 0.01$. The correlation coefficient between the two trials was 0.92 ($p \leq 0.001$) in both women and men. In the analysis described below, the results from the first trial have been used, as the rest of the subjects were tested once only.

Platform balance tests. A force platform (AMTI, Advanced Mechanical Technology Incorporation, model OR 6-5-1, Newton, Massachusetts), which was 50 × 46 cm and 10 cm higher than the floor, was used. The platform measures vertical forces (Z) expressed as movements in the sagittal (anterior–posterior, Y) and frontal (medio-lateral, X) planes and was connected to a personal computer (IBM). An AMTI SGA6-4 (Strain Gauge Amplifier system) was used in conjunction with the force platform. Software from Selcom (formerly Selspot, Box 250, 43325 Partille, Sweden) was used to calculate the mean position of the centre of pressure (COP) in relation to the platform coordinates, and to plot the movement of the COP data in relation to this mean position. The movement of the COP will be called the sway path. The sampling rate was 40 Hz.

The following parameters were selected for the tests: mean sway amplitude (mm) from the mean position in the anterior–posterior and medio–lateral directions, respectively, length (mm) of the sway path, mean velocity (mm/s) along the sway path and area (mm^2), described as an ellipse representing 40% of the measured values. As the time was constant, length and velocity have a linear relationship.

Tests:

1. Standing, hands behind their back and without shoes, on two legs with an angle of 30° between the medial lines of their feet for 30 s, looking at a black dot at a height of 1.60 m approximately 4 m away.
2. As above with closed eyes.
3. Standing on their right leg, hands behind their back and without shoes, for 10 s, looking at a black dot at a height of 1.60 m approximately 4 m away. The hipjoint of the

non-weight-bearing leg was in a neutral position and the knee flexed to approximately 90°.

4. Standing on their left leg as described above.

Performance variables. Voluntary isometric muscle strength was measured in the right and left knee extensors with a tensiometer (Cable Tensiometer Pacific Scientific, Anaheim, Calif., USA), and with the subject sitting in a special chair, with a hip angle of 90° and a knee angle of 90°. A cable was applied around the ankle and fixed to the wall. The moment arm from the knee joint was measured to calculate maximum torque values. The test was repeated three times and the highest value was recorded. In this study, only the results from the stronger leg were used. The tensiometer was calibrated, and there was no change in the calibrating factor during the test period.

The maximum walking speed was measured for 30 m indoors. The test was preceded by a test of the same distance at a spontaneously chosen speed.

Ability to climb onto boxes of varying heights (10, 20, 30, 40, 50 cm) without using a handrail was tested. The results from the better leg were used here.

Ability to rise from a chair, 45 cm high, without the support of their hands was tested and classified as performed without difficulty, on the one hand, or with some degree of difficulty or not at all, on the other.

Visual acuity was tested at a distance of 5 m, whenever applicable with spectacles. Visual impairment was defined as visus ≤ 0.4 for the better eye.

Hearing was classified as able/not able to hear speech in a conversational tone (without use of hearing aid) at a distance of 5 m.

Activities of daily living (ADL). Data concerning activities of daily living were collected by interview at home visits, and the ability in activities such as mounting stairs, picking up items from the floor, taking a bath or a shower, house cleaning, and shopping was assessed. Disability was defined as needing personal assistance, or difficulty in the different activities. The subjects were also asked if they used any kind of walking aid and whether they were bothered by dizziness, vertigo, impaired balance or general unsteadiness.

Statistical methods

All tests of correlation have been made on rank values, as most of the measurements used have skewed distributions. As it is assumed that some of the measurements are correlated to body composition, height and weight were taken into account by using partial correlation coefficients when testing for significant correlation. It should be noted that partial correlations calculated on rank values ought not to be interpreted as the square root of explained variance, but rather seen as a non-parametric index of strength of correlation. We have used this not as a perfect measure but rather as the best measure we could find. Tests for difference in mean value between two groups have been done with the permutation t-test (7).

RESULTS

The results from the performance tests and from the home visits and interviews are presented in Tables Ia + b.

Functional balance tests

The median value for standing on the right leg was 9 s in women and 20 s in men and the mean values 12.6 (SD 10.1) and 18.5 (SD 10.5) s, respectively, the difference being significant ($p \leq 0.001$). For the left leg, the median value was 7 s in women vs. 14 s in men and the mean values 11.0 (SD 9.5) and 16.8 (SD 11.0) s, respectively, the difference being significant ($p \leq 0.001$) (Figs. 1–2). However, when height was taken into consideration as a background factor, there was no significant difference between the sexes for the left leg, while the level of significance for the right leg was $p \leq 0.05$. The difference between the right and the left leg was significant in women ($p \leq 0.05$) but not in men.

