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Proposal for a new body sway evaluation method [1]

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Summary

This study is aimed at examining body sway factors for 1,107 healthy people aged fifteen to 69 and to propose a practical body sway evaluation method. The center of foot pressure measurement was carried out twice for one minute with a 1 minute rest. Thirty parameters with high reliability selected from six domains (distance, distribution of amplitude, area, velocity, power spectrum, and body sway vector) were summarized objectively into four body sway factors (unit time sway, front-back sway, left-right sway, and high frequency band power). Factor scores were calculated by the estimate equation and the total scores of parameters with high factor loadings. Considering this result, a total score for each factor was classified into four percentile categoris based on percentile rank. Using this classification criteria, body sway scores for each individual were classified into any of the above four percentile categoris for each factor. It was confirmed that young adults mainly belong to percentile categoris A and B and the elderly mainly belong to percentile categoris C and D. It was found that a great effect on body sway occurred when an individual's conscious condition changed (contracting a cold or after exercise). In conclusion, the body sway of healthy people can be explained by these four sway factors. An evaluation of the body sway pattern using the four sway factors may enable us to concretely understand individuals' disorders and abnormal states in addition to changes in body sway that occur with aging.

Introduction

Previous studies have mainly paid attention to discovering the existence of specific disorders and to obtain the underlying clinical application data (Goldie, Bach, & Evans, 1989; Mizuta & Miyata, 1993; Brooke-Wavell, Perrett, Howarth, & Haslam, 2002). Dizziness and wandering appear when an abnormality is found in the visuosensory, vestibular, and proprioceptive organs, or the skeletal muscle of limbs. Hence, until now, the body sway characteristics found in people with these specific disorders have been mainly evaluated from qualitative viewpoints(Japan Society for Equilibrium Reserch,1994). On the other hand, healthy people have small individual variations in body sway and show little specific body sway compared to those with disorders. Hence, it is necessary for them to synthetically evaluate the center of foot pressure movement using multiple parameters (Pyykko, 2000). Tokita, Tokumasu, Imaoka, Murase, & Fukuhara (2001) pointed out that each parameter on the center of foot pressure movement has a respective original test aim, but they evaluate only some aspects of body sway characteristics. Thus, it is necessary to synthetically evaluate the movement with multiple measurements.

Pyykko (2000) and Collins, De Luca, Burrows, & Lipsitz (1995) pointed out that it is not effective to understand body sway with several posture keeping strategies by using a single parameter. Previous studies recorded body sway patterns from the coordinates on bi-dimensional planes and have determined the relationships between body sway patterns and each disorder (Japan Society for Equilibrium, 1994). Kitabayashi, Demura, & Noda (2003) reported that the body sway pattern can be expressed quantitatively 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. Furthermore, the sway pattern can be synthetically understood by the above four factors.

An easy and simple evaluation method of body sway has been long desired in order to determine whether the cause of abnormal sway is attributable to the nervous system, muscle, bone joints, etc. in clinical settings (Tokita, et al., 2001). However, it was difficult using previous evaluation methods to judge whether dizziness and abnormal body sway occurred due to an abnormality in one of these areas. Tokita, et al. (2001) used standard deviations (SD) of some parameters to screen abnormal and normal sways and judged a person beyond 2 standard deviations or more to be abnormal. This method may be effective in distinguishing the body sway of healthy people verses individuals with disorders. However, almost all data of healthy people are concentrated within ±1 standard deviation of average due to small individual variations. Thus, Tokita, et al. (2001)'s approach is not always a valid method.

Demura, Kitabayashi, Noda, Yamada, & Imaoka (2004) reported that the body sway of young adults can be evaluated by four body sway factors. They classified the percentile rank based on individual variation into four domains for each factor and proposed the method of determining each individual's body sway pattern. In addition, it was shown that body sway patterns changed greatly when nerve function was greatly diminished due to alcohol consumption or conscious physical condition abnormalities and defects were present.

