Age and Ageing 1999; **28**: 289–293

Is there a relationship between balance, gait performance and muscular strength in 75-year-old women?

Karin Ringsberg, Paul Gerdhem, Jonas Johansson, Karl J. Obrant

Department of Orthopaedics, Malmö University Hospital, S-205 02 Malmö, Sweden

Address correspondence to: K. Obrant. Fax: (+46) 40 33 62 00. Email: karl.obrant@ortomas.lu.se

Abstract

Objective: to see if there is a relationship between clinical and laboratory tests of balance, muscular strength and gait in elderly women.
Design: a randomized population-based study.
Settings: Malmö, Sweden.
Methods: we investigated balance with a simple test of standing on one leg, as well as a computerized balance platform. Muscular strength was tested by computerized dynamometer. Extension and flexion of the knee and dorsiflexion of the ankle were tested. We measured the time and number of steps taken to walk a certain distance and the subjects' height and weight.
Participants: 418 randomly selected 75-year-old women, of whom 230 took part.
Results: there was no relation between the computerized balance tests and any of the other tests. The non-computerized balance test was correlated with gait time and number of steps ($r = -0.50$, $P < 0.001$ and $r = -0.40$, $P < 0.001$, respectively). Tests of extension and flexion, strength of the knee and ankle dorsiflexion were related to gait, speed and number of steps. Heavy women had poorer balance when assessed by the non-computerized test ($r = -0.32$, $P < 0.001$) and with the computerized, stable platform, eyes-open test ($r = 0.27$, $P < 0.001$) and eyes-closed test ($r = 0.44$, $P < 0.001$). The heavier an individual was, the slower her gait and the shorter her steps, despite having stronger knee muscles.
Conclusion: there is no relationship between the simple balance tests and computerized platform tests. Muscle strength of the leg is not necessarily linked to balance, but rather to gait performance.

Keywords: *balance, gait, muscle strength, old age*

Introduction

Balance deteriorates with age and is a risk factor for fractures [1]. If better balance could be achieved by muscular training, then balance and muscular exercise might decrease the incidence of falls [2–6]. Those with good muscular strength in the legs should have better balance than those with weaker legs. This has been proven in elderly nursing home residents with a history of falls compared with age-matched controls [7].

The relationship between muscular strength and balance as assessed by computerized tests has never been investigated, but an average correlation of $r = -0.55$ and lower, between clinical and laboratory balance testings has been found [8–11].

Postural control is complex, involving biomechanical/motor co-ordination and sensory organization components, and is dependent on vestibular, visual and psycho-social inputs. Different balance tests measure different components of postural control. Computerized balance platforms have been constructed to give objective measurements of sway under different conditions [12, 13]. One such balance platform is the Chattecx computerized balance system [13]. The measured variables from computerized balance plates summarize the postural sway of the subject by calculating how far movements of the centre of balance deviate from the mean centre of balance when the plate is stable and moving in different directions and when the individual has her eyes open and closed.

The purpose of this study was to find out whether the balance tests performed on the Chattecx balance platform were related to a simple standing-on-one-leg balance test in a large sample of older women. We also wanted to relate these findings to muscular power of the legs as evaluated by the Kin–Com and the Biodex computerized muscular testing machines.

Subjects and methods

Four hundred and eighteen women selected from the population register at random were invited to take part. Two hundred and thirty chose to participate, an attendance rate of 55%. The invitation was sent out on each woman's 75th birthday. The investigation took place a few months later. Of the 188 who did not participate, 24 were unable to attend before the last examination date, 38 had some illness and were unable to get to the examination, two women died before the test and nine were not found despite repeated telephone calls or letters. In addition, 150 women did not want to take part but gave no reason. Balance, gait performance and muscular strength were tested in all 230 women by the same examiner (K.R.). Institutionalized subjects were not actively excluded, but none of the women who chose to participate was in residential care.

Balance

Two different types of balance test were used. One was a simple, non-computerized, one-leg standing test and the other a computerized balance test where both static and dynamic balance were tested in four different ways. All tests were performed in bare feet and the subjects were asked to look straight ahead at a dot 1 m in front of them.

The one-leg standing test has been described previously [14]. The subjects were asked to stand on one leg at a time, with their eyes open or closed and with their hands on their hips. The position of the non-weight-bearing leg was chosen by the subject. The time until balance was lost (or maximum 30 s) was recorded for each of the four parts of this test. Three trials per test were allowed, the best was registered and all results were added to produce a score. The maximum achievable balance score was thus 120 s.

