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Body-sway characteristics during a static upright posture in the elderly

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Aim: This study aimed to determine the reliability and sex and age-level differences of body-sway parameters, based on center of pressure (COP) measurements, during a static upright posture in the elderly and to clarify their body-sway characteristics in comparison with those of young adults.

Methods: The subjects were 50 healthy elderly and 50 healthy young adults. They had no evidence or known history of disorder. The data sampling frequency was 20 Hz. Thirty-six highly reliable parameters were selected from the following seven domains: distance; position; distribution of amplitude; area; velocity; power spectrum; and vector. In addition, four body-sway factors (unit time sway, front-back sway and a left-right sway and the high-frequency band power) were also measured.

Results: In the elderly, most body-sway parameters had very high reliability and did not show significant sex or age-level differences. The degree of body sway was greater in the elderly than in young adults, and marked differences were found, especially in sway velocity and periodicity. The four body-sway factors showed almost the same tendency as the 32 sway parameters.

Conclusion: We judged that the body sway in the elderly showed large individual differences. Approximately 10% of the elderly subjects may be outside the standard range as compared to young adults, mainly in parameters relating to velocity and spectrum. Because the body-sway characteristics of the elderly are considerably different from those of young adults, we may need unique criteria to evaluate their body sway.

Keywords: elderly, evaluation of the center of pressure, static upright posture, young adults.

Introduction

Body sway during a static upright posture is controlled by the synkinesis of the limbs and body trunk based on information from posture adjustment functions such as the visuosensory, vestibular and proprioception organ systems.[1–4] The important function of brain and nerve systems in keeping a stable posture is maintained until a relative old age after sufficient development.[5]

However, the elderly find it increasingly difficult to maintain an upright posture because of the marked decline of the above systems.

Cummings *et al.* reported that the elderly have more cooperative disorders of the input and output systems used in posture maintenance.[6] On the other hand, Hirasawa *et al.* reported that the elderly 65–74 years of age have almost the same balance ability as young adults and that many of them could perform similar social

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activities.[7] The decline in various functions needed for posture maintenance occurs in old age, and the individual differences in the decline of these functions are large. As a result, individual differences in body-sway characteristics are also considered to become large.

Today, fall accidents in the elderly have become an important social problem. Their falls produce fractures. As a result, we have misgivings about the increase in the number of bedridden elderly.[8–10] The marked decline of various factors, such as balance function, leg muscle strength, agility and so on, in the elderly is considered to be the cause of these falls.[1,11,12] To evaluate functional decline in the elderly, posture stability when achieving a task with a movement was examined.[11,12]

Even if there were valid tests with high reliability to evaluate body-sway characteristics for young adults, they may not always be useful for the elderly who have declining function of various systems.[9] Previous studies[1,5,9,13] have mainly examined body-sway characteristics in the elderly using sway distance and area parameters. Other important parameters, such as those relating to velocity, periodicity and vector, have not been used extensively even though they are very important to properly evaluate body sway.

In addition, it is worth pointing out that there are few fundamental studies on the reliability and sex and age-level differences of body-sway parameters in the elderly.[9,10,14] It is necessary to properly determine their body-sway characteristics in comparison with those of young adults in addition to carrying out fundamental examinations of the reliability and sex and age-stage differences of body-sway parameters.

This study aimed to determine the reliability and sex and age-level differences of body-sway parameters, based on center of pressure (COP) measurements, during a static upright posture with open eyes in the healthy elderly and to clarify their body-sway characteristics compared with those of young adults.

Methods

Subjects

The subjects were 50 healthy elderly (17 men, aged 73.2 ± 6.27 years, 161.5 ± 6.57 cm tall, weighing 60.1 ± 8.29 kg; and 33 women, aged 72.7 ± 6.56 years, 147.7 ± 5.27 cm tall, weighing 53.2 ± 7.62 kg) and 50 healthy young adults (25 men, aged 21.1 ± 1.62 years, 173.3 ± 5.55 cm tall, weighing 67.0 ± 7.90 kg; and 25 women, aged 19.6 ± 1.42 years, 161.0 ± 5.85 cm tall, weighing 54.3 ± 6.19 kg). None of the subjects had evidence or known history of gait, posture or skeletal disorders. To examine the age-level differences of the elderly, they were divided into two groups based on the mean age of the subjects: (i) those under 75 years of age (nine men, aged 67.4 ± 4.23 years; and 21 women, aged 68.6 ± 4.14 years); and (ii) those over 75 years of age (eight men, aged 78.4 ± 3.23 years; and 12 women, aged 78.9 ± 4.12 years). The above groups are generally referred to as the young-old and the old-old, respectively. Mean ages showed significances between both groups in both sexes but not between sexes. Informed consent was obtained from all subjects.

