Clinical Rehabilitation 2006; **20:** 269–276

Identification of healthy elderly fallers and non-fallers by gait analysis under dual-task conditions

C Toulotte Laboratoire d'Etudes de la Motricité Humaine, Faculté des Sciences du Sport et de l'Education Physique, Lille and Laboratoire d'Analyse du Mouvement, Hôpital Roger Salengro, Lille, **A Thevenon** Hôpital Swinghedauw, Service de Rééducation et de Réadaptation Fonctionnelles, Lille, **E Watelain** Laboratoire d'Automatique de Mécanique et d'Informatique industrielles et Humaines, Université de Valenciennes, Valenciennes and **C Fabre** Laboratoire d'Etudes de la Motricité Humaine, Faculté des Sciences du Sport et de l'Education Physique, Lille, France

Received 22nd October 2004; returned for revisions 11th April 2005; revised manuscript accepted 29th July 2005.

Objective: We compared falling and non-falling healthy elderly subjects to identify balance disorders associated with falling. Gait parameters were determined when carrying out single and dual tasks.
Design: Case comparison study.
Setting: Subjects were studied in the gait laboratory at Hôpital Roger Salengro, Lille, France.
Subjects: A group of 40 healthy elderly women were assigned to one of two groups according to their falling history: 21 fallers aged 70.4 ± 6.4 years and 19 non-fallers aged 67.0 ± 4.8 years. All subjects performed first a single leg balance test with two conditions (eyes open/closed). Then, gait parameters were analysed under single-task and dual motor-task conditions (walking with a glass of water in the hand).
Main measures: Falls, number of times suspended foot touched the floor during the single leg balance test, cadence, speed, stride time, step time, single-support time, stride length and step length during walking under single- and dual-task conditions.
Results: During the single leg balance test, fallers placed their feet on the floor three times more often than non-fallers under eyes open conditions ($P < 0.05$) and twice as often under eyes closed conditions ($P < 0.05$). In the single-task condition, no significant difference in gait parameters was reported between fallers and non-fallers. There was a significant difference ($P < 0.05$) in the gait parameters (cadence, speed, stride and step time, single-support time) between fallers and non-fallers under dual-task conditions.
Conclusions: Dual tasks perturb walking in fallers, who exhibit deteriorated static balance. Consequently, walking under dual-task conditions plus a single leg balance test could be helpful in detecting walking disorders and planning physiotherapy to prevent falls.

Address for correspondence: Claire Toulotte, UFR STAPS, Université d'Artois, Chemin du Marquage, 62800 Lievin, France. e-mail: ctoulotte@wanadoo.fr

 10.1191/0269215506cr929oa

Introduction

Ageing-associated decline of sensorial function and muscular weakness of the lower limbs in elderly people leads to a gait pattern[1–5] that, associated with postural instability, can provoke falls.[1] Several authors have found that frail elderly fallers display a significantly slower walking speed than non-fallers.[4–8] This was due to a significant decrease in step length and an increase in double-support times[5] and a decrease of step length.[4] These different studies investigated easily quantifiable parameters such as walking speed, cadence, stride length, and stride time, and, as in most of the reports in the literature, were designed to study gait patterns in frail elderly fallers and non-fallers (dependent subject). However, when the objective is to understand how knowledge of changes in gait parameters can be useful in preventing falls in the healthy elderly, gait patterns must be carefully examined in the healthy elderly fallers and non-fallers (autonomous subject).

The Timed Up and Go Test[9] and the single-task test described by Tinetti[2] have been found useful for predicting falls in frail elderly subjects. When applied in healthy elderly subjects, these tests are too easy and insufficiently discriminative for falls. Test results obtained in frail elderly subjects cannot be extrapolated to healthy elderly subjects.