Static and dynamic balance were tested using the Chattecx computerized balance system, consisting of independent force-measuring transducers (foot plates) for the toe and heel of each foot. Each subject was assessed on four different 20-s balance tests: (i) standing on a stationary platform with eyes open, (ii) standing on the same stationary platform with eyes closed, (iii) standing on a platform with eyes closed and with the platform gliding horizontally backwards and forwards, and (iv) standing on the platform with eyes open and with the platform moving up and down. Data analyses of these four computerized balance tests involved registration of the movements of the subject's centre of balance during each 20-s test. The mean centre of balance was computed and a numeric value of the standard deviation of the time and the distance the subjects spent away from the centre of balance was recorded as the sway index (%).

Gait performance

The women were asked to walk as fast as they could in their ordinary shoes for 30 m with one turn. The time taken was recorded, as was the number of steps taken.

Muscular strength

Voluntary maximal isometric muscle strength of the right knee was tested over 5 s using a Biodex computerized dynamometer. Knee extension at 90° and knee flexion at 45° was used. Three trials in both directions were performed and the best attempt was recorded as work in Newton metre seconds (Nms).

Isometric dorsiflexion of the right ankle was tested using a Kin–Com kinetic communicator at 75° and at 90°. Peak force of the best attempt in the trial was recorded in Newtons. The duration of every contraction in all tests was 5 s per contraction. The subjects were asked to perform their maximal effort.

In addition, the weight and height of the subjects were recorded.

Statistical testing was performed using Spearman's rank order correlation and by setting the level of significance to $P < 0.01$ in order to avoid falsely positive findings due to multiple testings.

Results

The median values for the whole group and for the five balance tests performed are in Table 1.

In a comparison of the five different balance tests with each other, we found that the one-leg standing test did not correlate with any of the computerized tests. The correlation was in a comparison of the results from the computerized tests with the stable plate, i.e. with eyes closed and with eyes open ($r = 0.45$, $P < 0.001$). Also, the test with closed eyes on a stable plate was correlated with the plate moving horizontally ($r = 0.25$, $P < 0.001$). No other balance tests showed a correlation (Table 2).

The median values for the gait performance tests and the muscular strength tests are also in Table 1. There was a correlation for the different strength tests, best for knee flexion compared to knee extension ($r = 0.63$, $P < 0.001$) and knee extension compared to ankle dorsiflexion at 75° ($r = 0.29$, $P < 0.001$; Table 2). Individuals who walked 30 m in a shorter time and used fewer steps had also better balance as tested by one-leg standing time ($r = -0.50$, $P < 0.001$ and

Table 1. Median values of balance, gait performance and isometric muscular strength tests as well as weight and height for all subjects

Test	Median (lower and upper quartile)
Balancing on one leg (time, s)[a]	35.0 (13.5, 55)
Platform (sway index, %)	
Stable, eyes open	6.08 (5.0, 7.3)
Stable, eyes closed	7.8 (6.1, 9.7)
Horizontal movement, eyes closed	21.2 (19.2, 24.4)
Vertical movement, eyes open	28.9 (24.1, 34.6)
Gait performance	
Time to walk 30 m (s)	22.0 (20.0, 25.0)
No. of steps for 30 m	47.0 (43.0, 51.0)
Isometric muscular strength	
Knee extension 90° (Nms)[b]	276.7 (228.5, 330.4)
Knee flexion 45° (Nms)[b]	131.2 (108.2, 161.7)
Ankle dorsiflexion 75° (N)	88.5 (67.0, 111.0)
Ankle dorsiflexion 90° (N)	22.5 (0.0, 46.0)
Weight (kg)	66.0 (59.0, 75.0)
Height (cm)	162.0 (158.0, 166.0)

[a]Maximum score: 120.
[b]Maximum repetitive work.

$r = -0.40$, $P < 0.001$), respectively. No other balance tests were correlated to gait performance.

In a comparison of each of the five different balance tests with each of the four different muscular tests, only the non-computerized balance test showed a weak correlation with knee extension force ($r = 0.19$, $P = 0.004$; Table 2).

Tall individuals had slightly worse balance score than short individuals. This finding was recorded, however, only for one of the five tests, i.e. on the stable footplate with eyes closed ($r = 0.21$, $P = 0.001$; Table 2). Weight, on the other hand, was closely and negatively correlated with balance, both with the simple, non-computerized test and with the two tests on the computerized, stable footplate (Table 2). Also, heavier women had better knee extension force and knee flexion force, but they walked more slowly and took more steps than women who were lighter (Table 2).

