

Body Sway Characteristics during Static Upright Posture in Healthy and Disordered Elderly

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Abstract This study aimed to compare body sway characteristics of the healthy elderly and the disordered elderly. The subjects were 38 healthy elderly and 24 disordered elderly with disequilibrium. The latter consisted of two groups: 12 elderly with vestibular organ or central nervous systems disorder (central nervous disorders), and 12 elderly with disorder in other systems (other disorders). The measurement device can calculate the center of foot pressure (CFP) of vertical loads from the values of three vertical load sensors, which are located at the corners of an isosceles triangle on a level surface. The data sampling frequency was 20 Hz. Four body sway factors with high reliability (unit time sway, front-back sway, left-right sway, and high frequency band power) were used to evaluate body sway. As compared with healthy people, central nervous disorders had larger unit time sway, high frequency band power, and left-right sway factors. Other disorders were larger in unit time sway and high frequency band power factors. Central nervous disorders, as compared with other disorders, had larger unit time sway and left-right sway factors. Disorders produced large and fast sway, and central nervous disorders in particular showed a marked sway in the left-right direction. The existence of disease influenced body sway more than decline in various functions related to posture control with aging, because even with the same elderly, disorders showed a larger body sway. *J Physiol Anthropol Appl Human Sci* 24(5): 551–555, 2005 <http://www.jstage.jst.go.jp/browse/jpa>

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Introduction

People normally maintain a collapsing posture by integrating vestibular, visuosensory and somatosensory information from the central nervous system. Therefore, when the above-stated organ systems are impaired, dizziness and body sway appear (Japan Society for Equilibrium Research, 1994; Njiokiktjien, 1971). Based on this mechanism, previous studies recorded body sway patterns from the coordinates on bidimensional planes to determine the relationships between body sway patterns and each disorder (Japan Society for Equilibrium Research, 1994). For example, people with unilateral labyrinth disability show a large left-right sway, those with bilateral labyrinth disability show unique characteristics in a front-back sway, and those with subfolium disability show a front-back sway of about 3 Hz (Kapteyn, 1983). However, it has been pointed out that this evaluation of body sway pattern depends largely on the tester's subjectivity and there is not much objectivity (Shimada et al., 2003; Pyykko, 2000; Collins, 1995). If the body sway pattern can be expressed quantitatively, we can objectively evaluate people's body sway characteristics during static upright posture.

The elderly show marked declines in function such as in the brain and nervous system, leg muscles, or the senses and internal organs, which are very important in maintaining posture. Therefore, even healthy elderly show a larger body sway than is evident in young adults (Savelberg, 1999; Pyykko, 2000; Collins, 1995; Brooke-Wavell K et al., 2002). The body sway characteristics of the healthy elderly with declines in various functions can be made clear by comparison with those of the disordered elderly with a specific function disorder. Disequilibrium is generally defined as a disorder of vestibular organs, somatosensory organs or the autonomic nerve systems (Japan Society for Equilibrium Research, 1994). This suggests that body sway depends strongly on the above-stated functions. For example, when a person has a vision disorder, posture is

controlled by information from proprioception or the vestibular organ system. Disequilibrium is found more in vestibular organ or central nervous system disorders (Japan Society for Equilibrium Research, 1994). Previous studies have mainly examined people with vestibular and central vestibular system disorders (Inoue et al., 1992; Oku et al., 1994; Tokida et al., 1999; Wada et al., 1992). However, many elderly people have disorders (ocular, cervical, or generalized disorders) other than the above disorders. It is considered that the mechanism of the posture control system differs by the location and degree of the disorder, and the body sway characteristics may be also different (Shimada et al., 2003).

This study aimed to compare body sway characteristics of the healthy elderly, the elderly with vestibular organ or central nervous system disorders, and the elderly with disorders except the above-stated, and to clarify body sway characteristics of the elderly with disorders.

