BIOMECHANICAL ANALYSIS OF EQUILIBRIUM IN THE ELDERLY

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ABSTRACT

Objective: To analyze the biomechanical characteristics of balance in elderly people, based on pressure center oscillation in five foot positions, carried out with open and closed eyes. The sample was made up of 20 elderly people. Data were collected using a force platform (AMTI® OR6-5) adjusted to the frequency of 100Hz over 60 seconds. Methods: Data were filtered using a 4th order Butterworth filter and FFT (Fast Fourier Transform) as well as a 20 Hz low pass filter. The Kruskal-Wallis and Mann Whitney statistical tests were applied. Results: The cases with the least stability were the positions with eyes closed and those with a reduced sustentation polygon. The positions that presented the greatest stability were the feet 10cm apart at an angle of 45°, a free standing position, and that with feet parallel and 10cm apart, all with the eyes open. Conclusion: Visual feedback contributed to posture control.

Keywords: Balance. Elderly. Biomechanics.

Citation: *Cruz A, Oliveira EM, Melo SIL. Biomechanical analysis of equilibrium in the elderly. Acta Ortop Bras. [online]. 2010; 18(2):96-9. Available from URL: http://www.scielo.br/aob*

INTRODUCTION

The human body can be defined as a complex system of jointed segments in static or dynamic balance, where movement is caused by internal forces acting outside the joint axis, provoking angular displacements of the segments and by forces outside the body.[1]

It is also characterized as an unstable structure, in the format of a pendulum that balances itself on a very small base, whereas this configuration leads us to the need for active correction.[2]

Thus in adopting the upright biped posture, we have been challenged by the force of gravity to maintain the equilibrium of the body on a small supporting area delimited by the feet.[3]

Yet balance control depends on three perceptive systems: the vestibular, the proprioceptive and the visual.[4] The first is responsible for fast angular accelerations and decelerations, and is thus the most important for maintenance of the upright posture; the proprioceptive system allows perception of the body and limbs in space in a relationship of reciprocity; and the visual systems offers a reference for verticality, as it has two supplementary sources of information: vision, which situates the individual in his environment through retinal coordinates, and ocular motricity, which situates the eye in the orbit through cephalic coordination.[4]

Balance depends not only on the integrity of these systems, but also on sensory integration inside the central nervous system, which involves visual and spatial perception, effective muscular tonus, which adapts quickly to alterations, muscular strength and joint flexibility.[4] Sensory organization consists of the capacity of the CNS to select, supply and combine the vestibular, visual and proprioceptive stimuli.[4]

With the increase in age these postural control abilities are altered, favoring deficits in these adjustments. These alterations result from a decrease in the information conduction velocity, and in the processing of responses, which as they are slow and inadequate, generate situations of instabilities, increasing the predisposition to falls.[5] After all, aging is not just a passage through time, but also the accumulation of biological events that occur over time.[6]

However, the problems faced by the elderly begin when there is loss in the balance control process,[2] as the decline of postural control capabilities is a very serious and common problem in this population, with severe effects on their quality of life, besides entailing a high social cost for community.[1]

That being the case, the incidence of falls becomes a common and devastating event in elderly people, and although it is not an inevitable consequence of aging, it can signal the start of fragility or indicate an acute disease.[7] Statistically, problems of falls according to Hobeika[8] affect 65% of individuals over 60 years of age resulting from loss of balance and dizziness.

Therefore special emphasis is placed on the importance of investigating how balance behaves in this population, inasmuch as these results found could help in the application of proprioceptive training geared toward the prevention of falls and consequently of other pathologies resulting from these.

All the authors declare that there is no potential conflict of interest referring to this article.

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Article received on 10/14/08 and approved on 06/29/09

It is important to rouse the interest of the different specialists in the study of balance and posture in the elderly and for this reason it is extremely important to conduct research involving this population. As affirmed by Duarte et al.[3], to correct balance control problems, it is first necessary to identify where the difficulty lies.

In view of the foregoing and considering the shortage of studies relating to balance in the elderly, we consider justified the performance of this study with the general objective of evaluating the biomechanical characteristic of balance among elderly individuals (aged over 60 years) based on the variables of Center of Pressure Oscillation - COP considering the different foot placement positions with eyes open and with eyes closed.

