Comparative study of dynamic balance in fallers and non-fallers

Vénéra Ghulyan [1, 2], Michel Paolino [1]

[1] Clairval Hospital - Marseille - France
[2] Yerevan State University - Armenia

ABSTRACT

Objective: Postural instability and falls are common reasons for physician visits among elderly patients. Our objective was to identify posturography parameters that are relevant for evaluating postural stability in elderly patients and for identifying individuals at high risk of falls.
Material and methods: Dynamic posture was evaluated using the SPS platform (SYNAPSYS) in 202 patients with postural instability, including 59 with and 143 without a history of falling. All study patients were older than 60 years. Ramp and sinusoid stimulations were used with the eyes open and closed, in random order, to determine stability limits.
Results: Postural adjustments and voluntary movements were altered in the fallers compared to the nonfallers. Control of lateral stability was the most severely impaired component of postural control in the fallers.
Conclusion: This study identified parameters for generating and measuring postural responses in order to separate fallers and nonfallers among elderly patients with postural instability. Our results could be used to develop a protocol for objectively evaluating the risk of falls in elderly patients with postural instability.

(Fr ORL - 2005 ; 88 : 89 - 96)

Keywords: Falls, Postural instability, Elderly, Dynamic posturography, Translational platform.

Submitted for publication: febrary 2005
Accepted for publication: june 2005

Corresponding author: Michel Paolino
Service d’Exploration Oto-Neurologique
Hôpital Privé Clairval
317 Bd du Redon - 13009 Marseille - France
e-mail: michel.paolino@wanadoo.fr

INTRODUCTION

Aging is associated with loss of function of sensory systems [1-5], peripheral muscle effectors [6], and central structures [7-8] involved in postural control. The resulting balance disorders often cause falls [9]. Poor balance is a well-documented risk factor for falls [10-11]. The risk of falling in patients with balance disorders is high during events that require rapid postural adjustments. Early detection of abnormalities in dynamic postural control followed by appropriate rehabilitation, environment modification, and recommendations may help to prevent falls, thereby substantially improving the quality of life of elderly individuals.

We investigated dynamic postural control in elderly patients who presented with gradual-onset chronic postural instability carrying a possible risk of falling. Dynamic postural control was compared in patients with and without a history of falling.

The objective of this study was to identify the best dynamic posturography parameters for separating fallers from nonfallers. Subsequently, we will use the findings from this comparative study to develop a test protocol for evaluating the risk of falls in elderly patients with chronic postural instability.

MATERIALS AND METHODS

Patients

We studied 202 patients older than 70 years of age who presented with permanent postural instability of gradual onset. Among them, 143 patients with a mean age of 72.9±6.6 years had no history of falls and 59 with a mean age of 74.5±9.6 years (nonsignificant difference; F=0.86; P<0.35) had a history of at least two spontaneous falls within a year with no loss of consciousness or detectable cause (e.g., sudden paralysis, seizure, or heavy drinking). Medications included mild sedation (e.g., not more than 3 mg of bromazepam/day) in 43% of the study patients. Women contributed 76% of the fallers compared to only 56% of the nonfallers.

Institutionalization, use of walking aids, and cognitive dysfunction with a Mini-Mental Score 24 were exclusion criteria. Patients were excluded if they had a recent history of fractures or sprains. We also excluded patients with known vestibular disease responsible for abnormal bithermal caloric tests (Freyss diagram asymmetry greater than 15% based on the slow phase velocity of the nystagmus) or asymmetric nystagmus during rotation (directional preponderance >1 °/s). Patients with uncorrected visual disorders were excluded, as were patients with neurological, metabolic, vascular, or psychiatric disease.

Patients meeting inclusion and exclusion criteria were enrolled at our outpatient clinic, where they sought advice of their own accord or upon referral by another physician.

Translational platform

Dynamic postural control was evaluated using the SPS (SYNAPSYS, Marseille, France) platform to induce destabilizing perturbations. Responses designed to restore balance are assessed based on measurements of pressure center displacements, as described in detail elsewhere [12].

Posturography protocol

Translational ramp and sinusoid movements were used, and stability limits were evaluated for each patient. During ramp stimulations, recording duration was 51.2 s, during which six 0.1-m/s translations (three forward and three backward) spaced 8 seconds apart were delivered.