However, Demura, et al. (2004) created evaluation criterion for young adults and examined their body sway patterns. Middle-aged and elderly people exhibit considerably different sway than young adults. See also (Collins, et al., 1995). The elderly have decreased capability required to maintain stable posture, and their individual sway variations are also large (Hattori, Starkes, & Takahashi, 1992). The posture of persons with a vision disorder is controlled by information from proprispinal reflection or the vestibular organ system. Thus, sway parameters for young adults are not always useful for the elderly and people may be unable to properly evaluate the body sway of the elderly by evaluation criteria created for young adults. This study was aimed at examining body sway factors of healthy people with a wide age range of 15 to 69 years and at proposing a practical evaluation method of body sway by setting standard values by determining the body pattern of each individual with body sway factors.

Methods

Participants

Table 1 shows the participant's characteristics and breakdown by age-group. Additionally, 162 healthy people in their seventies or higher (males: 78, females: 84) also participated in the experiment to examine validity. The purpose and procedure of this study were explained. Informed consent was obtained from all participants. The experimental protocol was approved by the Ethics committee (Kanazawa University Health & Science Ethics Committee).

[Insert Table 1 about here]

Experimental Procedure

The measurement procedure followed the method prescribed in the standardization of the stabilometry test (Japan Society for Equilibrium Research;1994). The participants maintained a static upright posture with feet together (Romberg posture) for 1 min. The measurement was conducted in one trial. During the test, they were instructed to watch a circular target placed at eye level and to stand barefoot with their arms held comfortably and their eyes open. The measurements began after the subject’s posture and eyes were stable.

Experimental Equipment

The measurement instrument used was a stabilometer G5500 (Anima, Japan). This device can calculate the center of foot pressure movement of vertical loads by using values from three vertical load sensors which were placed on the peak of an isosceles triangle on a level surface. The data sampling frequency was set at 20 Hz.

Evaluation Parameters

Thirty parameters with high trial-to-trial and day-to-day reliability (over ICC=0.8) were selected from the following six domains: distance, area, velocity, distribution of the amplitude, power spectrum, and sway vector. Four factors of unit time sway, front-back sway, left-right sway, and high frequency band power were defined mainly by sway velocity parameters dividing the movement distance by unit time, by parameters evaluating the front and back sway, by parameters evaluating left and right sway, and by parameters with a high frequency band relating to the body sway, respectively. These parameters were compound parameters calculated from center positional parameters of X (right-left) and Y (front-back) directions in two dimensions to evaluate the body sway size. Table2 shows detailed explanation of each parameter.

The correction of sway parameters by physique in this study was not conducted for some of the following reasons: Demura, Kitabayashi, Noda, & Aoki (2008) did not correct by physique despite using the same parameters, and height or weight and thirty sway parameters had very low correlations (r=0.1-0.3) as well as partial correlations (r=0.1-0.2), excluding age effect.

[Insert Table 2 about here]

Data Analysis

A factor analysis with obliques promax-rotation was applied to the correlation matrix (30x30) consisting of 30 parameters calculated by using all participants (n=1107). Factor loadings correspond to correlations between a factor and each parameter. In addition, a factor is generally interpreted based on parameters with higher loading than 0.4 (contribution ratio 16%). Hence, in this study, the total score of standard scores of parameters with loading over 0.4 was used as a factor score considering simplicity. In addition, to clarify score distribution of each factor, after computing the percentile rank of the total score which added standard scores of parameters with loading larger than 0.4 for each factor, we classified the percentile rank into four percentile categories: A (0-25%), B (25-50%), C (50-75%), and D (75-100%)). B and C percentile categories correspond within the range -0.675(25%) -0.675(75%) of standard score (z). Each individual's body sway pattern was determined by the total score which was positioned in one of the above percentile categories.

Results

Table 3 shows the result of the factor analysis. Four factors with the same name (unit time sway, front-back sway, left-right sway and high frequency band power) as those reported by Kitabayashi, et al. (2003) who used young adults were interpreted. Also, parameters with high factor loadings in each factor were almost the same as those of Kitabayashi, et al. (2003), and about 75% of the total variance was explained by them.