MATERIALS AND METHODS

It is an exploratory descriptive survey,[9] conducted in the Biomechanics Laboratory of CEFID/UDESC, in which 20 elderly people took part, 10 men and 10 women, aged between 63 and 84 years (mean age 71.8 + 6.03 years), residents of the micro region of Greater Florianópolis/SC, selected by intentional non-probabilistic sampling. These individuals fulfilled the criterion of absence of problems in the visual, auditory, vestibular and musculoskeletal systems, diagnosed clinically by specialists.

After approval by the Institutional Review Board - CEPSH of UDESC on 4/1/2005, the data gathering process was initiated with the adoption of a pre-established routine. A questionnaire was initially applied to verify characteristics of the elderly people such as age, gender, stature, mass and state of health, followed by the performance of the cerebellar tests[10] (Romberg's Test and Finger-Nose Test) and the cranial nerve tests[10] (Deviation Test and Pointing Wrong Test).

Finally the participants went through with the acquisition of data on the variables of Center of Pressure Oscillation (COP), using an extensometric force platform AMTI OR6-5 with sampling rate of 100 Hz at a time of 60s as presented in Figure 1. A visual target was positioned at the height of the eyes of each individual for this acquisition, at a distance of 3 meters.[11]

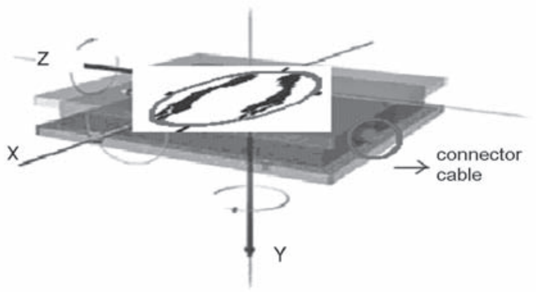

Figure 1 – *Positioning of the feet on the Force Platform*[11]

The following variables were selected for this study: Mean Displacement of COP in the anteroposterior direction (MDAP) and in the laterolateral direction (MDLL), Maximum Displacement of COP in the anteroposterior direction (MXAP) and in the laterolateral direction (MXLL), Displacement Area (ellipse 95%) of COP (AREA) and Mean Velocity of COP in the anteroposterior direction (VMAP) and in the laterolateral direction (VMLL).

For acquisition of the data of the COP variables on the Force Platform, the subjects were tested in five feet placement positions (Figure 2) and two visual conditions, both distributed randomly. The positions adopted were: P1 (feet together and parallel); P2 (ankles together and forefeet apart and at an angle of 45º); P3 (feet at a distance of 10cm and parallel), P4 (feet at a distance of 10cm and forefeet at an angle of 45º), and finally P5 (position found most comfortable) called free position, the only position not established in advance. All these positions were tested with eyes open and also with eyes closed.

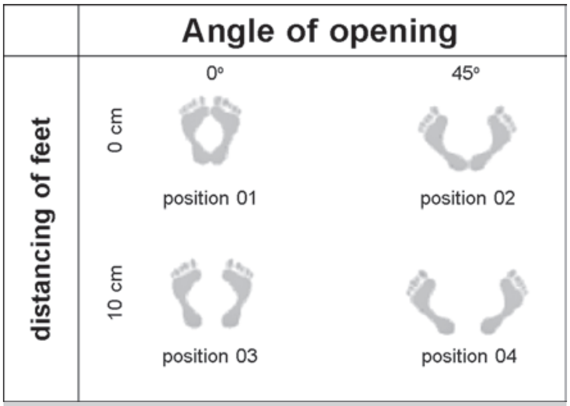

Figure 2 – *Pre-established positioning of the feet*[11]

The data were processed and exported from the Peak Motus System in the form of Excel worksheets, for data handling in the Matlab 6.5 program and afterwards in the SPSS 13.0 program.

The data were analyzed in a pre-established routine in the MATLAB 6.5 program in an individual process through a descriptive statistic (variation coefficient in percentage % and standard deviation) for the variables selected, whereas for the speeds and the displacements, the mean and the maximum value were calculated before the processing of the descriptive statistic.

The Kolmogarov-Smirnov and Shapiro-Wilk tests were used to verify whether the data were normally distributed. As the results did not present normal distribution, the Kruskal Wallis test was used for the comparison between the positions and visual conditions to compare the different positions and the Mann Whitney test to compare the visual condition. The significance level adopted for this study was $p<0.05$.