Geurts *et al*.[10] and Stelmach *et al.*[11] suggested that an evaluation of attention using dual-task situations could be useful since the many factors contributing to impaired balance control imply greater attention to maintain stability.[12,13] Thus, in their studies on elderly adults living in the community, Shumway-Cook *et al*.[14] and Lundin-Olsson *et al*.[15] found that the Timed Up and Go Test conducted under dual-task conditions can reveal balance disorders. Nevertheless, Shumway-Cook *et al*.[14] concluded that the ability to predict falls in frail elderly subjects is not enhanced by adding a secondary task because the Timed Up and Go Test time w.962s(Go)-Gte6

Each subject was interviewed successively by two clinicians working in separate rooms who noted the causes, and the number and dates of falls two years before the beginning of the study as well as the subject's current medication and physical activities. A fall was defined as any event that led to an unplanned, unexpected contact with a supporting surface.[14] According to Vellas *et al.*,[16] a subject was defined as a faller if at least one fall had occurred during the two years preceding the study. Applying the approach used in our geriatric unit's fall clinic, falls which had occurred more than two years before the study were not counted. Falls resulting from unavoidable environmental hazards such as a chair collapsing were excluded. The two clinicians compared the history described by each subject and together classed the subjects as fallers or non-fallers. The year and the month of each fall were recorded but not the exact dates. Likewise causes of falls were not recorded because the subjects frequently could not remember the exact problem and recall the precise causes of their falls because of multifactorial causes.

The Mini Mental State[17] was also determined; none of the subjects presented psychological or cognitive disorders. All subjects obtained the maximal score and were considered to have normal cognitive function (if the score was inferior at 24 points, the subject presents cognitive disorders). The fact that a subject could not remember the exact date of a fall but only the month was not considered to constitute a cognitive problem.

Five subjects were excluded from the study after these interviews because they used a walking aid or had a history of lower limb fracture. The study was thus conducted with 40 women who were assigned to one of two groups, according to their history of falling: 21 fallers aged 70.4 years ($\pm$6.4) and 19 non-fallers aged 67.0 years ($\pm$4.8). The fallers had experienced an average of 3.2 falls ($\pm$1.6) (1 to 7 falls) during the two years before this study.

Protocol

All the subjects performed the following tests in this order. First, a single leg balance test with eyes open followed by eyes closed, and second, gait analysis in single- and dual-task conditions were analysed.

Tests

Single leg balance test

Single leg balance test was studied under two conditions: eyes open and eyes closed. The subjects stood on one foot with their eyes open for 30 s[18] because the 5-s single leg balance test is too short for discrimination among healthy subjects. We counted the number of times the subject's suspended foot touched the floor during the 30-s test. The subjects had no support at the start of this test and were free to choose the foot to stand on. The chronometer was started as soon as the subject lifted one foot off the floor. If the subject placed her suspended foot on the floor during the test, the chronometer was stopped and was started again as soon as it no longer touched the floor. The leg was held free in space (90° knee flexion, 90° hip flexion). The number of times each subject placed the suspended foot on the floor was recorded.[3] The subjects then repeated the test with eyes closed.

Gait analysis

Spontaneous gait was studied with a VICON 370 system (Oxford Metrics Ltd, Oxford, UK) under single-task and dual-task conditions. Walking speed, step and stride length were collected using the VICON system. A 50 Hz camera was located 3.5 m from the centre of a 10-m walkway to cover the area required for one complete gait cycle. A second camera was placed at the end of the walkway and was aligned along the axis of progression to obtain an anterior view of the subject. The four other cameras were located 2 m from, and in alignment with, the four corners of the 10-m walkway. Forceplates were used to record cadence, step and stride time and single support time. Three AMTI (Advanced Mechanical Techonolgy Inc, Water-town, MA, USA) forceplates (250 Hz) located in the middle of the 10-m walkway were synchronized with the VICON cameras. Before data collection, the cameras were calibrated within a 2.8 m^2 calibration volume: width 1.0 m $\times$ height 1.8 m. Maximal error of VICON 370 data collection was 0.183 cm when the measured distance between two fully visible markers did not exceed 50 cm.[19] Six reflecting markers were placed on the subjects' right and left foot to record the gait parameters. Distances between markers always remained below 50 cm. The markers were placed over anatomical landmarks of the foot: two markers on the heels, two markers on the lateral malleolus, two markers on the heads of the second metatarsus. All positions of the markers were carefully checked by the same operator.

Ten single-task tests and 10 dual-task tests were performed in random order. The trials in single- and dual-task conditions were averaged. Under single- and dual-task conditions, the subjects were instructed to walk freely and to look at the red light placed on the second camera in front of them. In dual-task conditions, the subjects walked with a glass of water in their dominant hand and did not look at the glass. The same glass, filled with water 0.5 cm below the brim, was used by all subjects.