Sinusoidal stimulations lasting 25.6 s were delivered at frequencies of 0.25 Hz and 0.50 Hz. All translational tests were done in the anteroposterior plane with the eyes open and closed. They were delivered in random order. The patients were told to keep their balance without moving their feet. Stability limits were evaluated with the eyes open and the platform immobile by asking the patients to sway as far as possible in all directions while keeping their body straight and without moving their feet or falling. With this method, the ankle strategy is used to maintain balance (upside down pendulum).

Study parameters

Postural responses to ramp translations were quantified based on energy and time to restabilization. For sinusoidal translations, the study parameters were gain and postural response phase. All parameters evaluating postural responses were determined for pressure center displacements in the stimulation plane (Y) and the orthogonal plane (X). The method used to compute these parameters has been described elsewhere [12]). Limits of stability were assessed based on the area of the stabilogram, i.e., of the shape containing the maximum voluntary center-of-pressure displacement points (Smax).

Statistics

The parameters collected during ramp and sinusoidal stimulations were evaluated by analysis of variance (ANOVA) with fallers vs. nonfallers as the intergroup factor and eyes open vs. eyes closed as the intragroup factor; for sinusoidal stimulations, stimulation frequency (0.25 vs. 0.50 Hz) was also an intragroup factor. Smax was evaluated by ANOVA with fallers vs. nonfallers as the only factor. Tukey's HSD post-hoc test was used for pairwise comparisons. P values smaller than 0.05 were considered significant.

RESULTS

Ramp stimulations

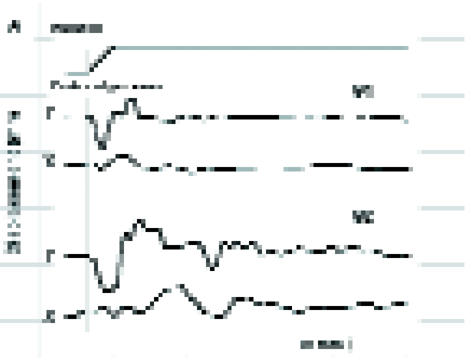
Group and visual condition were the main sources of significant variations in energy and restabilization time in X and Y (Table I).

Table I: Analysis of variance of the data from the ramp stimulations in 59 fallers and 143 nonfallers.
All patients were older than 60 years and had chronic instability.
The values of F and P show that falling history (faller vs. nonfaller) and visual condition (eyes open vs. eyes closed) were the main sources of significant variation in energy and time, in both Y and X.

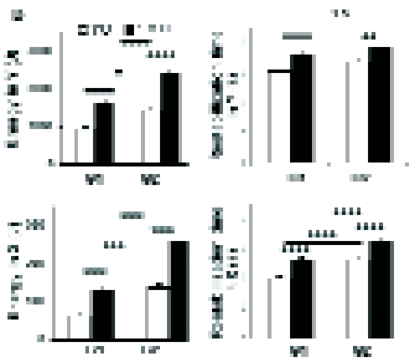
Sources of variation	Energy Y	Energy X	Times Y	TimesX
Groupe	32,16 (0,05)	106,08 (0,05)	7,99 (0,05)	45,09 (0,05)
Eyes open vs. Eyes closed	58,16 (0,05)	93,57 (0,05)	45,85 (0,05)	43,59 (0,05)

Figure 1A shows the Y and X stabilograms of two representative patients, one from each group, during 0.1-m/s ramp translations with the eyes open. The histograms in Figure 1B show that all study parameters were altered in fallers and in the eyes-closed condition. Interestingly, dynamic posture abnormalities in the fallers were greater in the plane perpendicular to the stimulation plane (X). Thus, in the fallers testing the eyes-open condition, anterior-posterior translations were associated with a 107% increase in energy

Figure 1: Postural responses to ramp stimulations.
A: *Postural responses in two representative patients, a faller and a nonfaller, to anterior ramp translation at 0.1 m/s, with the eyes open. Displacements of the center of pressure (ordinate, in mm) are far greater and restabilization time (abscissa, in s) is longer in the faller, in both Y and X.*



B: *Mean values (±sem) of energy expenditure during postural responses (in joules) and of the restabilization time (in s) in the two groups. Energy in both planes and restabilization time in X differentiated the two groups, both with the eyes open (EO) and with the eyes closed (EC).*



**P<0.05, **P<0.005, and ***P<0.0005, respectively* in X (P<0.0005) compared to same-age controls and with an only 52% increase in Y (P<0.05). A similar pattern was noted in the eyes-closed condition: the increase was 94% in X (P<0.0005) and 43% in Y (P<0.00005). Furthermore, the restabilization time was significantly longer in the fallers in X, in both the eyes-open and the eyes-closed conditions (32% [P<0.00005] and 24% [P<0.00005], respectively).