[Insert Table 3 about here]

Table 4 shows the correlation between each factor score and the total score in each factor. They were very high ($r > 0.9$).

[Insert Table 4 about here]

Table 5 shows the range values corresponding to each percentile rank (0 to 25% (A), 25 to 50% (B), 50 to 75% (C), 75 to 100% (D)) based on the total score in each factor. Total scores for each factor fell in one of the percentile categories A-D.

[Insert Table 5 about here]

Figure 1 shows the result of computed percentile category frequency of the total group as used as each age group based on the range values showed in Table 5. All factors in all age groups belonged to percentile categories A-D.

When the data are examined according to age group, the teen group was distributed almost evenly (20% - 30%) in four percentile categories, and data in the twenties-forties groups belonged more in the order of A (30% - 40%), B (25% - 30%), C (20% - 25%), and D percentile categories (10% - 20%), except for fourth factor in the thirties group. Although the fifties group data was equally distributed into four percentile categories like the teens group, the sixties group data belonged more in the order of D (25% - 45%), C (25% - 30%), B (15% - 25%), and A percentile categories (10% - 25%).

In order to examine the validity of these range values, data from the seventies group (70 - 90's: 162) was used. Two persons were judged to have an abnormal value (Z) and a majority (60% - 80%) belonged to C and D percentile categories, particularly to D percentile category (40% - 50%). This tendency was found particularly in the first factor.

[Insert Figure 1 about here]

Figure 2 shows an example of body sway pattern change occurring with a change in conscious condition (contracting a cold and after exercise) of a certain person (X). The domain of each factor changed sharply due to this change in conscious condition (in the case of a cold: the first factor A => D, the second factor A => C, the third factor B => D and the fourth factor C => D, after exercise : the first factor A => B, the second factor A => B, the third factor B => D and the fourth factor C => D).

[Insert Figure 2 about here]

Discussion

Kitabayashi, et al. (2003) reported that center of foot pressure sway can be synthetically understood by thirty-six parameters representing seven domains. Moreover, these authors applied the factor analysis to the correlation matrix which consisted of the above parameters obtained from young healthy people and interpreted four body sway factors (unit time sway, front-back sway, left-right sway and high frequency band power). In the present study, the factor analysis was applied to the correlation consisting of the same parameters obtained from 1,107 people from ten to seventy years old. As the result, four factors with the same four names (unit time sway, front-back sway, left-right sway and high frequency band power) were interpreted, and almost all of the same parameters showed high factor loadings to the same factors. It is judged that the body sway of healthy people can be explained by the above four sway factors and that they are useful parameters for evaluating their body sway.

In order to properly evaluate body sway, a simple and clear standard should be established (Tokita, et al., 2001). Demura, et al. (2004) tested a simplified evaluation and interpretation of an individual's body sway using young adults. In short, they established the range values classified into 0 to 25% (A), 25 to 50% (B (1)), 50 to 75% (B (2)), and 75 to 100% (C) percentile categories using percentile rank of the total score in four body sway factors, determined individual’s positions in each sway factor, and found the sway pattern of each individual based on four factors. It was confirmed that this body sway evaluation method has high reliability between trials. However, complicated calculations were required to obtain factor scores using an estimated equation to determine an individual’s body sway. In its place, a method was devised by using the total of standard scores of parameters with high factor loadings. Relationships between the factor scores obtained by the estimate equation and the above total scores in each factor were very high ($r > 0.9$). Hence, it was determined that the property of each factor can be fully evaluated even by the total scores.