The gait parameters measured were cadence (steps/min), walking speed (m/s), stride time (s), step time (s), single-support time (s), stride length (cm) and step length (cm).

Statistical analysis

Values are means ± the standard deviation ($m \pm$ SD). The anthropometric characteristics (age, weight, height) for fallers and non-fallers were compared using Student's unpaired t-test.

In order to compare the single leg balance test, analysis of variance (two-way ANOVA) was performed between fallers and non-fallers for the two conditions (eyes open and eyes closed).

Then, in order to study the parameters of gait between the two groups, an analysis of variance (two-way ANOVA) was performed between fallers and non-fallers for each parameter of the walking in the two conditions (single and dual task conditions). When the ANOVA demonstrated significant difference ($P < 0.05$), the means were compared using the post hoc test Student–Newman–Keuls correction. Statistically significant differences were reported for $P < 0.05$.

Results

Mean age of the 21 fallers (21 women) was 70.43 ± 6.43 years and mean weight and height were 69.57 ± 14.23 kg and 1.60 ± 0.07 m respectively. There were 19 non-fallers (19 women), mean age 67.05 ± 4.81 years and mean weight and height 72.17 ± 15.62 kg and 1.64 ± 0.07 m respectively. There was no significant difference between the anthropometric values for fallers and non-fallers.

The medications taken by the subjects are presented in Table 1. The practice of physical activities of subjects is shown in Table 2. Most of the subjects performed several physical activities independently in their clubs.

Single leg balance test

Fallers placed their foot on the floor 4.0 ± 3.8 times during the eyes-open 30-s single leg balance test and 9.6 ± 5.5 times during the eyes-closed test. Non-fallers placed their feet on the floor 1.1 ± 1.3 times during the eyes-open test and 5.6 ± 1.6 times during the eyes-closed test. The difference between fallers and non-fallers was significant in both conditions ($P = 0.003$) for the eyes-open test and ($P = 0.004$) for the eyes-closed test. Fallers placed their feet on the floor three times more often than the non-fallers under eyes-open conditions and twice as often under eyes-closed conditions.

Gait parameters (Table 3)

Comparison between groups

The cadence, speed, stride times, step times, single-support times, stride lengths and step lengths were not significantly different between fallers and non-fallers under single-task conditions (Table 3).

However, there was a significant difference ($P <$ 0.05) between the fallers and non-fallers under dual-task conditions for cadence, walking speed, stride time, step time and single-support time. The cadence of the fallers was 9 steps/min which was significantly ($P = 0.02$) lower than that for non-fallers. Fallers exhibited significantly

Table 1 Breakdown of medication used between fallers and non-fallers

Medication	Fallers ($N = 21$)	Non-fallers ($N = 19$)
Anti-inflammatory	4	3
Antidepressors	0	2
Antihypertension	10	14
Antalgics	3	0
Metabolic disorders	5	4
Hormone replacement therapy	2	4

N, number of subjects; few subjects took more than one medication.

Table 2 Breakdown of physical activities between fallers and non-fallers

	Frequency (h/week)	Fallers ($N=21$)	Non-fallers ($N=19$)
Walking	2	14	12
Aqua-gymnastics	1	10	9
Gymnastics	1	5	7
Bicycling	2	2	0
Swimming	1	1	1
Tai Chi Chuan	1	0	1
Boules (petanque)	2	1	0
Dancing	2	0	1

N, number of subjects. A few subjects practised more than one physical activity.

($P = 0.034$) slower walking speed (0.12 m/s), significantly ($P = 0.0042$) longer stride time (0.1 s), significantly ($P = 0.02$) longer step time (0.04 s) and significantly ($P = 0.012$) longer single-support time (0.09 s) than non-fallers. Meanwhile, no significant difference for stride and step length were reported ($P > 0.05$).

Comparison within groups

For non-fallers the cadence, speed, stride time, step time, single-support time, stride length and step length were not significantly different between single- and dual-task conditions.