Procedure

The measurement procedure followed the method prescribed in the standardization protocol of the stabilometry test.[11] Body sway is defined as sway of the body used to maintain posture by properly harmonizing the function of postural muscles based on information from visuosensory, vestibular and proprioception organ systems. The sway propriety of the body differs largely between standing with closed eyes and with open eyes.[11] Until now, in the case of healthy people, body sway during standing with open eyes has been generally measured.[10,14] This study aimed to clarify the sway propriety of healthy people standing with open eyes. The subjects maintained a static upright posture with closed feet (Romberg posture) and open eyes for 1 min. During the testing, they were instructed to watch a circular target placed at eye level, and they stood barefoot with their arms held comfortably. The measurements began after the subject's posture and eyes were stable. The test was measured three times with a 1-min rest period. A tester instructed the subjects not to change the position of their feet on the plate during the sitting rest period.

Materials

The measurement instrument was an Anima's stabilometer G5500 (Anima Co., Ltd, Tokyo, Japan). This machine can calculate the COP of vertical loads from the measurements 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.

Parameters

Individual differences of body sway in healthy people are very small. Hence, it is necessary to synthetically evaluate their COP movement based on several parameters.[15–19] Tokita *et al.* pointed out that each parameter measuring COP movement has a respective original test aim but evaluates only a part of the body-sway characteristic.[15] Therefore, it is necessary to look at it synthetically based on multiple measurement values. Pyykko[18] and Collins *et al.*[19] cited sway area, sway path, root mean square value of sway amplitude, power spectra, sway velocity and performance ratio as COP movement domains. Furthermore, they pointed out that COP movement with several posture-keeping strategies cannot be synthetically understood using a single domain. Demura *et al.*[16] and Kitabayashi *et al.*[20] reported that the characteristics of COP movement can be synthetically understood from seven domains. Thirty-six evaluation parameters representing the above-stated seven domains with high reliability were selected in this study. Evaluation parameters were distance-represented sway size (four parameters), area-represented sway magnitude (three parameters), velocity-represented sway velocity (three parameters), center position-represented sway position (two parameters), amplitude distribution-represented sway amplitude (four parameters), power spectrum-represented sway frequency (six position parameters and six velocity parameters) and vector-represented sway direction (four position parameters and four velocity parameters)[21] in addition to four body-sway factors (unit time sway, front-back sway, left-right sway and the high-frequency band power) (Table 1). This study did not correct parameters based on physique, because Kitabayashi *et al.* reported that the influence of the physique on body-sway parameters is small ($r < 0.4$).[20] This was also confirmed in our study.

Statistical analysis

Trial-to-trial reliability was examined by the intraclass correlation coefficient (ICC). The mean of trials 2 and 3 with high reliability was used as a representative value for the further analysis. Two-way ANOVA (sex × age-level) was used to examine the sex and age-level differences for the elderly body-sway parameters. Multiple comparisons were done by Tukey's honest significant difference method. The Student's *t*-test was used to examine the mean difference between the elderly and young adults. Each subject's factor score was calculated from the estimation equation made up using the complete estimation method. The factor score is calculated by substituting measurement values of each parameter into the estimation equation. SPSS ver. 10.5 software (SPSS Software, Chicago, IL, USA) was used for data analysis. Effect size (ES) was calculated to examine the size of the mean difference. An ES of 0.2 and under is generally interpreted as a small difference and 0.8 and over as a large difference. The level of statistical significance was based on Bonferroni's method. This method is distributed equally in 0.05 pair comparisons by dividing the total pair comparisons by 0.05.

Results

Table 2 shows the fundamental statistics and reliability coefficients (ICC) of 36 COP movement parameters and the two-way ANOVA results for the elderly. ICC were very high, at over 0.70 in all parameters for young adults and in all parameters except for two power spectrums for the elderly. It was confirmed that all parameters follow a normal distribution by the Kolmogorov–Smirnov (k–s) test ($\chi^2 = 10.96–18.23$). Significant sex and age-level differences were not found in all parameters, and correlations between age and parameters were also low ($r = 0.21–0.35$).