The restabilization time in Y was not significantly different in the fallers and nonfallers, with the eyes open or closed (Figure 1). However, the restabilization time in Y could not exceed 8 s, as this was the time separating two translations. In both groups, most of the patients were unable to recover their balance within 8 s. For instance, in the eyes-closed condition, restabilization before the next translation was achieved by the nonfallers in only 10% of cases and by the fallers in only 6% of cases.

Sinusoid stimulations

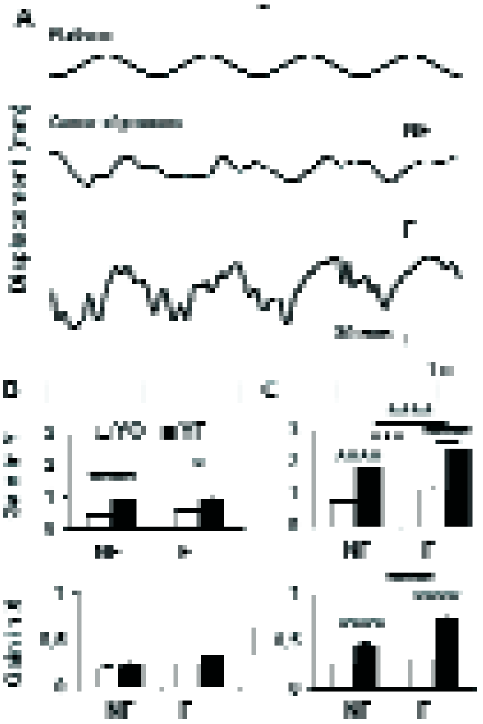
Table II shows the results for gain in the Y plane. Group, eyes open vs. closed, and stimulation frequency were the main sources of variation. Numerous interactions were found between the factors. Results were similar for gain in the X plane.

Table II: Analysis of variance of the data from the sinusoidal stimulations in 59 fallers and 143 nonfallers.
All patients were older than 60 years and had chronic instability. The results of the ANOVA show that falling history (faller vs. nonfaller), visual condition (eyes open vs. eyes closed), and stimulation frequency (0.25 Hz vs. 0.50 Hz) were sources of significant variation that differentiated individuals based on gain (in Y) of postural responses.

Sources of variation	F	*p*
Group	52,03	0,05
Vision (eyes open vs. closed)	359,85	0,05
Frequency 0.25 Hz vs. 0.50 Hz	410,05	0,05
Group X Vision	1,13	0,30
Group X Frequency	15,30	0,05
Vision X Frequency	79,87	0,05

Figure 2 shows the gain increases associated with a history of falling, the eyes-closed condition, and a higher stimulation frequency. Sinusoid stimulation at 0.50 Hz was associated with significantly different gain values between fallers and nonfallers in both the eyes-closed and the eyes-open condition. Thus, the 0.50 Hz frequency may be more useful than the 0.25 Hz frequency for detecting patients at high risk for falls (Figure 2).

Figure 2: Postural responses to sinusoidal translations.
A: *Postural responses in two representative patients, a faller and a nonfaller, to sinusoidal translations at a frequency of 0.50 Hz, with the eyes open. The mean values (±sem) of gain in response to sinusoidal translations at 0.50 Hz (**C**) are significantly different between the two groups; the difference is not significant with the 0.25 Hz stimulation (**B**).*



**P<0.05 and ***P<0.0005 between the group of fallers and the group of nonfallers*

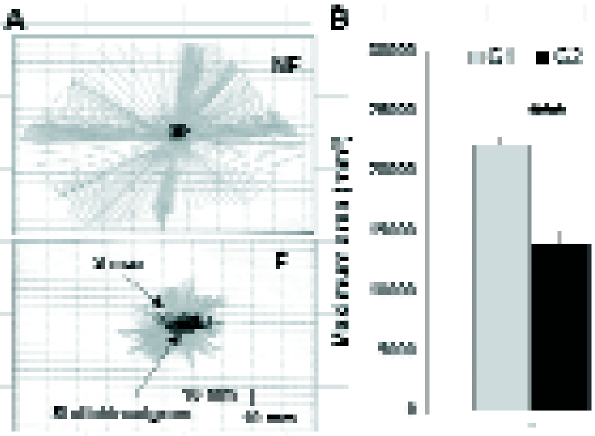
No significant differences in phase were found between the fallers and the nonfallers.