For fallers there were significant differences between single- and dual-task conditions for cadence ($P = 0.011$), walking speed ($P = 0.039$), stride time ($P = 0.007$), step time ($P = 0.008$), single-support ($P = 0.008$), stride length ($P = 0.03$) and step length ($P = 0.04$).

The cadence was significantly slower (9 steps/min) under dual-task conditions than under single-task conditions. Similarly, walking speed was significantly slower (-0.12 m/s) and stride length and step length were significantly shorter (-5.6 cm and -2 cm respectively). Stride time was significantly longer ($+0.1$ s) under dual-task conditions than under single-task conditions. Similarly, step time was significantly longer ($+0.03$ s) and single-support time was longer ($+0.07$ s).

Discussion

Significant differences were demonstrated between healthy elderly fallers and non-fallers performing single leg balance test eyes open and eyes closed. When walking freely under dual-task conditions, fallers and non-fallers displayed significant differences for cadence, walking speed, stride time, step time, single-support time and stride length.

When standing on one foot, fallers touched the floor with the suspended foot more often than did

Table 3 Parameters of walking performing single- and dual-task conditions for the two groups

	Fallers		Non-fallers	
	Single task	Dual task	Single task	Dual task
Cadence (steps/min)	116 ± 14† $P = 0.011$	107 ± 15†*	119 ± 10	116 ± 9* $P = 0.02$
Walking speed (m/s)	1.08 ± 0.30† $P = 0.039$	0.96 ± 0.19†*	1.12 ± 0.35	1.08 ± 0.17* $P = 0.034$
Stride time (s)	1.04 ± 0.13† $P = 0.007$	1.14 ± 0.16†*	1.02 ± 0.09	1.04 ± 0.09* $P = 0.0042$
Step time (s)	0.53 ± 0.06† $P = 0.008$	0.56 ± 0.07†*	0.51 ± 0.06	0.52 ± 0.05* $P = 0.02$
Single support (s)	0.48 ± 0.08† $P = 0.008$	0.55 ± 0.09†*	0.48 ± 0.05	0.46 ± 0.06* $P = 0.012$
Stride length (cm)	113.4 ± 28.5† $P = 0.03$	107.8 ± 16.2†	109.3 ± 30.3	108.5 ± 18.4
Step length (cm)	55.8 ± 14.3† $P = 0.04$	53.8 ± 10.7†	59.7 ± 22.1	61.3 ± 16.3

Values are mean ± SD; Single task: spontaneous walking; dual task: spontaneous walking with a full glass of water in dominant hand.
*$P < 0.05$ significant intergroup differences in dual task condition; †$P < 0.05$ significant intragroup differences between single and dual task.

non-fallers in both the eyes-open and eyes-closed conditions. Vellas *et al.*[16] and Hurvitz *et al.*[18] recorded that fallers touched the floor with their opposite foot more frequently and were unable to stand on one foot for 30 s with their eyes open. The single leg balance test thus reveals a significant difference between fallers and non-fallers and is a suitable test for identifying balance disorders in healthy elderly subjects. Nevertheless, although this test could be an indicator of balance disorders, it may not be totally pertinent because falling is a dynamic problem whereas standing on one foot is a static posture. Moreover, walking differs from standing balance in that the centre of gravity constantly moves beyond the base of support, so that the supporting leg can do little to alter this motion.[20] Thus the daily task of dynamic balance could be usefully assessed to predict falls in healthy seniors.

Our analysis of walking failed to demonstrate a significant difference between healthy elderly fallers and non-fallers walking freely under single-task conditions. Earlier studies contrary to our results that have demonstrated significant differences in gait analysis for fallers, with shorter stride and step lengths, slower walking speed and increased double support time, were conducted in institutionalized or frail elderly subjects.[5–7,21] These studies, in frail elderly subjects, demonstrated significant impairment in several gait parameters under single-task conditions, so these opposite results could be due to the subjects themselves. Differences in the subjects' age, general status (frail versus healthy) and physical activity (light activities practised regularly by our subjects) could explain the differences between these earlier results and our own. Indeed, the subjects in most of the published studies were 80–90 years old, sedentary and institutionalized, whereas our subjects were 61–73 years old, healthy and independent. Hence, in view of our results, we can hypothesize that a single leg balance test and a free walking test under single-task conditions are not suitable for predicting falls in healthy elderly subjects.