Table Ia. *Results from four performance variables ($n = 173$, 98 women and 75 men)*

For the first two, mean values and standard deviations are given, and for the other two the percentage

	Women	Men	p
Mean knee ext strength (Nm)	72.3 ± 15.6	111.5 ± 19.7	***
Mean max walking speed (m/s)	1.44 ± 0.26	1.68 ± 0.33	***
Stair-climbing capacity ≥ 40 cm (%)	48	91	***
Rising ability (%)	88	93	NS

Significance levels for difference between women and men: *** $p \leq 0.001$. NS = non-significant.

Table Ib. *Proportions of individuals with impairments and disabilities ($n = 173$, 98 women and 75 men)*

	Women (%)	Men (%)	p
Vision	13	5	NS
Hearing	2	4	NS
Dizziness	37	13	***
Use of walking aids	21	12	NS
Mounting stairs	30	25	NS
Picking up from floor	14	4	*
Bath/shower	23	4	***
House cleaning	33	13	**
Shopping	23	4	***

Significance levels for difference between women and men: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$. NS = non-significant.

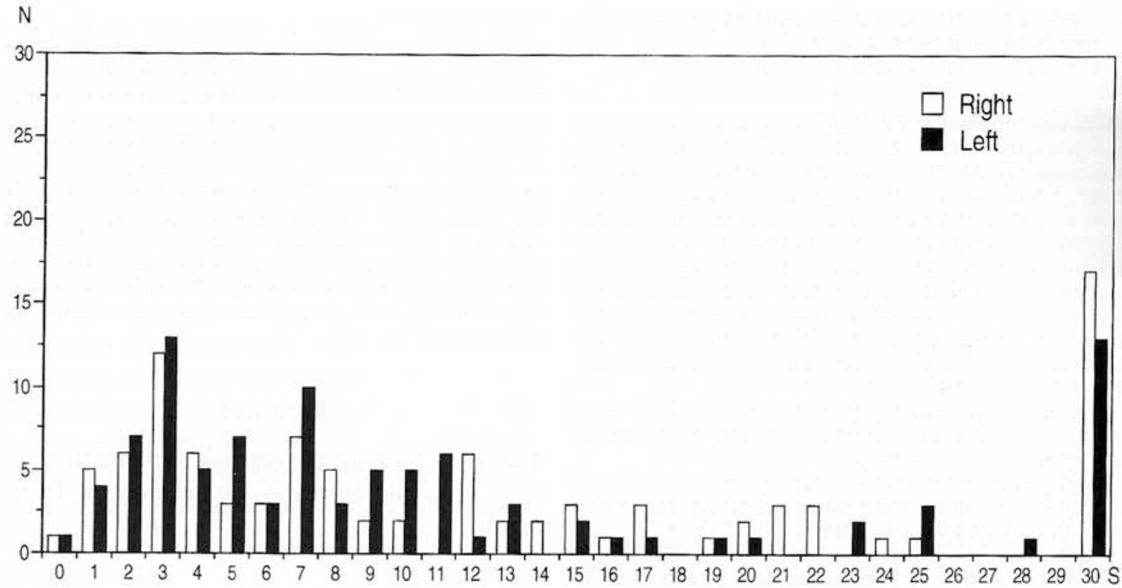

Fig. 1. One-leg stance in women ($n = 98$). Distribution of time spent on the right and left leg, respectively.

Among females, 18% managed to stand for 30 s on their right leg and 13% on their left, among males 35% managed 30 s on their right leg and 37% on their left. It should be noted that most of the subjects who were able to stand for around 15 s also managed 30 s (Figs 1–2).

The median number of oversteps/touches when walking in 'the eight', which was performed by 159 subjects (9 women and 5 men did not participate due to practical or physical problems) was 19 in women and 20 in men, and the mean values 21.5 (SD 13.3) and 23.0 (SD 12.9), respectively (NS) (Figs. 3–4).

The results of the static balance test for the better leg revealed a significantly ($p \leq 0.05$–0.01) better knee extensor strength and a significantly ($p \leq 0.001$) higher walking speed in both women and men with