Table 3 shows the test results between the means of the young adults and the elderly for sway parameters, coefficient of variation (CV), ES and frequency outside the young adults' mean + 3 standard deviation (SD) range. Significant age-stage differences between young adults and the elderly were found in 11 parameters, corresponding to 33% (11/36) of all parameters. All parameters except the ratio of A domains in the power spectrum were large in the elderly. Age-stage differences were marked, mainly in velocity and spectrum parameters (ES > 0.80). The CV tended to be larger in the elderly. The frequency outside the young adults' mean + 3 SD range was approximately 10% for velocity parameters and for the ratio of C domains of power spectrum parameters. The elderly have large individual differences, and their body sway dispersed in an increasing direction. Figure 1(a) shows an example of mean path length parameters.

Table 4 shows the test results between mean factor scores for the elderly and young adults. Significant differences found in three factors, except the third factor, were larger in the elderly. In particular, the fourth factor, related to the high-frequency band power, showed a very large difference (ES = 1.05). The variance of this factor was different from that of young adults and was large (Fig. 1b).

Discussion

Evaluation parameters of COP movement are theoretically categorized into the following seven domains from characteristics of the COP trajectory: distance; center average; distribution of the amplitude; area; velocity; power spectrum; and sway vector.[12,16] Demura *et al.*[16] and Kitabayashi *et al.*[21] compiled 114 parameters used so far in many studies and examined the trial-to-trial and day-to-day reliabilities, interrelationships between parameters and sex differences of these parameters. They reported that the characteristics of COP movement can be synthetically understood from only 36 parameters representing the aforementioned seven domains. Kitabayashi *et al.* reported that body-sway parameters could be objectively compressed and summarized into the following four sway factors using factor analysis: unit time sway; front-back sway; left-right sway; and high-frequency band power.[21]

Many previous studies reported that sex differences of body sway are not found in the elderly.[5,9,10] It was reported that body sway shows little age-change after sufficient development of the balance function[5] but becomes large in the elderly over 60 years[22] or 70 years[23] of age.

Table 1 Thirty-six center of pressure (COP) parameters and properties

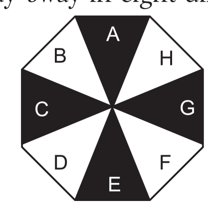
Domains	Parameters	Properties
Distance	Mean path length (cm/s)	Mean length of COP path
	Root mean square (cm)	Equation: $\sqrt{[1/N\{(SX_i - Xmean)^2 + S(Y_i - Ymean)^2\}]}$: Dispersion from COP
	Root mean square of X-axis (cm)	Equation: $\sqrt{\{1/N(SX_i - Xmean)^2\}}$
	Root mean square of Y-axis (cm)	Equation: $\sqrt{\{1/N(SY_i - Ymean)^2\}}$
Area	Area surrounding mean path length (1/cm)	Total path length was broken within the circumference area
	Area surrounding maximal amplitude rectangle (cm^2)	Area surrounding maximal amplitude rectangle for each axis
	Area surrounding root mean square (cm^2)	Area of the circle making the actual effective radius value
Position	Mean of X-axis (cm)	Center of position of X-, Y-axis for body-sway
	Mean of Y-axis (cm)	
Velocity	Mean velocity of X-axis (cm/s)	Mean velocity of X-, Y-axis for body-sway
	Mean velocity of Y-axis (cm/s)	
	Root mean square of sway velocity (cm/s)	Root mean square of sway velocity
Distribution of amplitude	Standard deviation of X-axis (cm)	Equation: $Sx = \sqrt{(1/NS(x_i - Xmean)^2)}$
	Standard deviation of Y-axis (cm)	Equation: $Sy = \sqrt{(1/NS(y_i - Ymean)^2)}$
	Standard deviation of X-axis velocity (cm/s)	Standard deviation of X- and Y-axis velocity
	Standard deviation of Y-axis velocity (cm/s)	
Power spectrum	Ratio of A domain for power spectrum of X-axis (%)	Power spectrum area by the fourier translation for body-sway value (X-, Y-, R-direction) divided A, B, C, domain. A domain, 0–0.2 Hz; B domain, 0.2–2 Hz; C domain, >2 Hz.
	Ratio of C domain for power spectrum of X-axis (%)	
	Ratio of A domain for power spectrum of Y-axis (%)	
	Ratio of C domain for power spectrum of Y-axis (%)	
	Ratio of A domain for power spectrum of R-axis (%)	
	Ratio of C domain for power spectrum of R-axis (%)	
	Ratio of A domain for power spectrum of X-axis velocity (%)	Power spectrum area by the fourier translation for body-sway velocity (X-, Y-, R-direction) divided A, B, C, domain. A domain; 0–0.2 Hz, B domain; 0.2–2 Hz, C domain; above 2 Hz.
	Ratio of C domain for power spectrum of X-axis velocity (%)	
	Ratio of A domain for power spectrum of Y-axis velocity (%)	
	Ratio of C domain for power spectrum of Y-axis velocity (%)	
	Ratio of A domain for power spectrum of R-axis velocity (%)	
	Ratio of C domain for power spectrum of R-axis velocity (%)	
Vector	Mean vector length of A direction sway (cm)	Mean distance of body-sway in eight directions (A to H)
	Mean vector length of C direction sway (cm)	
	Mean vector length of E direction sway (cm)	
	Mean vector length of G direction sway (cm)	
	Mean vector length of A direction velocity (cm/s)	
	Mean vector length of C direction velocity (cm/s)	
	Mean vector length of E direction velocity (cm/s)	
	Mean vector length of G direction velocity (cm/s)	Mean distance of body-sway velocity in eight directions (A to H)