Our results demonstrate that healthy elderly subjects, whether fallers or not, are not disturbed by the single-task condition, whereas fallers present significant walking disorders under the dual-task condition. Their cadence, walking speed, stride length and step length are significantly decreased and their stride time, step time, and single-support time are significantly longer under dual-task conditions than under single-task conditions. Lindenberger *et al.*[22] demonstrated that elderly adults had more difficulty memorizing words while walking than did young adults. Moreover, it is assumed that performing a task requires a given portion of the capacity of the central nervous system, and that if two tasks performed simultaneously require more than the total capacity, the performance on one or both tasks will be affected negatively.[23,24] Our results in fallers in dual-task conditions, with the second task being a motor task, are in line with the reports of Lindenberger *et al.*,[22] Kahneman[23] and Wickens,[24] where it was shown that dual tasks can interfere with walking. While the nature of the second task was different (memorizing task versus motor task), it seems to have had a similar impact but with different mechanisms, modifying the walking pattern or stopping walking.

Deficient structure and functioning of peripheral systems (vestibular and ocular system, proprioception) are certainly important factors since balance is more affected in the elderly than the young adult when sensory, proprioceptive or both inputs are altered.[25–28] However, recent experiments with elderly persons having a history of falls[29,30] provide additional evidence for the suggestion that higher integrative levels have a predominant role in postural control.[31] Thus, we can hypothesize that the structure and function of peripheral systems could be deficient in elderly fallers, making it more difficult to process two tasks simultaneously. This could lead to a modification of gait parameters and favour falls. Identifying which parameters are modified could be useful in developing a dual-task (motor and cognitive tasks) training strategy designed to prevent falling.

Our data from dual-task tests show that gait parameters are significantly altered in fallers but that there is no such change in non-fallers. Bowen *et al.*[32] demonstrated that adding a verbal task during walking decreases walking speed and increases the duration of the double-support phase. However, the results of Bowen *et al.*[32] focused on stroke victims, not healthy subjects, and the nature of the second task is different (verbal vs. motor). Kahneman[23] has suggested that the nature of the tasks competing for attention affects the degree of

Clinical messages

- The single leg balance test reveals a significant difference between fallers and non-fallers.
- For the gait parameters measured under single task condition, no significant difference appears between fallers and non-fallers.
- The gait parameters of fallers were disturbed by the dual task, whereas those of the non-fallers were not.

impact. Thus, the results of Bowen *et al*.[32] cannot be extended to the normally healthy population. It has also been suggested by Bronstein *et al*.[33] that the lack of adaptation to the second task is also illustrative of a more primitive form of postural control. This leads us to the hypothesis that healthy elderly fallers could lack capacity for adequate adaptation, disclosing the age-related fragility of the gait pattern expressed by changes in the different gait parameters under dual-task conditions.

In conclusion, significant differences were found between fallers and non-fallers when they performed a single leg balance test and when they walked freely under dual-task conditions, no difference being observed when they walked under single-task conditions. Gait analysis under dual-task conditions appears to unmask subclinical gait impairments which could provoke falls. A single leg balance test and gait analysis under dual-task conditions could be useful for detecting subjects prone to falls. Hence, healthy elderly subjects exhibiting abnormal gait parameters when performing dual tasks might benefit from an individualized dual-task exercise programme designed to improve the abnormal parameters and thus prevent falls, enabling them to maintain their social independence.