Based on this result, the percentile rank of the standard score in each factor was calculated using the same procedure as a previous study (Demura, et al., 2004), and the range values were set corresponding to 0 to 25% (A), 25 to 50% (B), 50 to 75% (C), and 75 to 100% (D) percentile categories. When classifying body sway scores of each individual based on these range values, it was confirmed that all people belonged to A - D percentile categories in all factors. Until now, the following had been clarified: Body sway is closely related to the development of the central nervous system including the cerebral cortex and maturity and aging of the sensory organs, motor organs, etc., and it decreases through infancy and later childhood, reaches the minimum at adolescence, and thereafter increases with age (Hattori, et al., 1992). The same tendency was also confirmed in this study. Thus, the A percentile category is the smallest, and the D percentile category is the largest in terms of the amount of body sway. Although people in the teenage group were equally distributed over four percentile categories when classifying based on the above criterion, more people in the twenties-forties groups belonged more to the A and B percentile categories (55% - 70%). Hence, it is judged that body sway of people in adolescence and middle-age is the smallest and most stable (Hattori, et al., 1972). On the other hand, more people in the sixties group belonged to the C and D percentile categories (50% - 75%). Almost all people (60% - 80%) in the seventy and over age group belonged to the C and D percentile categories. The above suggests that the elderly, with various decreased physical functions, have greater body sway. The unit time sway factor showed large changes with age. Kitabayashi, et al. (2003) reported that this factor is useful in evaluating body sway change due to age and the existence of postural disabilities. This factor reflected markedly a change with age because more individuals belonged to a percentile category in young adults and mainly to D percentile category in the elderly. Hence, it is considered that the present standard score has high validity and classification evaluation based on four percentile categories and is useful to evaluate the body sway of healthy people. Moreover, when examining changes in body sway patterns with a conscious condition (contracting a cold and after exercise) change of a certain individual, the percentile category of each factor changed greatly. In the case of poor or abnormal physical condition, specific unusual input transfer is performed in the central nervous system called visuosensory, vestibular, and proprioceptive organs which are posture control mechanisms. Different sway patterns from usual are also expressed with the occurrence of abnormalities in the output control system of the limbs' skeletal muscles. Also, from the present results, when there were poor or abnormal physical conditions, it was confirmed that the body sway pattern changes greatly. Hence, the present range values also have high validity in individual evaluation, and can evaluate conscious physical abnormalities and defects. In short, this may have a great deal of utility as a simple health indicator.

In conclusion, four body sway factors of unit time sway, front-back sway, left-right sway, and high frequency band power can explain the body sways of healthy people after adolescence, and characteristics of each factor can be evaluated by the total of the scores of parameters with high factor loadings. By determining the body sway pattern based on four sway factors in this study, it can be used to successfully evaluate the body sway change with age, and with disorder or body condition abnormalities in individuals.

This evaluation method, which is based on four body sway factors, is both simple and practical.

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Table 1 Participants characterestics

		age(yr)		height(cm)		weight(kg)	
	n	M	SD	M	SD	M	SD
male	463	35.7	15.9	169.1	6.5	64.2	9.2
female	644	35.6	17.4	156	6.9	51.9	7.1
	n	(male)	(female)		n	(male)	(female)
teens	178	64	114	forties	100	44	56
twenties	380	148	232	fifties	101	36	65
thirties	168	102	66	sixties	180	69	111

Table2 Detailed explanation of each parameter

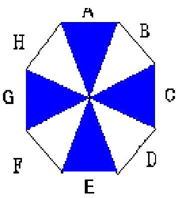
Domains	Parameters	Properties
Distance	Mean path length (cm/sec)	Mean length of center of foot pressure (COP) path
	Root mean square (cm)	Equation : $\sqrt{(1/N\{(\Sigma Xi\text{-}Xmean)^2+\Sigma (Yi\text{-}Ymean)^2\}}$: The dispersion from COP
	Root mean square of X-axis (cm)	Equation : $\sqrt{(1/N(\Sigma Xi\text{-}Xmean)^2}$
	Root mean square of Y-axis (cm)	Equation : $\sqrt{(1/N(\Sigma Yi\text{-}Ymean)^2}$
Area	Area surrounding mean path length (1/cm)	Total path length broken within the circumference area
	Area surrounding maximal amplitude rectangular (cm^2)	Area surrounding the maximal amplitude rectangle for each axis
	Area surrounding root mean square (cm2)	The area of the circle which makes the actual effect value radius
Velocity	Mean velocity of X-axis (cm/sec)	Mean velocity of X-, Y-axis for body-sway
	Mean velocity of Y-axis (cm/sec)	
	Root mean square of sway velocity (cm/sec)	Root mean square of sway velocity
Distribution of amplitude	Standard deviation of X-axis velocity (cm/sec)	Standard deviation of X- and Y-axis velocity
	Standard deviation of Y-axis velocity (cm/sec)	
Power spectrum	Ratio of A domain for power spectrum of X-axis (%)	Power spectrum area by the Fourier translation for the 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; above 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 the 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 8 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/sec)	
	Mean vector length of C direction velocity (cm/sec)	
	Mean vector length of E direction velocity (cm/sec)	
	Mean vector length of G direction velocity (cm/sec)	Mean distance of body-sway velocity in 8 directions (A to H)