Table 2 Means, standard deviations and intraclass correlation coefficient (ICC) of 36 center of pressure (COP) parameters and two-way ANOVA results

		ICC Young adults	Elderly		60–75 years M	60–75 years SD	≥75 years M	≥75 years SD	*r*	Two-way ANOVA F1	Two-way ANOVA F2	Two-way ANOVA IR
Age		–	–	Male	67.4	4.20	78.4	3.20	–	12.1†	1.98	1.02
				Female	68.6	4.10	78.9	4.10				
Distance	Mean path length (cm/s)	0.98	0.97	Male	1.3	0.35	1.3	0.41	0.32	0.03	1.09	0.16
				Female	1.2	0.28	1.2	0.22				
	Root mean square (cm)	0.95	0.92	Male	0.7	0.14	0.7	0.19	0.35	0.09	1.44	0.08
				Female	0.7	0.18	0.6	0.19				
	Root mean square of X-axis (cm)	0.94	0.93	Male	0.5	0.11	0.4	0.08	0.34	1.02	0.60	0.48
				Female	0.4	0.14	0.4	0.15				
	Root mean square of Y-axis (cm)	0.90	0.88	Male	0.5	0.13	0.5	0.20	0.30	0.09	1.48	0.00
				Female	0.5	0.15	0.5	0.15				
Area	Area surrounding mean path length (1/cm)	0.95	0.92	Male	26.4	7.27	27.0	8.83	0.35	0.03	2.17	0.08
				Female	32.6	12.43	32.1	12.07				
	Area surrounding maximal amplitude rectangle (cm^2)	0.95	0.93	Male	7.2	2.07	6.8	3.16	0.35	0.02	0.44	0.01
				Female	6.4	3.27	6.4	3.89				
	Area surrounding root mean square (cm^2)	0.91	0.91	Male	1.8	0.69	1.6	0.88	0.31	0.01	1.20	0.02
				Female	1.4	0.77	1.4	0.98				
Position	Mean of X-axis (cm)	0.96	0.94	Male	0.6	0.48	0.0	0.56	0.36	2.03	0.12	6.67
				Female	0.2	0.61	0.4	0.78				
	Mean of Y-axis (cm)	0.95	0.96	Male	0.2	1.54	–0.1	1.61	0.35	0.30	0.00	1.40
				Female	–0.2	1.13	0.0	0.73				
Velocity	Mean velocity of X-axis (cm/s)	0.96	0.96	Male	0.8	0.23	0.8	0.30	0.36	0.03	3.10	0.62
				Female	0.7	0.18	0.7	0.16				
	Mean velocity of Y-axis (cm/s)	0.94	0.96	Male	0.7	0.14	0.7	0.16	0.34	0.00	0.12	0.00
				Female	0.7	0.16	0.7	0.16				
	Root mean square of sway velocity (cm/s)	0.94	0.96	Male	1.7	0.41	1.7	0.52	0.34	0.03	1.70	0.19
				Female	1.6	0.36	1.6	0.30				
Distribution of amplitude	Standard deviation of X-axis (cm)	0.95	0.93	Male	0.5	0.11	0.4	0.08	0.35	1.02	0.60	0.48
				Female	0.4	0.14	0.4	0.15				
	Standard deviation of Y-axis (cm)	0.90	0.88	Male	0.5	0.13	0.5	0.20	0.30	0.09	1.48	0.00
				Female	0.5	0.15	0.5	0.15				
	Standard deviation of X-axis velocity (cm/s)	0.93	0.95	Male	1.3	0.38	1.3	0.49	0.33	0.06	3.18	0.61
				Female	1.2	0.30	1.1	0.26				
	Standard deviation of Y-axis velocity (cm/s)	0.95	0.96	Male	1.1	0.24	1.1	0.25	0.35	0.00	0.17	0.00
				Female	1.1	0.27	1.1	0.28				