Limits of stability during voluntary sway

ANOVA showed that group (fallers vs. nonfallers) was a significant source of variation in Smax [F1,18=31.84; P<0.0005]. Mean surface area in the fallers was decreased by 58% (P<0.00005) compared to the nonfallers. Figure 3 shows the results in two representative patients, one from each group.

Figure 3: Evaluation of the limits of stability.
A: *Statiokinesiogram (center-of-pressure displacements in the upright position define this term relative to the stabilogram – not done in the text) and limits of stability (gray area) in two representative patients, a faller and a nonfaller. The limits of stability were evaluated based on the surface area of the maximum voluntary displacements of the center of pressure (Smax).*

B: *Mean (±sem) Smax values in the fallers and nonfallers.*



****P<0.0005*

DISCUSSION

Ramp stimulation

Overall, ramp stimulation caused destabilization in nonfallers and marked destabilization in fallers. During ramp stimulation, the body is subjected to accelerations related to the beginning and end of the platform translation. Rapid postural adjustments are needed to prevent falling. The effectiveness of postural adjustments declines with normal or abnormal aging of the postural system [12-13]. In addition, the appropriateness of postural adjustments may be altered by anxiety related to fear of falling, which is typically marked in patients with a history of falls [14].
Postural responses in the fallers were more severely impaired in the perpendicular plane (X) than in the stimulation plane (Y). Thus, disorders in fallers predominantly affected the control of lateral stability (as assessed by energy and restabilization time in the X plane).

This finding supports previous evidence from static posturography studies that lateral displacements of the pressure center provide the best information on balance recovery and fall risk in older individuals; in contrast, the anteroposterior component is consistently altered and fails to discriminate between individuals at high risk and low risk of falls [15] or between elderly individuals with and without a history of falls [16].
In bipedal stance, side-to-side swaying reflects the ability to distribute the body weight evenly between the two lower limbs. The muscles involved are the hip abductors/adductors and the ankle pronators/supinators. Anteroposterior sway, in contrast, reflects variations in the activity of the ankle flexors [17]. Decreased effectiveness of postural responses in elderly patients with instability may stem from impaired central coordination of these two motor systems involved in postural control. Furthermore, asymmetric muscle strength loss in the lower limbs in elderly individuals is more marked in fallers than in nonfallers [18] and may explain the loss of lateral postural control. Rehabilitation should seek to restore symmetry.
Impairment of lateral postural control is a major risk factor when elderly individuals are faced with the destabilizing events that are common in everyday life (slippery floor or acceleration imposed by external factors for instance). Good lateral postural control is essential to making a protective step in response to destabilizing events [13-19]. This critical component of the balance-preservation response is markedly altered in elderly fallers. Impaired lateral postural control may contribute to recurrent falling.
Thus, our study showed that parameters characterizing lateral balance in X (energy and restabilization time) and energy in Y were the best variables for discriminating between fallers and nonfallers.

Sinusoidal stimulation

Sinusoidal stimulation provides two parameters for evaluating postural control, gain and phase. An increase in gain associated with a decrease in phase has been reported to indicate posture control impairment [12].
In our study, however, phase was similarly reduced in the two groups of elderly patients with chronic instability and therefore failed to discriminate between fallers and nonfallers. Thus, during sinusoidal translations at 0.25 Hz, sway was in phase with the stimulus. Absence of phase lag between the response and the stimulus has been reported in children with postural system immaturity [20] and indicates postural control impairment in elderly patients.
Gain, in contrast, showed differences between fallers and nonfallers, the eyes-open and eyes-closed conditions, and stimulation frequency (0.25 Hz vs. 0.50 Hz).

Limits of stability

Determination of stability limits is a simple test that is widely used for neurological, geriatric, and posturography evaluations. Reaction time, velocity of center-of-gravity displacements, directional control, and other parameters are often used to determine stability limits [21-22]. However, correlations linking these parameters to the risk of falling are weak. We measured the area of the maximal voluntary displacements of the center of pressure (Smax). In our population of elderly patients with chronic instability, this parameter was significantly reduced in the fallers compared to the nonfallers. The smaller Smax indicated decreased capacity for postural adjustments and/or voluntary movements, most notably in patients who were afraid they might fall. The decrease in Smax probably reflects difficulties met by older individuals in using the ankle strategy to maintain balance [23]: decreases in both range of motion and power of dorsal and plantar flexion at the ankle were significantly more marked in fallers than in nonfallers in earlier studies [24-25].