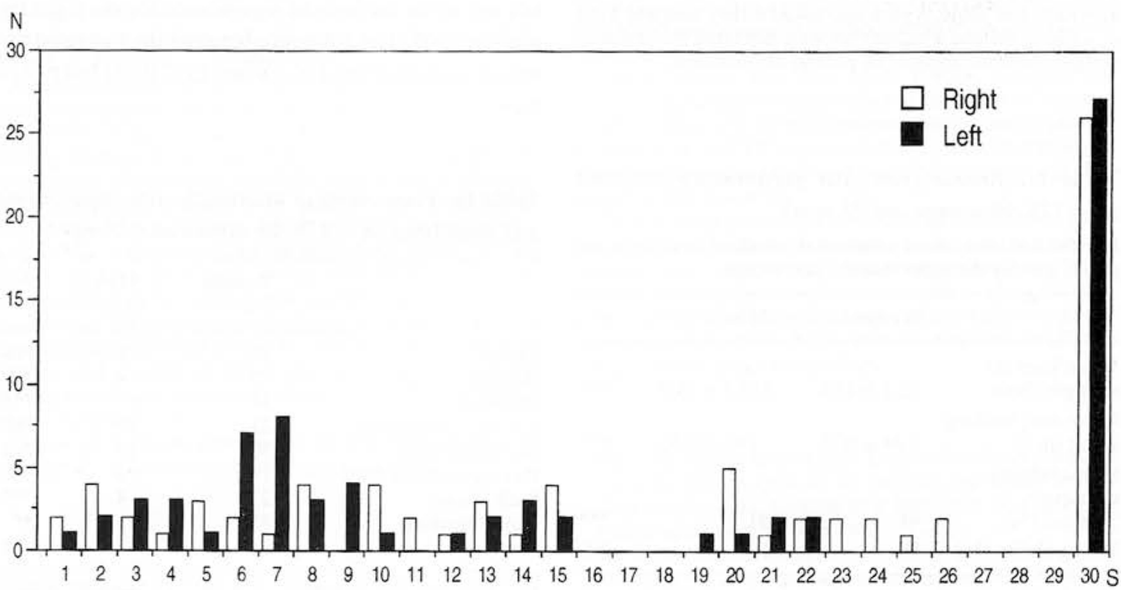

Fig. 2. One-leg stance in men ($n = 75$). Distribution of time spent on the right and left leg, respectively.

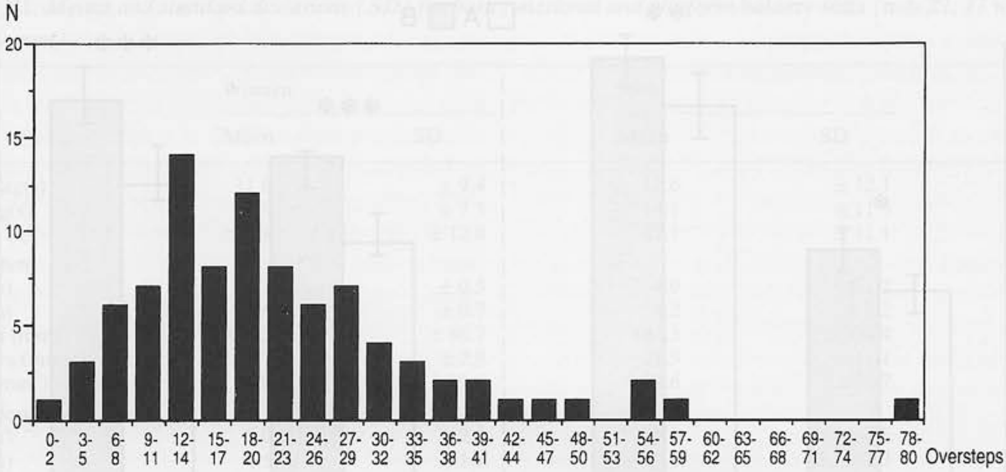

Fig. 3. Distribution of oversteps in 'the figure eight' in women ($n = 90$).

values on or above the median value (= 11 s in women and 24 s in men) compared with those with values below (Fig. 5). Sixty-seven per cent of the women on/above the median value vis-à-vis 26% of those below were able to climb ≥40 cm without using a handrail ($p \leq 0.001$), and in men 97% of those on/above vis-à-vis 84% of those below could manage ($p \leq 0.05$). Height and weight have been taken into consideration as background factors.

For both the static and dynamic balance tests, the strongest correlations were found with the performance variables, above all with climbing capacity, maximum walking speed and isometric knee extensor strength (Table IIa). There was a correlation between the two balance variables (standing on one leg, here the better leg, and 'the eight', $r = -0.57$, $p \leq 0.001$ in women and -0.38, $p \leq 0.01$ in men), but in their relation to ADL they demonstrated somewhat different patterns (Table IIb). The static test showed the strongest relation to difficulty in stair mounting (from the questionnaire) in men, to picking up in women and to cleaning in both sexes, while the dynamic test was most strongly related to stair mounting in both women and men. The two balance variables both