Power spectrum	Ratio of A domain for power spectrum of X-axis (%)	0.85	0.83	Male	30.3	10.57	27.2	8.32	0.25	0.66	1.26	0.49
				Female	25.8	5.86	25.5	7.72				
	Ratio of C domain for power spectrum of X-axis (%)	0.75	0.59	Male	12.7	3.98	14.1	4.27	0.25	0.17	1.53	0.42
				Female	14.9	3.34	14.6	3.60				
	Ratio of A domain for power spectrum of Y-axis (%)	0.81	0.77	Male	31.8	8.41	31.7	8.73	0.21	0.23	1.38	0.24
				Female	30.1	9.12	27.6	4.99				
	Ratio of C domain for power spectrum of Y-axis (%)	0.76	0.72	Male	16.8	3.96	15.3	2.48	0.26	0.26	2.34	1.55
				Female	17.2	5.23	19.9	6.04				
	Ratio of A domain for power spectrum of R-axis (%)	0.84	0.81	Male	23.7	3.81	23.4	5.55	0.24	0.08	0.37	0.17
				Female	22.0	6.11	23.1	4.78				
	Ratio of C domain for power spectrum of R-axis (%)	0.89	0.92	Male	17.2	3.55	17.8	3.22	0.29	0.26	0.49	0.12
				Female	18.6	4.06	18.8	5.49				
	Ratio of A domain for power spectrum of X-axis velocity (%)	0.94	0.91	Male	5.4	3.80	5.0	2.91	0.34	0.21	1.29	0.46
				Female	4.1	1.15	4.3	1.59				
	Ratio of C domain for power spectrum of X-axis velocity (%)	0.94	0.92	Male	23.4	3.85	24.6	3.53	0.34	0.33	3.11	0.61
				Female	26.4	3.35	26.2	4.58				
	Ratio of A domain for power spectrum of Y-axis velocity (%)	0.92	0.90	Male	5.3	3.23	5.3	1.82	0.32	0.13	0.14	0.01
				Female	5.1	1.95	4.8	1.30				
	Ratio of C domain for power spectrum of Y-axis velocity (%)	0.91	0.95	Male	29.6	6.68	28.0	3.12	0.31	0.01	0.64	0.10
				Female	30.5	5.34	30.9	6.81				
	Ratio of A domain for power spectrum of R-axis velocity (%)	0.72	0.56	Male	8.6	1.49	8.8	1.91	0.12	2.14	2.75	1.62
				Female	7.1	1.32	8.5	1.70				
	Ratio of C domain for power spectrum of R-axis velocity (%)	0.95	0.94	Male	44.2	5.90	44.4	5.17	0.35	0.04	4.61	0.61
				Female	48.4	3.36	47.5	4.87				
Vector	Mean vector length of A direction sway (cm)	0.87	0.83	Male	0.7	0.25	0.6	0.21	0.27	0.00	1.01	0.00
				Female	0.6	0.17	0.6	0.19				
	Mean vector length of C direction sway (cm)	0.86	0.88	Male	0.6	0.16	0.5	0.12	0.26	1.66	1.07	0.35
				Female	0.5	0.16	0.5	0.16				
	Mean vector length of E direction sway (cm)	0.88	0.85	Male	0.7	0.18	0.7	0.32	0.28	0.00	2.47	0.22
				Female	0.6	0.28	0.6	0.13				
	Mean vector length of G direction sway (cm)	0.84	0.84	Male	0.6	0.12	0.6	0.14	0.24	0.33	1.16	0.08
				Female	0.5	0.23	0.5	0.19				
	Mean vector length of A direction velocity (cm/s)	0.93	0.95	Male	1.1	0.22	1.1	0.21	0.33	0.00	0.10	0.01
				Female	1.0	0.28	1.0	0.27				
	Mean vector length of C direction velocity (cm/s)	0.96	0.95	Male	1.2	0.33	1.3	0.46	0.36	0.23	2.57	0.72
				Female	1.1	0.30	1.1	0.26				
	Mean vector length of E direction velocity (cm/s)	0.91	0.94	Male	1.1	0.27	1.1	0.26	0.31	0.06	0.18	0.37
				Female	1.1	0.26	1.1	0.27				
	Mean vector length of G direction velocity (cm/s)	0.92	0.95	Male	1.2	0.35	1.2	0.42	0.32	0.01	2.55	0.41
				Female	1.1	0.28	1.1	0.27				

†$\alpha' = P < (0.05/2)/36 = 0.000694$. F1, main effect (age-level); F2, main effect (sex); IR, interaction. 60–75 years group (nine men and 21 women), ≥75 years group (eight men and 12 women).