In all four muscular tests, the stronger the individual, the higher the walking speed and the longer the steps (Table 2).

Discussion

The women in this study were exactly 75 years old. We chose this since it is the age when the number of hip fractures starts to increase steeply, especially in women [12]. If intervention against impaired balance is possible, this would perhaps be the age at which such intervention would be cost-effective [15]. All women who participated were living at home and therefore represent a generally healthy group.

The clinical balance tests and the tests of knee muscle strength and gait have been used earlier and differences have been found between urban and rural women, who differed in physical activity [16, 17].

There was a very poor correlation between the different balance tests. There was no relationship between the simple standing-on-one-leg test with any of the four computerized tests. Also, the four computerized tests were poorly correlated with each other—except for the one with the stable platform and the eyes closed and open. The different results from these various tests strengthen the theory that they may be measuring different aspects of postural control and are not comparable. It seems plausible that a woman of 75 who cannot stand on either leg for a long time with her eyes open or closed would be more prone to falling. Also, subjects with large postural sway, independent of the stability of the ground, may be prone to falling. Large prospective studies with falls or fractures as end-points are needed to determine which balance tests are clinically important.

Neither of the muscular strength tests in knee extension, knee flexion or ankle dorsiflexion at different degrees was related to any of the balance tests, with one minor exception (knee extension force and non-computerized balance test). This is somewhat discouraging, since the theoretical basis for improving balance by muscular strength training may thus not be valid, at least in elderly women living at home.

Elderly people often stumble, and frequent fallers have weak knee extension and ankle dorsiflexion [17, 18]. We found that muscular strength of the legs was highly related to gait performance both in the speed of walking and in taking fewer, longer steps. Whether this also means that exercises for individuals with poor muscular strength will result in improved gait performance is uncertain.

The two anthropometric variables—weight and height—were also investigated in relation to the balance tests and muscular strength as well as gait performance. Tall individuals had somewhat poorer balance, but only in one of the five different balance tests performed (with eyes closed and on the stable, computerized platform). Weight, on the other hand, had a high correlation with several of the balance tests, both non-computerized and computerized. Lean people had better balance than obese people. This is not surprising, since the centre of body weight is more centralized in thinner people. Individuals with hip fractures are leaner than others—on average by 7 kg [19]. Reduced soft tissue padding over the lateral aspect of the hip may be important in sustaining a hip fracture. However, the results presented here are based on reasonably healthy, elderly women living at home. In hip fracture cases other factors, such as poor general health, immobility, medication and cognitive impairment, may explain a propensity to fall [20–22]. If less healthy individuals, such as those in nursing homes had

Table 2. Correlation coefficients (r) and levels of significance in a comparison of the different balance, gait performance and isometric muscular strength tests as well as weight and height with each other: one-leg standing time is higher the better the balance, whereas all four platform tests result in lower values the better the balance

	Balance					Gait performance[c]		Isometric muscular strength			
		Stable platform		Moving platform				Knee		Ankle dorsiflexion	
	Time on one leg	Eyes open	Eyes closed	Horizontal[a]	Vertical[b]	Time taken	No. of steps	90° extension	45° flexion	75°	90°
Balance											
Time on one leg	–										
Stable platform											
Eyes open	NS	–									
Eyes closed	NS	$r = 0.45$; $P < 0.001$	–								
Moving platform											
Horizontal[a]	$r = -0.23$; $P = 0.0011$	NS	$r = 0.25$; $P < 0.001$	–							
Vertical[b]	NS	$r = 0.20$; $P = 0.002$	NS	NS	–						
Gait performance[c]											
Time taken	$r = -0.50$; $P < 0.001$	NS	NS			–					
No. of steps	$r = -0.40$; $P < 0.001$;	NS	NS			$r = 0.79$; $P < 0.001$	–				
Isometric muscle strength											
Knee											
90° extension	$r = 0.19$; $P = 0.004$	NS	NS	NS	NS	$r = -0.37$; $P < 0.001$	$r = -0.29$; $P < 0.001$	–			
45° flexion	NS	NS	NS	NS	NS	$r = -0.26$; $P < 0.001$	$r = -0.21$; $P = 0.001$	$r = 0.62$; $P < 0.001$	–		
Ankle dorsiflexion											
75°	NS	NS	NS	NS	NS	$r = -0.22$; $P < 0.001$	$r = -0.25$; $P < 0.001$	$r = 0.29$; $P < 0.001$	$r = 0.22$; $P = 0.001$	–	
90°	NS	NS	NS	NS	NS	NS	$r = -0.23$; $P < 0.001$	NS	NS	$r = 0.63$; $P < 0.001$	–
Anthropometric variables											
Weight	$r = -0.32$; $P < 0.001$	$r = 0.27$; $P < 0.001$	$r = 0.44$; $P < 0.001$	NS	NS	$r = 0.22$; $P = 0.001$	$r = 0.24$; $P < 0.001$	$r = 0.16$; $P = 0.02$	$r = 0.22$; $P < 0.001$	NS	NS
Height	NS	NS	$r = 0.21$; $P = 0.001$	NS	NS	NS	NS	NS	$r = 0.22$; $P = 0.001$	NS	NS

