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【Original Article】

The effect of the package holding on the center of foot pressure

Running Head: Postural control while holding a package

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Abstract

The purpose of this study was to examine the influence of holding a package with one hand on the CFP during a static upright posture. Fifteen healthy male adults participated in this study to keep the posture for 1 minute while holding a weight (7 weight conditions: 0%, 5%, 10%, 20%, 30%, 40%, and 50% of maximal jerk strength) with one hand. Body sway during a static upright posture with each weight was evaluated by the center of foot pressure (CFP) deflection. Before the CFP test, the bilateral difference of body weight was measured with each load weight to reveal the shift of the center of gravity. In the results of one-way ANOVA, the bilateral difference of body weight was significant between the weight conditions, and became significantly higher with increasing weight. On the other hand, the mean factor scores of CFP parameters with an increase of the package weight tended to increase markedly above 30% MVC (Factor 1, 3, and 4) or 40% MVC (Factor 2). There was no significant difference between mean factor scores in load weights from 0% to 30% in any factor. There is little CFP deflection for upright postural control with package weights up to 30% MVC. However, over 40% MVC there is a large CFP deflection, and the tendency is to keep the posture with high frequency CFP sway.

Key words: package weight, static upright posture, jerk strength, factor score

Introduction

In daily living, there are often cases of holding packages with one hand during shopping. The weight of a package in one hand closely relates to posture change and postural control. A person makes an unconscious body change, such as flexion of the upper body against the package, to keep postural control. The package load makes a posture imbalance toward the sagittal plane of the body, and may cause unbalanced walking.

Ghori and Luckwill [1] reported that holding a package with one hand increases the EMG of an ipsilateral lower limb, and effects walking movement patterns. Moreover, previous studies that examined the relation between holding a package and falling in the elderly reported that holding a package increases the incidence rate of falling [2-4]. In a survey on falling while holding a package using healthy elderly, Iiboshi [2] reported that 31.3% of the elderly fell while walking and holding a package, and 35.7% held the package with one hand. A falling accident is a serious matter that can make an aged person bedridden, and it is important to prevent falling.

Until now, there have been few studies on how holding a package with one hand causes a change in the body posture or the center of gravity of body. Useful information may be obtained to prevent falling accidents by revealing the change of body sway while holding a package. First, we observed the center of foot pressure (CFP) in a static upright posture while holding a package with one hand, and focused attention on how package weight causes an increase in body sway. From these examinations, how holding the package with one hand increases the risk of falling may be revealed. The elderly are not valid as subjects to determine the critical weight that markedly increases the CFP because a large load in one hand imposes a great burden on the femur and lumbar vertebra [5, 6].

The purpose of this study was to examine the influence of holding a package with one hand on the CFP in a static upright posture in young adults.

Materials and Methods

Subjects

Fifteen healthy male adults (age: 20.5±2.8 yrs, height: 72.8±5.9 cm, body weight: 67.3±6.9 kg) participated in this study. The subject's physical characteristics were almost the same as the age-matched national standard value [7]. All subjects were informed in advance of the experiment protocol. They agreed to voluntary participate in the experiments. This study was approved by the institution’s human subjects ethics committee.

Experimental condition and Protocol

This study selected 7 relative load weights (0%, 5%, 10%, 20%, 30%, 40%, 50% MVC) based on maximal jerk strength by the dominant hand as the package conditions. The experiment was done with a crossover design: all subjects performed the CFP test for 1 minute, holding each package weight. In the pilot study, we confirmed that the maximal weight load to be able to stand for 1 min while holding a package is 50% MVC. Each subject’s experiment order was allocated at random, and their dominant hand was determined by the Edinburgh Handedness Inventory [8]. All subjects were judged to be right handed.

Measurement device and procedure

1) Jerk strength and grip strength

Maximal jerk strength was measured with a back-dynamometer (TY-300, YAGAMI, JAPAN). Subjects stood up sideways on the plate of the back-dynamometer, and grasped the handle only with the dominant hand. They jerked the handle up slowly and forcefully with shoulder and trunk strength (Figure 1) without flexing the knees. Each subject was also measured for maximal grip strength using the hand-dynamometer (DM-100S, YAGAMI, JAPAN) to determine the relation with the maximal jerk strength. Each measurement was carried out twice, and the higher value was used for data analysis.