Methods

Subjects

The subjects were 38 healthy elderly and 24 disordered elderly with disequilibrium who were in hospital or had gone to a hospital. Disequilibrium was classified into vestibular organ or central nervous system disorders and other system disorders (Japan Society for Equilibrium Research, 1994). Disordered elderly were divided into two groups: 12 elderly with vestibular organ or central nervous system disorders and 12 elderly with other system disorders. Hereafter, both groups are termed central nervous disorders and other disorders, respectively. Table 1 shows the characteristics of the three groups. Before measurement, the purpose and procedure of this study were explained in detail to the subjects and nurses who were taking care of the disorders. Informed consent was obtained from all subjects and nurses. Disorder disease names were judged by a doctor, and it was confirmed that the healthy elderly did not have a specific illness.

Experimental procedure

The measurement procedure followed the method prescribed by the standardization of the stabilometry test (Japan Society for Equilibrium Research, 1994). The subjects maintained a static upright posture with closed feet (Romberg posture) for

1 min. During the testing, they were instructed to watch a circular achromatic target placed at eye level and stood bare-foot with their arms held comfortably and their eyes open. The measurements began after the subject's posture and eyes were stable. The test was measured 3 times with a 1 min rest period. We instructed them not to change the position of their feet on the plate during the rest period in a sitting position.

Experimental instrument

The measurement instrument was an Anima's stabilometer G5500. This machine can calculate the center of foot pressure (CFP) of vertical loads from the values of three vertical load sensors, which are located at the corners of an isosceles triangle on a level surface. The data sampling frequency was 20 Hz.

Evaluation parameters

Evaluation parameters of CFP movement are theoretically categorized into the following 7 domains from the characteristics of the CFP trajectory: distance, center average, distribution of the amplitude, area, velocity, power spectrum, and sway vector (Demura et al., 2001; Mizuta et al., 1993). Kitabayashi et al. (2003) reported that 32 body-sway parameters selected from 6 domains, excluding the center average domain, were objectively compressed and summarized into the following 4 sway factors using factor analysis: unit time sway (F1), front-back sway (F2), left-right sway (F3) and high frequency band power (F4). Each factor from F1 to F4 was defined mainly by sway velocity parameters, dividing the movement distance by unit time, by parameters evaluating the amount of front and back sway, by parameters evaluating left and right sway, and by parameters with a high frequency band relating to body sway. Therefore, the above-stated 4 body sway factors were used to evaluate body sway.

Data analysis

One-way ANOVA was used to examine mean differences of area parameters. ANCOVA was used to examine mean differences of body sway factors in consideration of the gender and age-level differences. Multiple comparisons used Tukey's HSD method. Each subject's factor score was calculated from an estimation equation made up using the complete estimation method. The level of statistical significance (α) was set at

Table 1 Characteristics of healthy and disorders groups

	Healthy elderly (n=38)		Disorder A (n=12)		Disorder B (n=12)	
	Male (n=17)	Female (n=21)	Male (n=6)	Female (n=6)	Male (n=4)	Female (n=8)
Age (yr)	73.2±6.27	75.5±4.15	75.5±6.15	77.1±6.82	76.0±6.13	76.6±4.76
Height (cm)	161.5±6.57	146.1±5.42	161.8±7.90	142.8±9.37	158.8±5.90	147.1±9.76
Weight (kg)	60.1±8.26	51.9±7.92	61.1±9.36	46.6±8.30	61.1±9.36	47.7±7.69

Note Disorder A: Elderly with vestibular organ or central nervous system disorder

Disorder B: Elderly with other system disorders (proprioception system, cardiopath, and climacteric disorders, and disorders except the disorder A)
mean±SD

$p < 0.05$. The α was adjusted based on Bonferroni's method for a comparison between group means.

Results

Figure 1 shows the center changes of pressure trajectories of each group from the averaged time series calculated from individual time series data. Significant differences were found in area parameters, and they were larger in patients with central nervous disorders than in healthy people, as shown in Table 2.

Table 3 shows the ANCOVA test results of body sway factors. Significant differences were found in unit time sway,

left-right sway and the high frequency band power but not in front-back sway. Unit time sway was larger in the order of central nervous disorders, other disorders, and healthy people. Left-right sway was larger in the central nervous disorders than in other disorders and healthy people. High frequency band power was larger in the disorder groups than with healthy people.