Table 3 Significant differences between means of young adults and the elderly, CV, ES, and frequency of +3 SD for 36 COP parameters

		Young adults			Elderly			t-value	ES	Frequency
		M	SD	CV	M	SD	CV			
Distance	1 Mean path length (cm/s)	1.0	0.22	21.6	1.3	0.32	24.8	4.87†	0.97‡	6 (12%)
	2 Root mean square (cm)	0.7	0.18	24.0	0.7	0.19	27.5	1.88	0.38	
	3 Root mean square of X-axis (cm)	0.4	0.12	28.5	0.4	0.13	31.4	0.52	0.10	
	4 Root mean square of Y-axis (cm)	0.6	0.16	27.5	0.5	0.16	31.9	2.28	0.46	
Area	5 Area surrounding mean path length (1/cm)	23.2	8.03	34.6	30.6	11.44	37.4	3.68†	0.74‡	7 (14%)
	6 Area surrounding maximal amplitude rectangle (cm^2)	6.8	3.12	46.1	6.6	3.31	49.9	0.20	0.04	
	7 Area surrounding root mean square (cm^2)	1.9	0.86	45.9	1.5	0.86	56.0	1.91	0.38	
Position	8 Mean of X-axis (cm)	0.0	0.49	1476.7	0.3	0.68	245.2	2.59	0.52	
	9 Mean of Y-axis (cm)	–0.9	1.84	198.3	–0.1	1.23	883.4	2.50	0.50	
Velocity	10 Mean velocity of X-axis (cm/s)	0.6	0.16	25.9	0.7	0.22	30.1	2.97	0.59	
	11 Mean velocity of Y-axis (cm/s)	0.5	0.11	20.1	0.7	0.16	23.9	5.47†	1.09‡	9 (18%)
	12 Root mean square of sway velocity (cm/s)	1.4	0.29	21.6	1.7	0.40	24.5	4.23†	0.85‡	3 (6%)
Distribution of amplitude	13 Standard deviation of X-axis (cm)	0.4	0.12	28.5	0.4	0.13	31.4	0.52	0.10	
	14 Standard deviation of Y-axis (cm)	0.6	0.16	27.5	0.5	0.16	31.9	2.28	0.46	
	15 Standard deviation of X-axis velocity (cm/s)	1.0	0.26	25.6	1.2	0.36	30.1	2.86	0.57	
	16 Standard deviation of Y-axis velocity (cm/s)	0.9	0.17	20.0	1.1	0.27	24.2	5.22†	1.04‡	8 (16%)
Power spectrum	17 Ratio of A domain for power spectrum of X-axis (%)	29.1	5.33	18.3	26.7	8.05	30.2	1.79	0.36	
	18 Ratio of C domain for power spectrum of X-axis (%)	13.9	2.77	19.9	14.3	3.74	26.2	0.59	0.12	
	19 Ratio of A domain for power spectrum of Y-axis (%)	34.6	5.77	16.7	30.1	8.36	27.8	3.10	0.62	
	20 Ratio of C domain for power spectrum of Y-axis (%)	16.2	3.71	22.9	17.5	5.10	29.1	1.44	0.29	
	21 Ratio of A domain for power spectrum of R-axis (%)	27.7	4.93	17.8	22.8	5.50	24.1	4.60†	0.92‡	
	22 Ratio of C domain for power spectrum of R-axis (%)	15.6	2.51	16.0	18.3	4.30	23.5	3.78†	0.76‡	5 (10%)
	23 Ratio of A domain for power spectrum of X-axis velocity (%)	5.0	1.33	26.8	4.5	2.34	52.2	1.24	0.25	
	24 Ratio of C domain for power spectrum of X-axis velocity (%)	25.2	3.48	13.8	25.6	3.99	15.6	0.49	0.10	
	25 Ratio of A domain for power spectrum of Y-axis velocity (%)	6.2	1.62	26.0	5.1	2.09	41.1	2.98	0.60	
	26 Ratio of C domain for power spectrum of Y-axis velocity (%)	26.8	3.31	12.3	30.2	5.71	18.9	3.54†	0.71‡	7 (14%)
	27 Ratio of A domain for power spectrum of R-axis velocity (%)	8.5	1.34	15.7	8.0	1.71	21.4	1.83	0.37	
	28 Ratio of C domain for power spectrum of R-axis velocity (%)	43.5	3.62	8.3	47.0	4.75	10.1	4.12†	0.82‡	2 (4%)
Vector	29 Mean vector length of A direction sway (cm)	0.7	0.19	26.9	0.6	0.20	32.6	2.13	0.43	
	30 Mean vector length of C direction sway (cm)	0.5	0.17	32.9	0.5	0.16	30.4	0.10	0.02	
	31 Mean vector length of E direction sway (cm)	0.7	0.20	28.2	0.6	0.26	41.5	1.99	0.40	
	32 Mean vector length of G direction sway (cm)	0.5	0.18	33.4	0.5	0.19	36.0	0.29	0.06	
	33 Mean vector length of A direction velocity (cm/s)	0.8	0.18	21.7	1.0	0.26	24.9	5.04†	1.01‡	6 (12%)
	34 Mean vector length of C direction velocity (cm/s)	1.0	0.23	23.8	1.1	0.34	30.2	2.69	0.54	
	35 Mean vector length of E direction velocity (cm/s)	0.8	0.17	20.7	1.1	0.27	25.3	5.29†	1.06‡	9 (18%)
	36 Mean vector length of G direction velocity (cm/s)	1.0	0.23	23.5	1.2	0.33	28.4	3.24	0.65	