***** insert Figure 1 near here *****

2) Body weight

The body may lean to the holding side while holding a package with one hand. In other words, the center of gravity moves to the holding side to keep the body balanced. To confirm the degree of magnitude, the bilateral difference of body weight was measured for each package load. It was defined as the difference between total body weight and body weight on the holding side (right foot) measured with a weighing machine. Subjects were instructed to keep the same measurement posture during both measurements. Each measurement was carried out twice, and the average value was used for data analysis.

3) Center of foot pressure (CFP) and parameters

A stabilometer was used (G5500, Anima, Japan) for CFP measurement. This instrument can calculate the CFP of vertical loads from the values of three vertical load sensors, which are put on the peak of an isosceles triangle on a level surface. Data was sampled at 20 Hz and transferred to a PC following A/D conversion [9-11]. For the CFP measurement , the subject stood on a stabilometer footprint and kept Romberg's posture in which the inside of both feet touch, while looking forward closely at a fixed point. The subject held the package with one hand, and CFP was measured for 1 min when the posture became stable. The CFP measurement for each package load was carried out twice, and the average value was used for further analysis. The rest (sitting position) between trials was 1 minute. All subjects practiced the CFP measurement once prior to the experiment.

The 36 evaluation parameters for CFP deflection were selected for their high trial-to-trial reliability and logical validity [9, 11] (see Table 1). Kitabayashi et al. [12] summarized these parameters into the following four factors using factor analysis: deflection velocity (F1), anteroposterior deflection (F2), lateral direction (F3) and the high frequency band of the power spectrum (F4). Each factor score was calculated using factor score coefficients reported by Kitabayashi et al. [12].

***** insert Table 1 near here *****

4) Data analysis

Trial to trial reliabilities of both maximal strength (jerk and grip) tests were examined using intraclass correlation coefficients (ICC). Pearson's correlation was used to reveal the relation between both strength tests, the package weight and the bilateral difference of body weight. One-way ANOVA was used to reveal the influence of the load weight on the bilateral difference and factor scores for CFP parameters. Tukey's HSD test was used for a multiple comparison test. The level of statistical significance was set at $p<0.05$.

Results

Reliability of maximal jerk and grip strengths

The ICCs of the jerk and grip strengths were very high (ICC=0.96-0.97), and their correlation coefficient was significantly high ($r=0.82$, $p<0.05$).

Relation between the package weight and the bilateral difference of body weight

Figure 2 shows the change of the bilateral difference of body weight with an increase in the package weight, and the result of one-way ANOVA. The bilateral difference of body weight was significant between the weight conditions, and was significantly higher with an increase in weight. Moreover, the linear regression coefficient (dependent parameter: bilateral difference of body weight, independent parameter: package weight) was significant (regression coefficient=1.03, $p<0.05$). The contribution ratio of the load weights of the package was very high (99.86 %).

***** insert Figure 2 near here *****

The influence of holding a package with one hand on the CFP parameters

Figure 3 shows the change of CFP factor scores with an increase in the package weight, and the result of one-way ANOVA. All factors tended to increase markedly above 30% MVC (F1, F3, and F4) or 40% MVC (F2). There was no significant difference between mean factor scores in load weights from 0% to 30% in any factor. A significant difference between mean factor scores, except for F3, was found above 40% MVC.

***** Insert Figure 3 near here ******

Discussion

Iiboshi [2] reported that holding a package lateral to the body with one hand was the most common situation for the elderly who experienced falls when walking and holding a package. It may be easy to lose body balance while walking and holding a package with one hand, but this act is often performed as a daily living activity. To prevent falling, it is important to determine how package weight makes the falling-risk increase. First, we examined the influence of various package weights on the CFP during a static upright posture. Previous studies examining a change of posture or gait while holding a package used a constant load weight [13-15] or a relative load weight based on the individual's grip strength or body weight as the load weight [2, 5, 16]. In daily living, the weight of a package such as a shopping bag is within the limits of holding with one hand, and it may be meaningful to examine the influence of the constant load weight on postural control. However, if the study's aim was to reveal how a package load makes the CFP larger, relative load should be chosen. We developed the maximal jerk strength test using the dominant hand, which was a similar motion to holding a package with one hand. Trial to trial reliability was very high (ICC=0.96) as well as that of grip strength. Although the maximal jerk test may not be popular, it is a valid test to determine the load weight held with one hand.