[a]Eyes closed.
[b]Eyes open.
[c]30 m walk.

been able to participate, different results might have been found. Nevertheless, our sample was sufficiently large and balance and muscular strength were tested in several ways so that, if a true and important relation between these variables existed we would probably have found it.

Key points

- There is a poor relationship between clinical and laboratory balance tests.
- A clinical, one-leg standing, balance test is related to gait, speed and number of steps.
- There is a low correlation between muscle tests of the lower limb and gait, speed and number of steps.
- Older women who are heavy walk more slowly and take more steps than their lighter counterparts.

References

1. Campbell JA, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. J Gerontol Med Sci 1989; 44: M112–7.

2. Nevitt MC, Cummings SR, Kidd S, Black D. Risk factors for recurrent nonsyncopal falls. JAMA 1989; 261: 2663–8.

3. Johansson G, Jarnlo G-B. Balance training in 70-year-old women. Physiother Theory Pract 1991; 7: 121–5.

4. Lord SR, Ward JA, Williams P, Strudwick M. The effect of a 12-month exercise trial on balance, strength and falls in older women: a randomised controlled trial. J Am Geriatr Soc 1995; 43: 1198–206.

5. Campbell AJ, Robertson MC, Garnder MM, Norton RN, Tilyard MW, Bochner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. Br Med J 1997; 25: 1065–9.

6. Hopp J. Effects of age and resistance training on skeletal muscle: a review. Phys Ther 1993; 73: 361–73.

7. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. J Am Geriatr Soc 1987; 35: 13–20.

8. Berg KO, Maki BE, Williams JI, Holiday PM, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehab 1992; 73: 1073–80.

9. Ekdahl C, Jarnlo GB, Andersson SI. Standing balance in healthy subjects. Scand J Rehab Med 1989; 21: 187–95.

10. Horak FB. Clinical measurement of postural control in adults. Phys Ther 1987; 67: 1881–5.

11. Tinetti ME, Speechly M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319: 1701–7.

12. Jarnlo G-B. Hip Fracture Patients. Background factors and function. Thesis, University of Lund, Sweden, 1990.

13. Grabiner MD, Lundin TM, Feuerbach JW. Converting Chattecx balance system vertical reaction force measurements to centre of pressure excursion measurements. Phys Ther 1993; 73: 316–9.

14. Frändin K, Sonn V, Svantesson V, Grimby G. Functional balance tests in 76-year old women in relation to performance, ADL and platform tests. Scand J Rehab Med 1995; 27: 231–41.

15. Wolf SL, Kutner NG, Green RC, McNeely E. The Atlanta FICSIT study: two exercise interventions to reduce frailty in elders. J Am Geriatr Soc 1993; 41: 329–32.

16. Ringsberg K. Muscle strength differences in urban and rural populations in Sweden. Arch Phys Med Rehab 1993; 74: 1315–8.

17. Ringsberg KA, Gärdsell P, Johnell O, Jónsson B, Obrant KJ, Sernbo I. Balance and gait performance in an urban and a rural population. J Am Geriatr Soc 1998; 46: 65–70.

18. Woolacott MH, Shumway-Cook A. Changes in posture across the life span—a system approach. Phys Ther 1990; 70: 799–807.

19. Karlsson KM, Johnell O, Nilsson BE, Sernbo I, Obrant KJ. Bone mineral mass in hip fracture patients. Bone 1993; 14: 161–5.

20. Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community dwelling women. J Am Geriatr Soc 1994; 42: 1110–7.

21. Tinetti ME, Ginter SF. Identifying mobility dysfunction in elderly patients. JAMA 1988; 259: 1190–3.

22. Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people. Arch Intern Med 1989; 149: 1628–33.

Received 4 November 1997; accepted in revised form 3 June 1998

Grandfather, wounded in the war, with his grand-daughter. © Sally and Richard Greenhill.