Table3 The result of factor analysis for health people (10-70 year old people)

	F1	F2	F3	F4
Root mean square of sway velocity(cm/s)	0.999	0.006	-0.064	-0.041
Mean path length(cm/s)	0.965	-0.005	-0.036	0.083
Standard deviation of X-axis velocity (cm/s)	0.950	0.006	-0.080	-0.026
Mean velocity of X-axis(cm/s)	0.946	-0.002	-0.070	-0.011
Mean vector length of C direction velocity (cm/s)	0.935	-0.002	-0.049	-0.012
Mean vector length of G direction velocity (cm/s)	0.934	0.008	-0.071	-0.025
Mean velocity of Y-axis(cm/s)	0.908	0.010	-0.016	-0.023
Standard deviation of Y-axis velocity (cm/s)	0.906	0.024	-0.027	-0.042
Mean vector length of A direction velocity (cm/s)	0.869	0.024	0.003	-0.032
Mean vector length of E direction velocity (cm/s)	0.866	0.032	-0.018	-0.036
Root mean square of Y-axis(cm)	0.020	0.999	-0.262	0.038
Mean vector length of A direction sway (cm)	0.088	0.817	-0.134	0.035
Mean vector length of E direction sway (cm)	0.033	0.813	-0.102	0.029
Root mean square(cm)	0.205	0.722	0.139	0.057
Area surrounding root mean square(c㎡)	0.222	0.689	0.111	0.062
Ratio of A domain for power spectrum of R-axis(%)	-0.622	0.665	0.137	0.004
Area surrounding maximal amplitude rectangular (c㎡)	0.465	0.455	0.160	-0.030
Area surrounding mean path length (1/cm)	0.045	-0.553	-0.274	0.168
Ratio of A domain for power spectrum of X-axis(%)	-0.382	-0.083	0.970	0.087
Root mean square of X-axis(cm)	0.477	0.026	0.737	0.046
Ratio of A domain for power spectrum of X-axis velocity (%)	-0.294	-0.065	0.726	-0.113
Mean vector length of C direction sway (cm)	0.411	0.037	0.656	0.019
Mean vector length of G direction sway (cm)	0.419	0.057	0.596	0.011
Ratio of C domain for power spectrum of R-axis velocity (%)	-0.003	-0.066	0.063	0.920
Ratio of C domain for power spectrum of X-axis velocity (%)	-0.102	0.027	0.064	0.800
Ratio of C domain for power spectrum of Y-axis velocity (%)	-0.015	0.045	0.029	0.780
Ratio of C domain for power spectrum of R-axis (%)	0.307	-0.178	-0.220	0.542
Ratio of C domain for power spectrum of Y-axis (%)	-0.158	0.284	-0.083	0.494
Ratio of C domain for power spectrum of X-axis (%)	0.024	0.067	-0.091	0.484
Ratio of A domain for power spectrum of R-axis velocity (%)	0.122	0.106	-0.138	-0.516
Contribution rate	43.605	20.681	6.964	4.536
F1	1.000			
F2	0.442	1.000		
F3	0.157	0.574	1.000	
F4	0.234	-0.212	-0.421	1.000