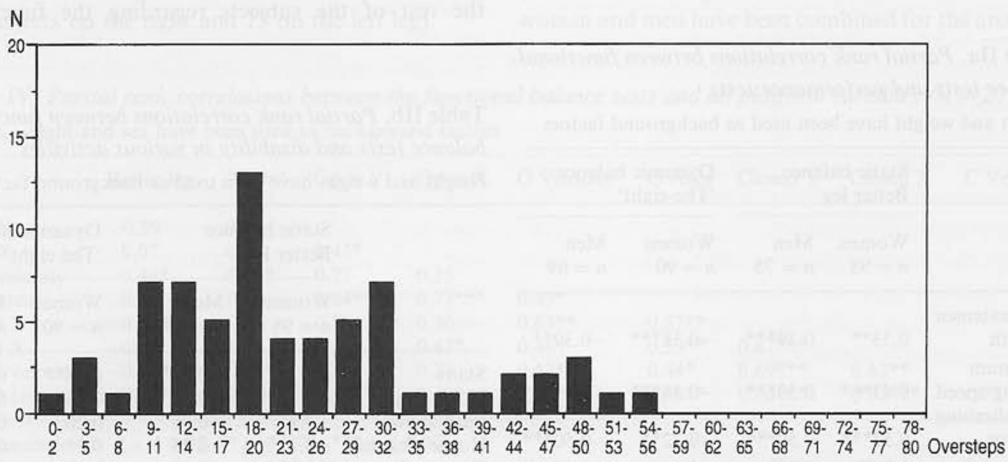

Fig. 4. Distribution of oversteps in 'the figure eight' in men ($n = 69$).

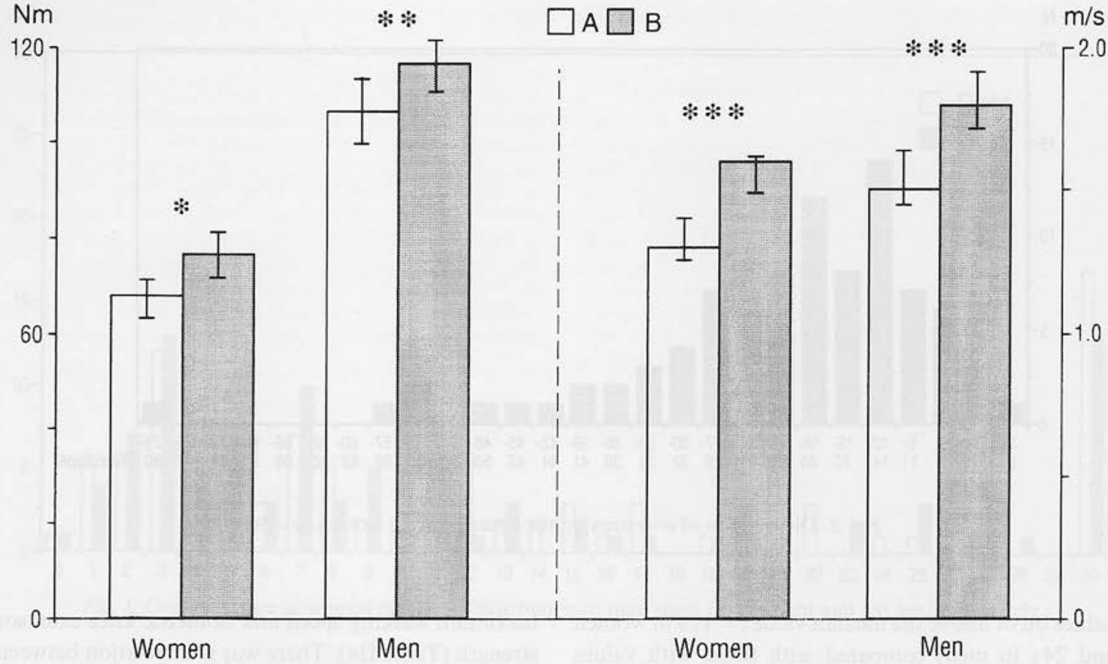

Fig. 5. Knee extensor strength (Nm) and maximum walking speed (m/s) for subjects below (A) and on/above (B) the median value for the better leg in the static balance test. Mean values and 95% confidence intervals are given. Significance levels for difference between A and B are shown: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

revealed a moderate correlation to perception of dizziness, better leg: $r = -0.38$, $p \leq 0.001$ in women and -0.37, $p \leq 0.001$ in men, 'the eight': $r = 0.34$, $p \leq 0.01$ in women and 0.22, NS in men. Use of walking aids was only correlated to the static test in men ($r = -0.25$, $p \leq 0.05$), and there was no correlation between impaired vision and functional balance. Hearing could not be related to other tests, as very few subjects were found to have impairment.

Platform tests ($n = 27$)

There was no significant difference between the group selected for the additional platform balance tests and the rest of the subjects regarding the functional

Table IIa. *Partial rank correlations between functional balance tests and performance tests*

Height and weight have been used as background factors

	Static balance Better leg		Dynamic balance 'The eight'	
	Women $n = 98$	Men $n = 75$	Women $n = 90$	Men $n = 69$
Knee extensor strength	0.33**	0.39***	−0.38***	−0.39**
Maximum walking speed	0.43***	0.50***	−0.44***	−0.41***
Stair-climbing capacity	0.52***	0.50***	−0.32**	−0.50***
Rising ability	0.26**	0.26*	−0.16	−0.13

Significance levels: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Table IIb. *Partial rank correlations between functional balance tests and disability in various activities*

Height and weight have been used as background factors

	Static balance Better leg		Dynamic balance 'The eight'	
	Women $n = 98$	Men $n = 75$	Women $n = 90$	Men $n = 69$
Stairs	−0.11	−0.31**	0.28**	0.28*
Picking up	−0.32**	−0.18	0.16	0.23
Bath/shower	−0.15	−0.08	0.20	0.15
House cleaning	−0.22*	−0.23	0.21	0.04
Shopping	−0.17	−0.07	0.12	0.04

Significance levels: * $p \leq 0.05$, ** $p \leq 0.01$.