RESULTS

The Kruskal Wallis test was used to compare the evidence of the COP variables among the different foot placement positions, with eyes open and with eyes closed. It was also verified whether there was a significant relation between the COP variables and the visual condition.

The results of the comparison among the five foot placement positions with the COP variables can be observed in Tables 1 and 2.

Analyzing the results contained in Table 1, it is verified that: a) *with eyes open* there were statistically significant differences for the variables ellipse area, amplitudes and displacement speeds. In decreasing order of the mean values of these variables for the different positions, it is perceived that the greatest differences are respec-

Table 1 – *Comparison of the COP variables among different orthostatic positions, with eyes open*.

		Eyes Open			
Variable	**Positions**	$\overline{X}$ **posts**	$\overline{X}^2$	**gl**	P
	Position1	21.7			
	Position2	65.1			
MDAP	Position3	54.2	27.3	4	0.0
	Position4	59.9			
	Position5	51.7			
	Position1	29.2			
	Position2	67.9			
MDL	Position3	50.1	19.3	4	0.001
	Position4	47.9			
	Position5	57.5			
	Position1	81.5			
	Position2	65.6			
AREA	Position3	37.2	45.7	4	0.0
	Position4	30.5			
	Position5	37.8			
	Position1	75.4			
	Position2	63.2			
VELAP	Position3	41.2	31.9	4	0.0
	Position4	42.3			
	Position5	30.4			
	Position1	89.3			
	Position2	66.9			
VELL	Position3	32.5	67.8	4	0.0
	Position4	26.3			
	Position5	37.5			
	Position1	47.8			
	Position2	48.5			
MAXAP	Position3	64.6	6.1	4	0.195
	Position4	46.2			
	Position5	45.5			
	Position1	50.7			
	Position2	56.7			
MAXL	Position3	54.6	3.3	4	0.517
	Position4	49.0			
	Position 5	41.6			

Table 2 – *Comparison of the COP variables among different orthostatic positions, with eyes closed.*

		Eyes Closed			
Variable	**Positions**	$\overline{X}$ **posts**	$\overline{X}^2$	**gl**	P
	Position1	39.8			
	Position2	41.7			
MDAP	Position3	60.3	8.1	4	0.088
	Position4	57.1			
	Position5	53.8			
	Position1	47.8			
	Position2	50.8			
MDL	Position3	53.0	0.9	4	0.928
	Position4	47.0			
	Position5	53.9			
	Position1	83.4			
	Position2	63.0			
AREA	Position3	30.6	47.1	4	0.0
	Position4	34.0			
	Position5	41.7			
	Position1	76.6			
	Position2	54.8			
VELAP	Position3	35.2	24.9	4	0.0
	Position4	42.6			
	Position5	43.3			
	Position1	86.0			
	Position2	65.6			
VELL	Position3	28.0	61.0	4	0.0
	Position4	27.2			
	Position5	45.7			
	Position1	49.2			
	Position2	54.9			
MAXAP	Position3	39.8	4.3	4	0.367
	Position4	51.6			
	Position5	57.1			
	Position1	44.2			
	Position2	52.0			
MAXL	Position3	45.0	5.9	4	0.204
	Position4	47.8			
	Position5	63.5			

tively for MDAP (P2>P4>P3>P5 and P1), MDLL (P2>P5>P3>P4 and P1), AREA (P1>P2>P5>P3 and P4), VMAP (P1>P2>P4>P3 and P5) and VMLL (P1>P2>P5>P3 and P4). b) *With eyes closed* (Table 2), the significant differences were obtained only in the variables displacement speeds and ellipse area. Special emphasis is placed on the positions, in decreasing order of mean values for the variables AREA and VELAP (P1>P2>P5>P4 and P3) and for the variable VELL (P1>P2>P5>P3 and P4).

After this the Mann Whitney test was applied to identify such differences variable by variable and it was verified that: a) *with eyes open* there were statistically significant results for the variables ellipse area, amplitudes and mean displacement speeds.

In the variable mean anteroposterior displacement of COP (MDAP), it was observed that positions P2,P3,P4 and P5 presented higher values in relation to P1 (smaller base area) although there was no significant difference among them.

In the variable mean laterolateral displacement of COP (MDLL), position P2 presented a higher value in relation to the other positions P1, P3, P4 and P5 and there was no difference among these.