The maximal jerk strength correlated highly with the grip strength ($r=0.82$, $p<0.05$). Therefore, it may be possible to change it to grip strength. Incidentally, there was no significant correlation between the maximal jerk strength and body weight. The bilateral difference of body weight while holding a package was significantly larger with an increase in package weight except for 0% and 5% MVC. Moreover, the contribution ratio was very high (99.86%), and it is suggested that as package weight increases by 1% MVC, the bilateral difference of body weight increases by approximately 1.03 kg. Namely, the center of body gravity is considered to move to the side of the package in proportion to the load weight when holding above 5% MVC with one hand.

The factor scores of CFP displacement were also larger with an increase of package weight, as was the bilateral difference of body weight. However, there were no significant differences between mean factor scores of 0%, 5%, 10%, 20%, and 30% in any factor. Deflection velocity (F1), lateral deflection (F3), and high frequency band of the power spectrum (F4) tended to be approximately constant until 20% MVC, and to markedly increase over 30% MVC. Although the mean center of body gravity for 1 minute moved in proportion to an increase of the package weight, the CFP displacement changed little until 30% MVC or 40% MVC. A postural control strategy is to keep the body balanced by moving the center of gravity toward the package. However, this strategy can work until the package weight is 30% MVC, but over 40% MVC, it may be hard to keep stability.

Converting data in this study to the absolute package weight, the mean ± SD of maximal jerk strength is 61.2 ±11.8 kg (*ergo*: 30% MVC and 40% MVC correspond to 20.5 kg and 27.27 kg, respectively). If the package weight is below 20.5 kg, postural control may keep the body balanced. Chansirinukor et al. [17] reported that a backpack loaded to over 15% of body weight made it hard to keep postural control in young adults. The package weight in this study, which effects the CFP displacement, may be higher as compared with that of their study. Lee and Lee [13] reported that the CFP distance increased as the position of the package was higher. The disagreement of the findings may due to a difference in the package position.

Rothwell [18] reported that myotatic reflex of the lower limbs in the feedback for postural control was very sensitive, and while modifying the body sway little by little, the cutaneous sense of planta contributes to modifying the body sway. The feedback for postural control by the myotatic reflex of the lower limbs may not be enough with a package weight over 30% MVC, because the deflection velocity (F1) and the high frequency band of power spectrum

(F4) is markedly larger over that of 30% MVC as compared with anteroposterior and lateral deflection (F2 and F3) (see Figure 3).

This study examined the package weight that influences CFP displacement during upright posture using young adult males. There is a possibility that the CFP displacement would be markedly larger over the fixed weight in other age levels. The critical point observed in this study that the CFP displacement is large (40% MVC) may differ in the elderly with a decrease of lower-limb strength. Because holding a package with one hand was determined to effect the body sway during static upright posture, it will be necessary to further examine the effect on gait stability where it is harder to control body balance than it is in a static upright posture.

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Table and Figure captions

Table 1 Characteristics of 36 COP parameters. (Kitabayashi. T. et al., 2003)

Figure 1 Schema of the maximal jerk strength.

Figure 2 Relation between load weight of package (%MVC: x) and the bilateral difference of body mass.

Figure 3 Mean and SD of factor scores of CFP parameters and results of the ANOVA between load weight of package.