That is to say, the central nervous disorders were associated with greater unit time sway, left-right sway, and high frequency band power than was the case in healthy people, and with greater unit time sway and high frequency band power than was the case in other disorders. Central nervous disorders likewise showed larger unit time sway and left-right sway than

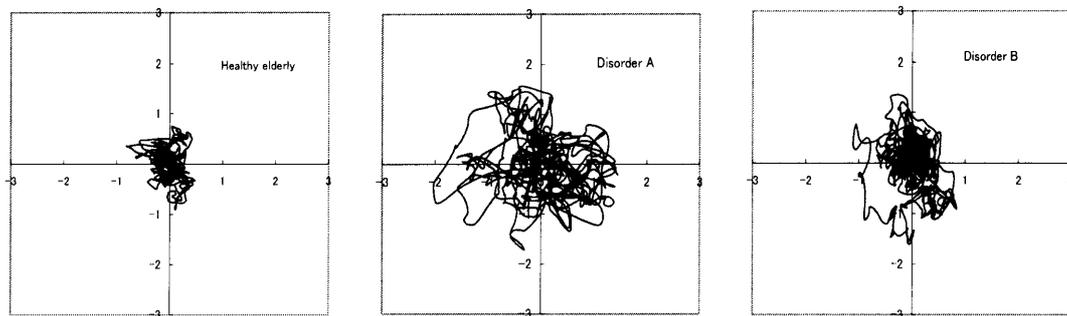


Fig. 1 Center of pressure trajectories of the healthy and disordered elderly.

Note) This is averaged time series data for each group calculated from the individual time series data. Disorder A: Elderly with vestibular organ or central nervous system disorders. Disorder B: Elderly with other system disorders.

Table 2 One-way ANOVA test results of area parameters

Parameters	Healthy elderly (n=38)		Disorder A (n=12)		Disorder B (n=12)		F-value	Multiple comparison
	M	SD	M	SD	M	SD		
Area surrounding mean path length (1/cm)	30.8	10.9	23.5	12.8	26.3	14.1	1.86	
Area surrounding maximal amplitude rectangle (cm ²)	6.5	3.3	23.9	16.8	14.1	13.6	14.01*	Disorder A > Healthy elderly
Area surrounding root mean square (cm ²)	1.5	0.9	4.1	2.6	2.6	1.7	12.08*	Disorder A > Healthy elderly

Note) $\alpha' = 0.05/3 = 0.0167$, $F(2,59,0.0167) = 4.389$ * $F\text{-value} > 4.389$

Disorder A: Elderly with vestibular organ or central nervous system disorder

Disorder B: Elderly with other system disorders

Table 3 ANCOVA test results of body sway factors

Factors	Healthy elderly (1)		Disorder A (2)		Disorder B (3)		F-value	Multiple comparison	(1) vs (2)	(1) vs (3)	(2) vs (3)
	M	SD	M	SD	M	SD			ES	ES	ES
F1: unit time sway	-5.87	5.08	17.05	14.19	1.52	9.85	29.68*	(2) > (3) > (1)	2.72	1.11	1.37
F2: front-back sway	0.00	3.98	-0.43	4.43	0.43	4.92	0.21				
F3: left-right sway	-3.03	5.27	8.73	9.99	0.86	6.99	12.48*	(2) > (3), (1)	1.72		1.48
F4: high frequency power band spectrum	-0.71	1.07	1.44	2.02	0.80	1.70	10.89*	(2), (3) > (1)	1.54	1.18	

Note) $\alpha' = 0.05/4 = 0.0125$, $F(2,59,0.0125) = 4.724$ * $F\text{-value} > 4.724$

Result of multiple comparison ((1): Healthy elderly (2): Disorder A (3): Disorder B)

Disorder A: Elderly with vestibular organ or central nervous system disorders

Disorder B: Elderly with other system disorders

the other disorders. The effect size (ES) of the differences between all factors was also very large (ES=1.11–2.72).