Table III. *Means and standard deviations (SD) for both functional and platform balance tests (n = 27, 17 women and 10 men)*

	Women		Men		
	Mean	SD	Mean	SD	*p*
Right leg(s)	11.8	± 9.4	16.6	± 12.1	NS
Left leg(s)	9.9	± 7.5	14.1	± 11.5	NS
'Eight' (n)	22.9	± 12.8	27.1	± 11.1	NS
Eyes open					
Y (mm)	3.7	± 0.5	4.0	± 1.2	NS
X (mm)	3.6	± 0.7	4.2	± 1.2	NS
Length (mm)	530.5	± 86.7	867.3	± 334.4	**
Velocity (mm/s)	17.7	± 2.9	28.9	± 11.1	**
Area (mm^2)	64.0	± 19.6	79.6	± 38.7	NS
Eyes closed					
Y (mm)	5.0	± 2.0	6.6	± 2.7	NS
X (mm)	4.5	± 1.2	5.8	± 2.3	NS
Length (mm)	771.9	± 232.8	1723.6	± 858.2	***
Velocity (mm/s)	25.7	± 7.8	57.5	± 28.6	***
Area (mm^2)	118.7	± 82.6	212.6	± 153.0	NS

Significance levels for difference between women and men: ** $p \leq 0.01$, *** $p \leq 0.001$. NS = non-significant.
Key to symbols: Y = mean sway amplitude from the mean position in anterior–posterior direction; X as above in medio–lateral direction.

balance tests or the other variables presented above. Mean values and standard deviations for all platform test variables are given in Table III. There was a significant difference between women and men regarding velocity (and therefore also length) with eyes open ($p \leq 0.01$) as well as with eyes closed ($p \leq 0.001$), with higher values for the men. When height was taken into account as a background factor, only the difference regarding velocity/length with open eyes remained significant ($p \leq 0.05$). In the present report, only the tests performed on two legs are presented, as very few subjects managed to stand for 10 s on one leg (10 subjects on the right and 13 on the left leg).

In Tables IV and V we have chosen to present only the velocity along the sway path, as length and velocity become identical when the time is constant.

The functional, static balance test was significantly related to velocity along the sway path for the platform test with eyes open and to mean sway in the anterior–posterior direction, velocity and area tested with eyes closed. The functional, dynamic test was significantly correlated to velocity tested with both open and closed eyes. Strong correlations were found between most variables within the platform test (Table IV). Owing to the small number of subjects, women and men have been combined for the analysis.

Table IV. *Partial rank correlations between the functional balance tests and all platform variables (n = 27)*
Height, weight and sex have been used as background factors

	Better leg	'Eight'	Open Y	Open X	O Velocity	O Area	Closed Y	Closed X	C Velocity
Open Y	−0.39	0.24							
Open X	0.07	0.08	0.45*						
Open velocity	−0.46*	0.44*	0.27	0.25					
Open area	−0.30	0.32	0.84***	0.77***	0.43*				
Closed Y	−0.43*	0.36	0.32	0.36	0.63**	0.57**			
Closed X	−0.24	0.36	0.23	0.47*	0.46*	0.53**	0.87***		
Closed velocity	−0.41*	0.41*	0.39	0.23	0.62**	0.44*	0.69***	0.62**	
Closed area	−0.42*	0.35	0.30	0.41*	0.60**	0.56**	0.96***	0.93***	0.73***

Significance levels: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.
Key to symbols: Y = mean sway amplitude from the mean position in anterior–posterior direction; X as above in medio–lateral direction.
Open/O refers to eyes open and Closed/C to eyes closed.

Table V. *Partial rank correlations between three performance tests and all platform variables (n = 27)*
Height, weight and sex have been used as background factors

	Knee extensor strength	Maximum walking speed	Stair-climbing capacity
Open Y	0.10	0.13	−0.20
Open X	0.08	0.13	−0.18
Open velocity	0.00	−0.21	−0.09
Open area	0.06	0.02	−0.17
Closed Y	0.19	−0.25	0.18
Closed X	0.20	−0.15	0.13
Closed velocity	0.23	0.09	0.09
Closed area	0.19	−0.21	0.13

All values were non-significant.
Key to symbols: Y = mean sway amplitude from the mean position in anterior–posterior direction; X as above in medio–lateral direction. Open refers to eyes open and Closed to eyes closed.