Tabel4 The correlations between factor score and total of standard scores

		standard scores			
		F 1	F 2	F3	F 4
factor score	F1: unit time sway	0.995	0.537	0.313	0.248
	F2: front-back sway	0.477	0.980	0.582	-0.083
	F3: left-right sway	0.060	0.447	0.969	-0.416
	F4: high frequency power band spectrum	0.189	-0.086	-0.319	0.916

Note 1) factor score was computed by the complete estimation method

2) Total of standard scores of parameters with high factor loadings was computed

Table5　The range values equivalent to each percentile rank based on the total of standard scores

	F1	F2	F3	F4
0%	-16.646	-7.563	-9.272	-10.642
25%	-6.115	-3.647	-2.815	-2.830
50%	-1.887	-1.243	-0.444	-0.298
75%	3.688	2.213	2.164	2.478
100%	66.170	50.610	19.528	18.715

	F1	F2	F3	F4
0% or less	S	S	S	S
0～25%	A	A	A	A
25～50%	B	B	B	B
50～75%	C	C	C	C
75～100%	D	D	D	D
100% or more	Z	Z	Z	Z

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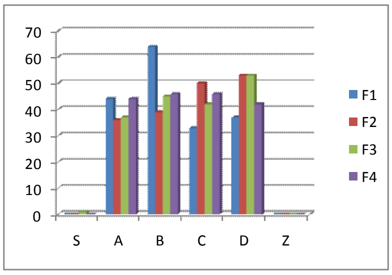
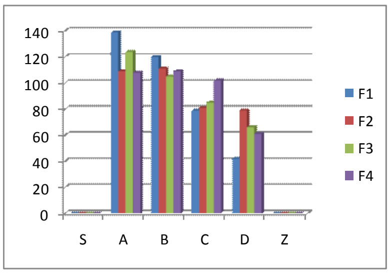
	F1	F2	F3	F4
S	0	0	1	0
A	44	36	37	44
B	64	39	45	46
C	33	50	42	46
D	37	53	53	42
Z	0	0	0	0