†t-value > 3.39, ‡Large difference (ES > 0.80). CV, Coefficient of variation; ES, Effect size. Frequency: Frequency outside of the young adults' mean + 3SD range. $\alpha' = 0.05/36 = 0.00139$, $t(49, 0.00139) = 3.39$.

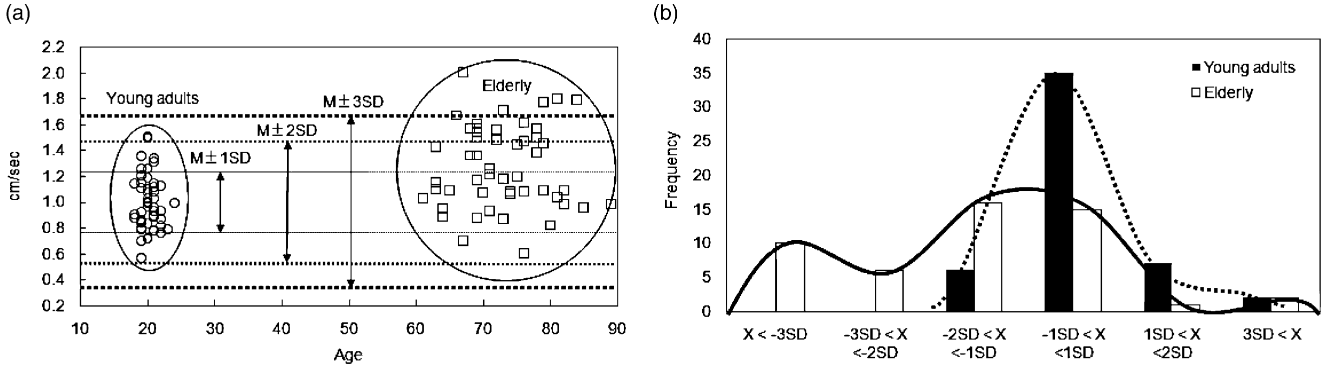


Figure 1 Typical example of frequency differences with standard deviations (SD) for (a) mean path length and (b) high-frequency band power spectrum.

Table 4 Significant differences between mean factor scores for the elderly and young adults and effect size

Factors (parameter number)	Young adults		Elderly		t-value	ES
	M	SD	M	SD		
F1: Unit time sway (1, 10, 11, 12, 15, 16, 33, 34, 35, 36)	–3.5	9.09	3.5	11.88	3.24†	0.65‡
F2: Front-back sway (2, 4, 5, 6, 7, 14, 21, 29, 31)	1.6	3.65	–1.6	5.35	3.39†	0.68‡
F3: Left-right sway (3, 13, 17, 23, 30, 32)	0.9	7.40	–0.9	8.16	1.18	0.24‡
F4: High frequency band power spectrum (18, 20, 22, 24, 26, 27, 28)	0.7	0.92	–0.7	1.53	5.23†	1.05§

†t-value > 2.59. ‡Moderate difference (ES: 0.20–0.79). §Large difference (ES > 0.80). $\alpha' = 0.05/4 = 0.0125$, $t(49,0.0125) = 2.59$.