Differences between the sexes have been taken into consideration, using sex as a background factor. No significant correlations were found between the performance and platform variables (Table V). As very few subjects within the platform group had difficulties with daily life activities, the ADL-variables have not been analysed regarding correlation to the platform variables.

DISCUSSION

In the present study, we have been able to show relationships between functional balance tests and performance variables such as knee extensor strength and maximum walking speed and also, to some extent, between functional balance tests and platform tests. The results also revealed sex differences, which will be discussed below.

The distribution of the subjects in the static functional test, the one-legged stance, tended to divide them into two main groups, and significant differences between the groups were found regarding leg muscle strength and walking speed in both women and men. This distribution is noteworthy and could provide a basis for further research on the predictive power of this test regarding risk of falling.

The test also showed higher values in men than in women, who were able to stand for 68% of the time of men on their right leg and 66% on their left. The better results in men could be connected with the greater muscle strength in men, as standing on one leg is probably demanding for the leg muscles, confirmed here by the demonstrated significant correlation between standing time and knee extensor strength and, in another study, between standing time and hip muscle strength (16). This is in agreement with a study by Balogun et al. (1), who tested single-limb stance for the dominant leg in different age groups and who found that males had consistently higher scores than females. Era (12) suggests that the ineffective functioning of the posture control system among the elderly may partly be due to weakened muscle function. It has also been found that elderly nursing home residents who had a history of falls had severe impairments in overall ankle muscle strength when compared with age-matched nursing home control subjects with no history of falls (32).

The values from the functional balance tests differ from those presented by Johansson & Jarnlo (17) in that their subjects performed better in both the static and the dynamic test. However, we tested a larger number of subjects, who belonged to a representative sample of 76-year-old men and women, while their study involved 34 women, 70 years of age. Also, the testing procedure regarding 'the figure eight' differed, as their subjects wore shoes and followed the beat of a metronome. We decided to let the subjects choose their own speed, as some might find it difficult to follow a given beat. In both studies, only one attempt was allowed. As the subjects who performed two attempts in the present study generally revealed better results the second time, it is recommended to allow at least two trials when using the test for evaluation of, for example, a training programme. Bohannon et al. (5), who tested one-leg balance in a sample of 31 men and women, 70–79 years old, using the value for the better leg, reported results that are more in line with our values.

One has to bear in mind, that the sensory and motor processes involved in control of balance are to some extent task-specific (8). There was an association between the two functional tests used in the present study, but according to Daleiden (8) a static balance task, such as quiet standing, may be monitored predominantly by the somatosensory system, whereas a dynamic balance task, such as stepping, in which the body and head are in motion, may place greater demands on the visual and vestibular systems.

As expected, functional balance was correlated to practically all performance tests involved in the study. This is in line with a study by Iverson et al. (16), who found correlations between one-legged stance and muscle strength in flexors, extensors and abductors of the hip in a sample of 54 men, 60–90 years old. In the present study, ability to rise from a chair was related to static (but not to dynamic) balance. There is probably a greater need of leg muscle strength for both standing on one leg and rising from a chair than for walking in 'the figure eight'. The strength of the correlation between balance function and muscle strength or walking speed varies among studies, which can be expected, as functional decline can be caused by many different and accumulating factors (9).

Perception of dizziness was also found to be correlated to functional balance. Dizziness can be seen as a symptom of some deficit within the balance system, a marker for other conditions such as sensory impairment, vascular disease or arthritis, which increase the risk the elderly run of becoming disabled (6).

The platform tests, performed by a sub-group, were done in order to compare them with the functional tests. The small number of subjects made it necessary to treat women and men together, which limits the analysis. Strong correlations were found between the different recorded parameters, as also described in a study by Berg et al. (4). It was possible to show that some of the platform variables were related to the functional balance tests, but there was no correlation between the platform and the performance tests (leg muscle strength and maximum walking speed). However, Mathias et al. (21) reported a correlation between sway path and walking speed in 32 elderly subjects with balance disturbances, and Ekdahl et al. (10) found correlations between length, velocity and area on the platform, on the one hand, and one-leg stance blind-folded and maximum walking speed, on the other. Berg et al. (4) demonstrated correlations between a Balance Scale developed by them and standing on both feet on a platform with eyes open. In agreement with the present study, these authors found that larger amplitude and speed of sway are indicative of poorer functional balance.

In comparison with a previous study (10), where the same type of platform and similar tests were used, the results from the present study generally showed a greater sway. However, in that study the subjects stood with their feet close together and with their arms hanging, while our subjects had an angle of 30° between their feet and their arms behind their back. Also, that study involved younger age groups, of which the oldest, aged 60–64, consisted of 10 women and 10 men.