References

1 Sudarsky L. Geriatrics: gait disorders in the elderly. *N Engl J Med* 1990; **322**: 1441–46.
2 Tinetti ME. Performance oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986; **34**: 119–26.
3 Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med* 1988; **319**: 1701–707.
4 Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people. *Arch Intern Med* 1989: 1628–33.
5 Maki BE. Gait changes in older adults: predictors of falls or indicators of fear. *J Am Geriatr Soc* 1997; **45**: 313–20.
6 Cho CY, Kamen G. Detecting balance deficits in frequency fallers using clinical and quantitative evaluation tools. *J Am Geriatr Soc* 1998; **46**: 426–30.
7 Medell JL, Alexander NB. A clinical measure of maximal and rapid stepping in older women. *J Gerontol A Biol Sci Med* 2000; **55**: 429–33.
8 Woollacott MH, Shumway-Cook A, Nashner LM. Aging and posture control: changes in sensory organization and muscular coordination. *Int J Aging Hum Dev* 1986; **23**: 97–114.
9 Podsiadlo D, Richardson S. The timed 'up and go': a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc* 1991; **39**: 142–48.
10 Geurts AC, Mulder TW, Nienhuis B, Rijken RA. Dual-task assessment of reorganization in persons with lower limb amputation. *Arch Phys Med Rehabil* 1991; **72**: 1059–64.
11 Stelmach GE, Zelaznik HN, Lower D. The influence of ageing and attentional demands on recovery from postural instability. *Age Ageing* 1990; **2**: 155–61.
12 Cordo P, Nashner L. Properties of postural adjustments associated with rapid arm movements. *J Neurophysiol* 1982; **47**: 287–302.
13 Horak FB, Anderson M, Esselman P, Lynch K. The effect of movement velocity, mass displaced and task certainly on associated postural adjustments made by normal and hemiplegic individuals. *J Neurol* 1984; **47**: 1020–28.
14 Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the timed up and go test. *Phys Ther* 2000; **80**: 896–903.
15 Lundin-Olsson L, Nyberg L, Gustafson Y. Attention, frailty, and falls: the effect of a manual task on basic mobility. *J Am Geriatr Soc* 1998; **46**: 758–61.
16 Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ. One leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc* 1997; **45**: 735–38.
17 Folstein MF, Folstein ME, Mc Hugh PR. 'Mini Mental State', a practical method for grading the

cognitive state of patient for the clinician. *J Psychiatr Res* 1975; **12**: 189–98.
18 Hurvitz EA, Richardson JK, Werner RA, Ruhl AM, Dixon MR. Unipedal stance testing as an indicator of fall risk among older outpatients. *Arch Phys Med Rehabil* 2000; **81**: 587–91.
19 Richards JG. The measurement of human motion: a comparison of commercially available systems. *Hum Mov Sci* 1999; **18**: 589–602.
20 Winter DA. *The biomechanics and motor control of human gait: normal, elderly and pathological*, second edition, Waterloo Biomechanics, 1991.
21 Wolfson L, Whipple R, Amerman P, Tobin JN. Gait assessment in the elderly rating scale and its relation to falls. *J Gerontol* 1990; **45**: 12–19.
22 Lindenberger U, Marsiske M, Baltes B. Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychol Aging* 2000; **15**: 417–36.
23 Kahneman D. *Attention and effort*. Prentice-Hall, 1973.
24 Wickens CD. Processing resources in attention. In Parasuraman R, Davies DR eds. *Varieties of attention*. Academic Press, 1984: 63–102.
25 Teasdale N, Stelmach GE, Breuing A. Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. *J Gerontol* 1991; **46**: 238–44.
26 Teasdale N, Bard C, Larue J, Fleury M. On the cognitive penetrability of posture control. *Exp Aging Res* 1993; **19**: 1–13.
27 Hay L, Bard C, Fleury M, Teasdale N. Availability of visual and proprioceptive afferent messages and postural control in the elderly. *Exp Aging Res* 1996; **108**: 129–39.
28 Simoneau M, Teasdale N, Bourdin C, Bard C, Fleury M, Nougier V. Aging and postural control: postural perturbation caused by changing the visual anchor. *J Am Geriatr Soc* 1999; **47**: 235–40.
29 Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol* 1997; **52**: 232–40.
30 Woolley SM, Czaja SJ, Drury CG. An assessment of falls in elderly men and women. *J Gerontol* 1997; **52**: 80–87.
31 Stelmach G, Teasdale N, DiFabio R, Phillips J. Age related decline in postural control mechanisms. *Int J Aging Hum Dev* 1989; **29**: 205–23.
32 Bowen A, Wenman R, Mickelborough J, Foster J, Hill E, Tallis R. Dual task effects of talking while walking on velocity and balance following a stroke. *Age Ageing* 2001; **30**: 319–23.
33 Bronstein AM, Hood JD, Gresty MA, Panagi C. Visual control of balance in cerebellar and parkinsonian syndrome. *Brain* 1990; **113**: 767–79.