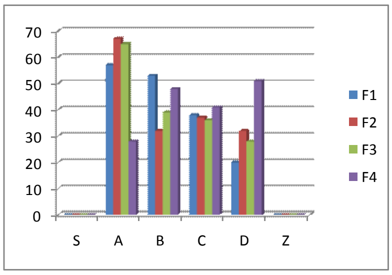
20-29yer 380

	F1	F2	F3	F4
S	0	0	0	0
A	139	109	124	108
B	120	111	105	109
C	79	81	85	102
D	42	79	66	61
Z	0	0	0	0



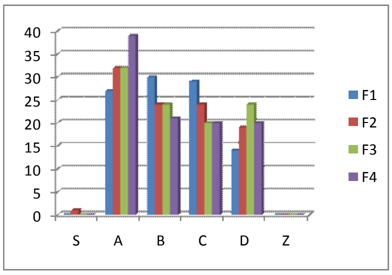
30-39yer 168

	F1	F2	F3	F4
S	0	0	0	0
A	57	67	65	28
B	53	32	39	48
C	38	37	36	41
D	20	32	28	51
Z	0	0	0	0



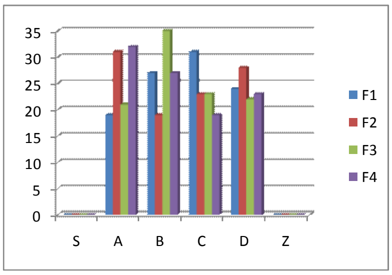
40-49yer 100

	F1	F2	F3	F4
S	0	1	0	0
A	27	32	32	39
B	30	24	24	21
C	29	24	20	20
D	14	19	24	20
Z	0	0	0	0



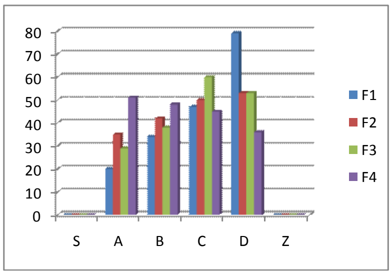
50-59yer 101

	F1	F2	F3	F4
S	0	0	0	0
A	19	31	21	32
B	27	19	35	27
C	31	23	23	19
D	24	28	22	23
Z	0	0	0	0



60-69yer 180

	F1	F2	F3	F4
S	0	0	0	0
A	20	35	29	51
B	34	42	38	48
C	47	50	60	45
D	79	53	53	36
Z	0	0	0	0



70yer or more 162

	F1	F2	F3	F4
S	0	0	0	0
A	8	15	17	23
B	16	39	25	25
C	40	41	50	38
D	97	67	70	74
Z	1	0	0	2

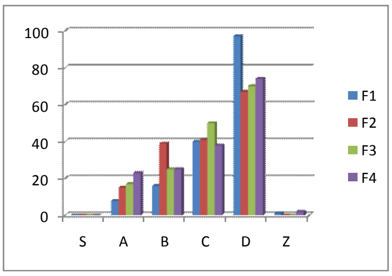
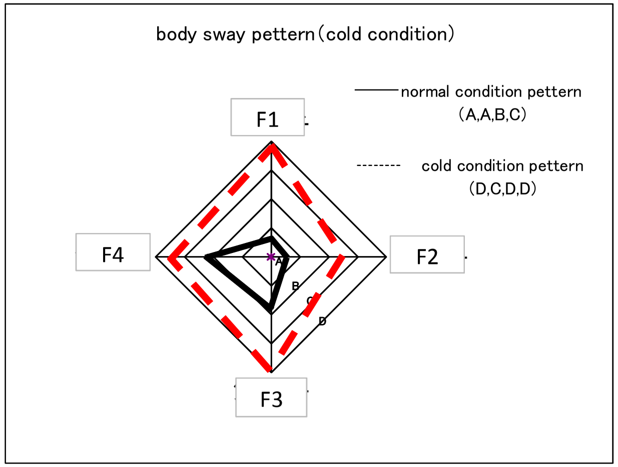
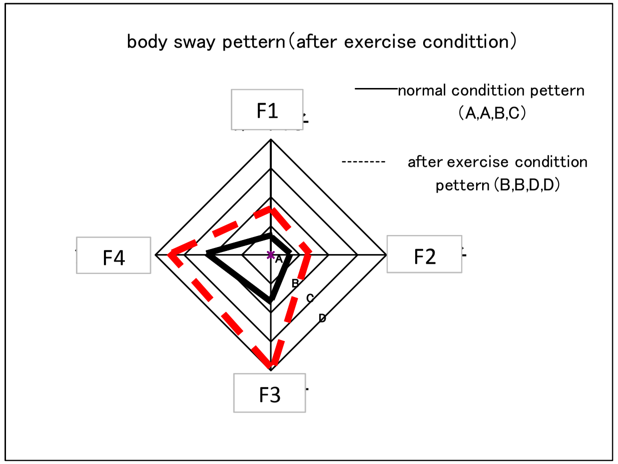


Figure1　The result of having computed the category frequency of age groups (aged 10-60's: 1107 people and aged 70's people) based on the standard point



	small ←→ A	B	C	large D
F1: unit time sway	●			○
F2: front-back sway	●		○	
F3: left-right sway		●		○
F4: high frequency power band spectrum			●	○

	nomal ●		cold ○
F1	A	⇒	D
F2	A	⇒	C
F3	B	⇒	D
F4	C	⇒	D



	small ←→ A	B	C	large D
F1: unit time sway	●	○		
F2: front-back sway	●	○		
F3: left-right sway		●		○
F4: high frequency power band spectrum			●	○

	normal ●		exercise○
F1	A	⇒	B
F2	A	⇒	B
F3	B	⇒	D
F4	C	⇒	D

Figure2 The example of body sway pattern change of the self-conscious condition (cold and after exercise) of certain individual (X)