Difference in age may have contributed to discrepancies in the results, as many studies have demonstrated a decreased balance function with increasing age (1, 5, 10, 11, 16, 23, 25, 33). Era & Heikkinen (11) found that the extent of postural sway while standing, with eyes both open and closed, was clearly correlated with age. Woollacott (33) has demonstrated that onset latencies of postural muscle responses in the ankle dorsiflexors are significantly slower in the elderly adult (61–78 years of age) than in the young adult (19–38 years old), and that elderly subjects are more likely to coactivate antagonist muscles and to use a hip strategy rather than an ankle strategy in balancing.

Various studies have demonstrated increased sway with advancing age, but also that there is a great intersubject variation (2). It has also been shown that subjects decreased their postural sway with repeated testing, and that voluntary compensation such as concentration might influence the outcome (2). Certainly factors such as anxiety, level of attention given to the test (4) or motivation play a certain role. It has been demonstrated, however, that the reliability of a test battery carried out on the same type of force platform that was used in the present study may be regarded as acceptable (10).

Women performed better than men in the platform tests, where men had a greater tendency to sway. The latter result might be explained by the difference in body height, which means a higher position of the centre of gravity in men. On the other hand, other studies have found a greater sway in women than in men, for example, in a group of 269 healthy women and 134 men of an age varying from 18 to 87 years (25). However, comparing sway measurements in different decades, Thyssen et al. (28) were able to demonstrate that in the sixth decade men swayed more than women. Thus, the tendency to sway seems to increase more in men than in women with increasing age, which could explain variations in findings. Also Ekdahl et al. (10) and Pyykkö et al. (23) showed that women, as in the present study, had better values than men on the platform.

Balance function can be improved through training (12, 17, 18, 19, 20, 27). It would be interesting to know to what extent the decrease in balance function with age is due to disuse. A previous report within the same population study showed a positive relationship between earlier physical activity level and performance variables such as leg muscle strength and walking speed at age 76 (15). As the present study revealed correlations between the same performance variables and balance, it can be expected that balance is also influenced by activity patterns. In the study by Iverson et al. (16), correlations between balance function and activity level, as well as between balance and hip muscle strength, were shown, and Era (12) has found that it is possible to influence the functioning of the posture control system among elderly men with the help of physical training.

A minority of the subjects included in the present report were dependent in ADL. This explains why most correlations between ADL and balance were very low (Table IIb). There was, however, a tendency toward higher correlations with instrumental, more complex activities, which is consistent with a report regarding validation of a balance instrument called Functional Reach, which also showed a strong association with Instrumental ADL, but a more modest association with Personal ADL (31). This is consistent with results showing that dependence on assistance from another person starts with instrumental activities (26). Studies involving more disabled subjects are needed, and Daleiden (8) states that clinical research is required to further relate improvements in balance to functional levels of ambulation and ADL. However, in a population of 31 elderly people (mean age 83 years), close correlations were demonstrated between the Balance Scale and Barthel Mobility sub-scale, Tinetti's Balance sub-scale and the timed 'Up and Go' (4).

Some of our tests can also be found in Tinetti's assessment (29), and the advantage of functional tests is that they are easy to perform irrespective of locality and expensive equipment, and that they are close to daily life activities. Topper et al. (30) studied the predictive power of Tinetti's test and of platform tests. They found that activity-based testing of certain tasks may be useful in indicating a specific need for intervention to reduce the risk of falling during related everyday activities, but that in terms of predicting risk of falling, a static posturography test may be more reliable.

In conclusion, both static and dynamic functional balance tests offer valuable information about the balance function of elderly people and the tests were moderately correlated to leg muscle strength and maximum walking speed.