CONCLUSION

Our results show impaired dynamic postural control in fallers compared to nonfallers. The difference between the two groups was found both during destabilizing perturbations that required automatic adjustments to prevent falls and during voluntary movements. In addition, impairments in dynamic postural control in fallers were greatest for lateral balance. Thus, we identified a number of dynamic posturography parameters that were significantly different in fallers and nonfallers. These results could be used to develop a posturography protocol specifically designed to assess the risk of falling in elderly patients with chronic instability.

REFERENCES

1. Sekuler R, Hutman LP. Spatial vision and aging. I: Contrast sensitivity. J Gerontol. 1980; 35: 692-699.

2. Skinner HB, Barrack RL, Cook SD. Age-related decline in proprioception. Clin Orthop. 1984; 184: 208-211.

3. Paige GD. Senescence of human visual-vestibular interactions. 1. Vestibulo-ocular reflex and adaptive plasticity with aging. J Vestib Res. 1992; 2: 133-151.

4. Igarashi M, Saito R, Mizukoshi K, Alford BR. Otoconia in young and elderly persons: a temporal bone study. Acta Otolaryngol Suppl. 1993; 504: 26-29.

5 Baloh RW, Ying SH, Jacobson KM. A longitudinal study of gait and balance dysfunction in normal older people. Arch Neurol. 2003; 60: 835-839.

6. Lexell J. Human aging, muscle mass, and fiber type composition. J Gerontol A Biol Sci Med Sci. 1995; 50: 11-16.

7. Camicioli R, Moore MM, Sexton G, Howieson DB, Kaye JA. Age-related brain changes associated with motor function in healthy older people. J Am Geriatr Soc. 1999; 47: 330-334.

8. Whitman GT, Tang Y, Lin A, Baloh RW, Tang T. A prospective study of cerebral white matter abnormalities in older people with gait dysfunction. Neurology 2001; 57: 990-994.

9. Bloem BR, Steijns JA, Smits-Engelsman BC. An update on falls. Curr Opin Neurol. 2003; 16: 15-26.

10. Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. J Gerontol. 1989; 44: M112-117.

11. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. Can J Public Health 1992; 83 Suppl 2: S7-11.

12. Lacour M. Posture et équilibre : Nouvelles méthodes de traitement du signal posturographique. Edition Solal, Marseille. Evaluation des déficits posturaux de sujets âgés ou pathologiques: Intérêt de nouvelles méthodes de traitement du signal stabilométrique: Ghulyan V, Paolino M, Lopez C, Dumitrescu M, Lacour M. 2004, Fr ORL - 2005 ; 88 : 97-102.

13. Maki BE, Edmondstone MA, McIlroy WE. Age-related differences in laterally directed compensatory stepping behavior. J Gerontol. 2000; 55: M270-277.

14. Vellas BJ, Wayne SJ, Romero LJ, Baumgartner RN, Garry PJ. Fear of falling and restriction of mobility in elderly fallers. Age Ageing 1997; 26: 189-193.

15 Williams HG, McClenaghan BA, Dickerson J. Spectral characteristics of postural control in elderly individuals. Arch Phys Med Rehabil. 1997; 78: 737-744.

16. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Gerontol. 1994; 49: M72-84.

17. Winter D, Prince F, Frank J, Powell C, Zabjek K. Unified theory regarding A/P and M/L balance in quiet stance. J Neurophysiol. 1996; 75: 2334-2343.

18. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age Ageing 2002; 31: 119-125.

19. Rogers MW, Hedman LD, Johnson ME, Cain TD, Hanke TA. Lateral stability during forward induced stepping for dynamic balance recovery in young and older adults. J Gerontol A Biol Sci Med Sci. 2001; 56: M589-594.

20. Berger W, Discher M, Trippel M, Ibrahim IK, Dietz V. Developmental aspects of stance regulation, compensation and adaptation. Exp Brain Res. 1992; 90: 610-619.

21. Brauer SG, Burns YR, Galley P. A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. J Gerontol A Biol Sci Med Sci. 2000; 55: M469-476.

22. Wallmann HW. Comparison of elderly nonfallers and fallers on performance measures of functional reach, sensory organization, and limits of stability. J Gerontol A Biol Sci Med Sci. 2001; 56: M580-583.

23. 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.

24. Lee LW, Kerrigan DC. Identification of kinetic differences between fallers and nonfallers in the elderly. Am J Phys Med Rehabil. 1999; 78: 242-246.

25. Sieri T, Beretta G. Fall risk assessment in very old males and females living in nursing homes. Disabil Rehabil. 2004; 12: 718-723.