Discussion

Evaluation parameters of CFP movement are theoretically categorized into 6 domains, and the characteristics of CFP movement can be synthetically understood from 32 parameters representing the above-stated 6 domains (Demura et al., 2001; Mizuta et al., 1993; Yamaji et al., 2001; Kitabayashi et al., 2002). The authors judged that these parameters have high reliability and validity (Demura et al., 2001; Kitabayashi et al., 2002).

Even the healthy elderly have a larger body sway than young adults (Savelberg, 1999; Pyykko, 2000; Collins, 1995; Brooke-Wavell K et al., 2002). The elderly with specific disorders are considered to have unique body sway characteristics when compared with healthy people. Many elderly people have disorders (ocular, cervical, or generalized disorders) other than disequilibrium. They also have different body sway characteristics from healthy people. This study divided them into elderly people with vestibular organ or central nervous system disorders and those with other system disorders, and compared their body sway characteristics with those of healthy people.

Healthy people and the two disorder groups showed a visually different body sway, as shown in Fig. 1, and the area parameters were significantly larger in those with central nervous disorders than in healthy people. A significant difference between the healthy and disorder groups was found in the three factors of unit time sway, left-right sway and high frequency power band. It was confirmed that because of very large differences (ES>0.80), central nervous disorders differ to some degree in 3 factors in healthy people, and in unit time sway and left-right sway as compared with other disorders. Other disorders differ to some degree in unit time sway and the high frequency power band from those of healthy people.

Unit time sway is related to the decline of the posture control function (Kitabayashi et al., 2002; Tokita et al., 2001). It may be influenced by the decline of nervous transmission and space recognition in central nervous disorders, and in the other disorders by ocular, cervical, or generalized disorder function decline, and pain in joints from osteoarthritis and lumbago. However, vestibular organ or central nervous system disorders may considerably influence body sway, because even with the same disordered elderly, central nervous disorders showed a larger body sway.

The present results suggest that the existence of these diseases has more influence than decline in various functions related to posture control with aging. The left-right sway factor is effective when evaluating the sway of a person with labyrinthine vertigo, or an individual difference of sway reflecting the influence of physique such as joints and bearing (Kitabayashi et al., 2002; Tokita et al., 2001). Central nervous disorders include people with labyrinthine vertigo,

parkinsonism and brainstem disease. Mizuta et al. (1993) reported that people with unilateral labyrinth disability show large left-right sway. Many previous studies (Marcoet et al., 1994; Inoue et al., 1992; Oku et al., 1994; Tokita et al., 1997) reported that parkinsonism produces large and quick body sway characteristics because of the hypertonia of the musculus triceps surae and the inhibition of ankle joint dorsal flexion. People suffering from brainstem or cerebellum disease show a large body sway. As also seen in this study, the body sway of people with central nervous disorder, including the above, was marked as compared with not only healthy people but also the other disorders. Left-right sway may be one of their major characteristics.

Front-back sway can measure the overall decline of the posture control function, and can be effective in evaluating movement characteristics caused by the marked decline of leg muscles. This sway can be used to judge dizziness and balance functional disorder with hypertonia of the spinal reflex. However, no significant difference between groups was found. The feet and knee joints move and adjust easily to the front-back direction due to the structure of the body, but this is difficult in the left-right direction (Kitabayashi et al., 2002).

The front-back direction is adjustable and can be stabilized by plantar or dorsal flexion of the ankle joints, and extension or flexion of the knee joints. Thus, it is inferred that body sway in the front-back direction can be controlled even for the disordered elderly, and there was little marked difference.

The high frequency band power factor, which is effective in discriminating periodicity characteristics (Kitabayashi et al., 2002; Tokita et al., 2001), was larger in the 2 disorder groups than in the healthy people. Kapteyn (1983) reported that periodicity features of the disorders are found in the high frequency band. Body sway characteristics in disordered people are considered to be low and fast.

In summary, when compared with healthy people, disordered people show large and fast body sway characteristics. Central nervous disorders show a marked sway in the left-right direction also as compared with the other disorders. The existence of disease may influence body sway considerably more than declines in function related to posture control with aging.

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