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REFERENCES

1. Balogun, J. A., Akindele, K. A., Nihinlola, J. O. & Marzouk, D. K.: Age-related changes in balance performance. Disabil Rehabil *16:* 58–62, 1994.
2. Berg, K.: Balance and its measure in the elderly: a review. Physiother Can *41:* 240–246, 1989.
3. Berg, K., Wood-Dauphinée, S., Williams, J. I. & Gayton, D.: Measuring balance in the elderly: preliminary development of an instrument. Physiother Can *41:* 304–311, 1989.
4. Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J. & Wood-Dauphinée, S. L.: Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil *73:* 1073–1080, 1992.
5. Bohannon, R. W., Larkin, P. A., Cook, A. C., Gear, J. & Singer, J.: Decrease in timed balance test scores with aging. Phys Ther *64:* 1067–1070, 1984.
6. Boult, C., Murphy, J., Sloane, P., Mor, V. & Drone, C.: The relation of dizziness to functional decline. J Am Geriatr Soc *39:* 858–861, 1991.
7. Cox, D. R. & Hinkley, D. V.: Theoretical Statistics. Chapman and Hall Ltd., London, 1974.
8. Daleiden, S.: Weight shifting as a treatment for balance deficits: a literature review. Physiother Can *42:* 81–87, 1990.
9. Duncan, P. W., Chandler, J., Studentski, S., Hughes, M. & Prescott, B.: How do physiological components of balance affect mobility in elderly men? Arch Phys Med Rehabil *74:* 1343–1349, 1993.
10. Ekdahl, C., Jarnlo, G. B. & Andersson, S. I.: Standing balance in healthy subjects: evaluation of a quantitative test battery on a force platform. Scand J Rehab Med *21:* 187–195, 1989.
11. Era, P. & Heikkinen, E.: Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. J Gerontol *40:* 287–295, 1985.
12. Era, P.: Posture control in the elderly. Int J Technol Aging *1:* 166–179, 1988.
13. Eriksson, B. G., Mellström, D. & Svanborg, A.: A medical–social intervention in a 70-year-old Swedish population. A general presentation of methodological experience. Compr Gerontol (C) *1:* 49–56, 1987.
14. Frändin, K. & Grimby, G.: Assessment of physical activity, fitness and performance in 76-year-olds. Scand J Med Sci Sports *4:* 41–46, 1994.
15. Frändin, K., Mellström, D., Sundh, V. & Grimby, G.: A life span perspective on patterns of physical activity and

functional performance at the age of 76. Gerontology *41:* 109–120, 1995.
16. Iverson, B. D., Gossman, M. R., Shaddeau, S. A. & Turner, M. E. Jr.: Balance performance, force production and activity levels in noninstitutionalized men 60–90 years of age. Phys Ther *70:* 348–355, 1990.
17. Johansson, G. & Jarnlo, G. B.: Balance training in 70-year-old women. Physiother Theor Pract *7:* 121–125, 1991.
18. Judge, J. O., Lindsey, C., Underwood, M. & Winsemius, D.: Balance improvements in older women: Effects of exercise training. Phys Ther *73:* 254–262, 1993.
19. Ledin, T., Kronhed, A. C., Möller, C., Möller, M., Ödkvist, L. M. & Olsson, B.: Effects of balance training in elderly evaluated by clinical tests and dynamic posturography. J Vestib Res *1:* 129–138, 1990/91.
20. Lord, S. R., Caplan, G. A. & Ward, J. A.: Balance, reaction time and muscle strength in excercising and nonexercising older women: A pilot study. Arch Phys Med Rehabil *74:* 837–839, 1993.
21. Mathias, S., Nayak, U. S. L. & Isaacs, B.: Balance in elderly patients: The 'get-up and go' test. Arch Phys Med Rehabil *67:* 387–389, 1986.
22. Podsiadlo, D. & Richardson, S.: The timed 'up and go': A test of basic functional mobility for frail elderly persons. J Am Geriatr Soc *39:* 142–148, 1991.
23. Pyykkö, I., Jäntti, P. & Aalto, H.: Postural control in elderly subjects. Age Ageing *19:* 215–221, 1990.
24. Ring, C., Nayak, L. & Isaacs, B.: Balance function in elderly people who have and have not fallen. Arch Phys Med Rehabil *69:* 261–264, 1988.
25. Sackley, C. M. & Lincoln, N. B.: Weight distribution and postural sway in healthy adults. Clin Rehabil *5:* 181–186, 1991.
26. Sonn, U. & Hulter Åsberg, K.: Assessment of activities of daily living in the elderly. A study of a population of 76-year-olds in Gothenburg, Sweden. Scand J Rehab Med *23:* 193–202, 1991.
27. Stones, M. J. & Kozma,. A.: Balance and age in the sighted and blind. Arch Phys Med Rehabil *68:* 85–89, 1987.
28. Thyssen, H. H., Brynskov, J., Jansen, E. C. & Münster-Swendsen, J.: Normal ranges and reproducibility for the quantitative Romberg's test. Acta Neurol Scand *66:* 100–104, 1982.
29. Tinetti, M. E.: Performance-oriented assessment of mobility problems in elderly patients. J Am Geriatr Soc *34:* 119–126, 1986.
30. Topper, A. K., Maki, B. E. & Holloday, P. J.: Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/or type of fall? J Am Geriatr Soc *41:* 479–487, 1993.
31. Weiner, D. K., Duncan, P. W., Chandler, J. & Studentski, S. A.: Functional reach: A marker of physical frailty. J Am Geriatr Soc *40:* 203–207, 1992.
32. Whipple, R. H., Wolfson, L. I. & Amerman, P. M.: The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. J Am Geriatr Soc *35:* 13–20, 1987.
33. Woollacott, M.: Changes in posture and voluntary control in the elderly: Research findings and rehabilitation. Top Geriatr Rehabil *5:* 1–11, 1990.
34. Woollacott, M. H.: Age-related changes in posture and movement. J Gerontol *48 (Special issue):* 50–60, 1993.

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