This study divided the elderly into two groups – those under and over 75 years of age – and examined sex and age-level differences of 36 evaluation parameters. Significant sex and age-level differences were not found in all parameters, and correlations with the age were also low.

Kitabayashi *et al.* reported that a significant sex difference was found in only six of the 36 parameters, but the influence on body sway was not very large because of the moderate effect size.[21] From the present results, it was also judged that the influence of sex and age-level differences on body sway in the elderly can be disregarded; however, the sample size was not large enough to properly examine sex and age-level differences. It will be necessary to examine the above problems with a larger sample size in the future.

Based on the above results that the influence of sex and age-level differences on body sway can be disregarded in the elderly, we examined the reliability of body-sway parameters and factors in the elderly using pooled sex data. The ICC of most parameters were very high at 0.80 and over. Hattori *et al.* reported that the trial-to-trial and day-to-day reliabilities of body-sway parameters were high for the elderly.[22] Therefore, reliability in a static upright posture is also considered to be high in the elderly. It was confirmed that the reliabilities (ICC = 0.72–0.98) of parameters are very high also in young adults, as seen in a previous study.[16]

To determine the body-sway characteristics of the elderly, their values were compared with those of young adults. As a whole, parameters relating to distance, area and vector were larger in the elderly. Their body sway was thus considered to be larger.[8,17] Previous studies have also suggested that the body sway in the elderly is large, based on the results of parameters evaluating the sway size, such as path length.[9,10,14] The components of the functional decline that leads to larger body sway in the elderly are thought to include the following: aging of labyrinth and proprioception systems; decline in lower limb muscle strength needed to maintain posture; and poor adjustment ability of lower limb muscles related to moving bodyweight.[8,10]

Large differences were found in parameters relating to the velocity and spectrum of the total 36 parameters. This suggests that the body sway in the elderly differs remarkably in velocity and periodicity from that in young adults. The activity amount of the elderly as compared with young adults is less.[7] Furthermore, the functions of the labyrinth and proprioception systems and leg muscle strength, which are important to maintain standing posture, decrease in the elderly.[8,10] Hence, body sway in the elderly is considered to involve short and quick sways used to maintain steady posture due to the above influences.

Approximately 10% of the elderly fell outside the area of the young adult distribution. A similar tendency was confirmed for spectrum parameters, especially for high-frequency parameters. The individual difference in the elderly body sway is considered to be large as is the distribution range because of their large CV. Nakagawa *et al.*[23] and Hattori *et al.*[22] suggested that the individual difference in body sway is large in the elderly. From the above, when evaluating the distribution characteristics of their body sway using those of young adults as the criterion, some of them may be judged to be abnormal simply because of their large body sway. Therefore, when evaluating sway characteristics in the elderly, it is necessary to consider their distribution characteristics.[12,23]

Of the four sway factors that can synthetically be used to evaluate body sway,[21] a significant difference was found in three factors (unit time sway, front-back sway and the high-frequency band power), and their differences were interpreted to be moderate or large. As shown in Figure 1(b), distribution characteristics in the high-frequency power factor differ quite a bit from those in young adults.

The fourth factor can be interpreted as a high-frequency band power factor, because it is mainly defined by parameters with a high-frequency band relating to the body sway. Body sway of the high-frequency band beyond 1 Hz reflects the activity of the propriospinal reflex.[15,24] That the periodicity of sway is high frequency means that the body sways mincingly and quickly.

These results suggest that the elderly have individual differences in body sway. Moreover, the body sway in the elderly is considered to involve short and quick sways as the result of the fourth factor. Useful findings were obtained on body-sway characteristics of healthy elderly people.

In summary, most body-sway parameters in the elderly have very high reliability, and the influence of sex and age-level differences in the elderly over 60 years of age on body sway is not very large. The elderly have larger body sway and larger individual differences than do young adults, and the marked differences are found in parameters relating to velocity and periodicity. Furthermore, 10% of the elderly may be judged to fall outside of the young adults' standards for velocity and spectrum parameters. Their body-sway factors show almost the same tendency as the 36 sway parameters. Because of the difference in body-sway characteristics between the elderly and young adults, we may need to design unique criteria for evaluating body sway in the elderly.

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