In the variable ellipse area (AREA) the value of position P1 (smaller base area) was higher than other positions. And among the others, position P2 presented a higher value than the positions P3, P4 and P5. It is important to emphasize that there was no significant difference among P3, P4 and P5.

Both for the variable VMAP (mean speed of COP in the anteroposterior direction), and for the variable mean speed of COP in the laterolateral direction (VMLL); the highest value was verified for position P1 (smaller base area) in relation to the other positions. Position P2 presented a higher value than positions P3, P4 and P5, with no significant difference among these three positions.

b) *With eyes shut* significant differences were only verified among the positions in three variables: ellipse area and mean displacement speeds of COP.

In the variable VMAP (mean speed of COP in the anteroposterior direction), higher values were obtained for position P1 (smaller base area) in relation to P2, P3, P4 and P5. Position P2 presented a higher value than position P3 and there were no significant differences among the values of positions P3, P4 and P5.

In the variable mean speed of COP in the laterolateral direction (VMLL), the value obtained for position P1 (smaller base area) was higher than the other positions. Position P2 presented a higher value in relation to the values of positions P3, P4 and P5, and position P5 presented a higher value than P3 and P4, which presented similar values in relation to each other.

Finally the variable ellipse area (AREA), unlike the other variables, presented statistically significant differences between the same positions in the two visual situations: eyes open and eyes closed.

For this variable, the value of position P1 (smaller base area) was higher than the other positions. Position P2 presented a higher value than P3, P4 and P5, whereas there were no significant differences among these three positions.

DISCUSSION

In the comparison of the five positions in the seven variables of COP, with eyes open and with eyes closed, higher values were verified in the COP variables and, therefore, less stabilization in the following decreasing order: position 1 (feet together and parallel), position 2 (ankles together and forefeet apart and at an angle of 45º), followed by positions 3 (feet parallel and at a distance of 10cm) and 5 (free), which presented relatively better results, whereas position 4 (ankles at a distance of 10cm and forefeet at an angle of 45º) was the most stable.

There was no access to studies that would enable a comparison of results, yet Mouzat[12] verified that distancing has an important influence for better stabilization. Over all the parameters studied, excluding dispersion of anteroposterior COP, the angle has an influence only on mainly lateral speed, on lateral dispersion, on the radius and consequently on the area. According to Mouzat[12] the dimension of the effect of distancing is very clearly superior to that of the angle.

In the comparison of the effects of visual conditions, in the five positions it was observed with *eyes open* the mean variables of anteroposterior and lateral displacement, position P1 (smaller base area) was the one that presented least oscillation, stressing that visual contribution assists in the maintenance of balance directly. This finding has an explanation in the tendency of the coupling force between visual information and postural oscillation and the influence of the continuous alterations of visual information on postural oscillations.[13] In the same manner, visual contribution is emphasized with the increase of age, as a reduction of somatosensory and vestibular participation is observed, as is an increase of visual contribution.[14]

In the anteroposterior displacement speed, the highest value was for P1 (smaller base area) in relation to P3, P4 and P5, indicating that the speed of adjustments for balance maintenance in the positions with smaller base area is necessarily higher. According to Reynolds15, these results can be explained by the fact that the central nervous system is capable of altering the foot trajectory rapidly, in simultaneously ensuring that balance is not threatened.

In the ellipse area, both for eyes open and closed, the highest mean values were for positions P1 and P2 (positions with less distancing between the feet) in relation to the others, indicating that in situations of smaller base area of body sustention, the COP oscillation area is larger, with the presence of greater imbalance. This case confirms the better stability in P3, P4 and P5, which exhibit similar results, as there is an improvement of stability of the orthostatic posture when the distancing and/or angle between the feet increase and the oscillations of the subject are decreased.[11]

CONCLUSIONS

In view of the results and with a basis on the theoretical benchmark consulted, it is concluded that:

In relation to stability, position P4 (ankles 10cm apart and forefeet at an angle of 45º) was the one with greatest stability, followed, respectively, in decreasing order, by positions P3 (ankles 10cm apart and forefeet parallel) and P5 (spontaneous position) sustained by smaller ellipse areas, lower speeds and amplitudes of anteroposterior and laterolateral displacements.

The visual feedback presented an important contribution in postural control, in all five feet placement positions that were tested, increasing or decreasing stability in the orthostatic position.

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