Postural control while holding a package

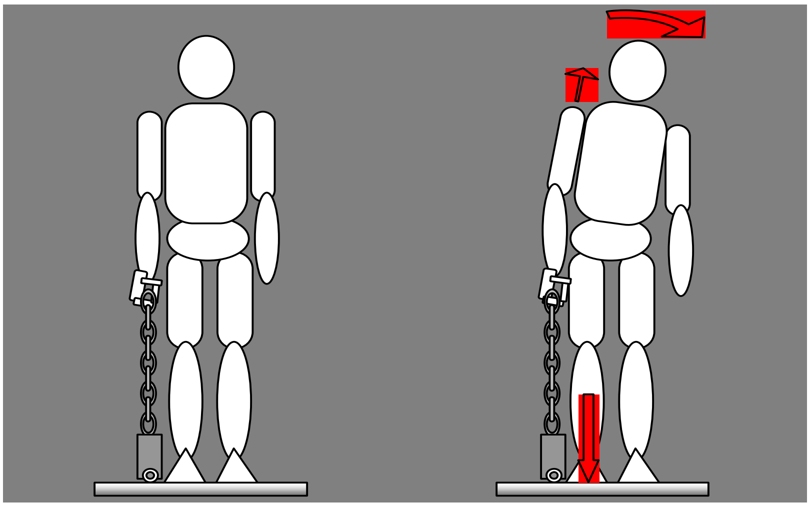


Figure 1

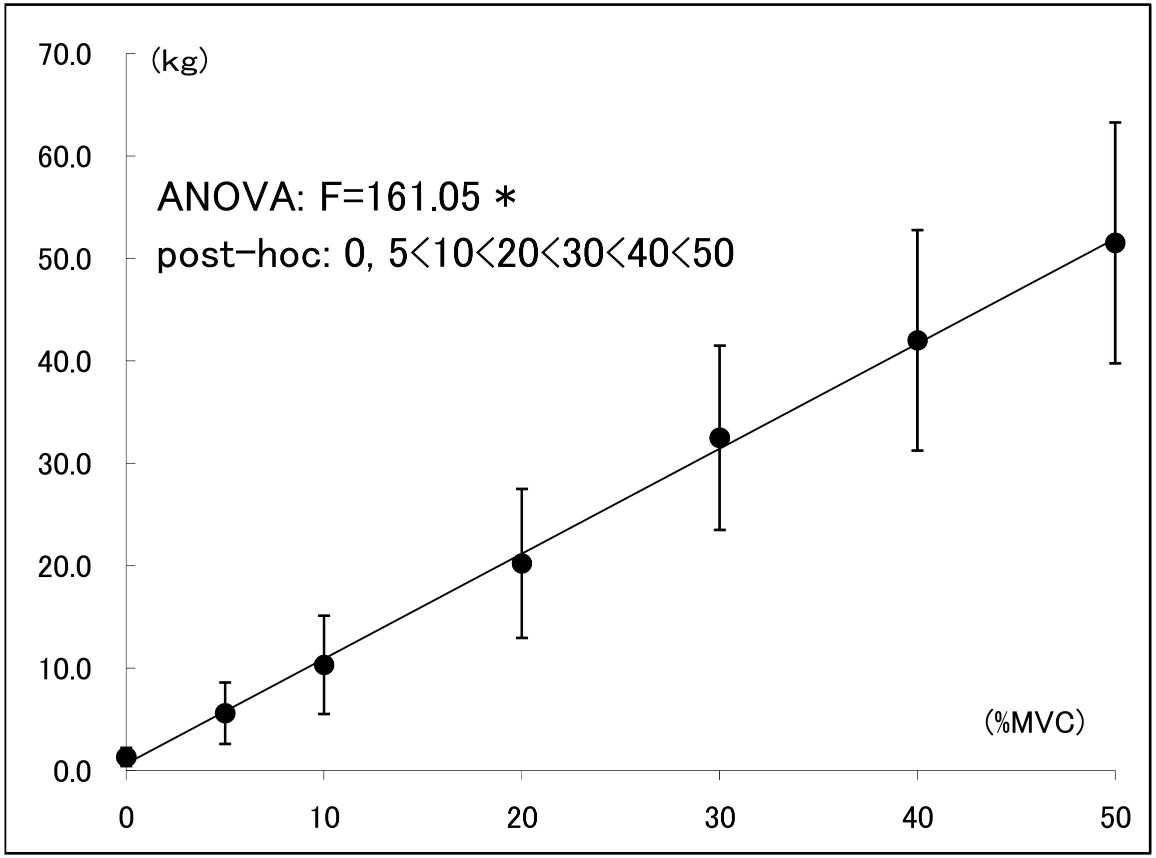


Figure 2 The relation between load weight of package (%MVC: x) and the difference of body mass in bilateral.

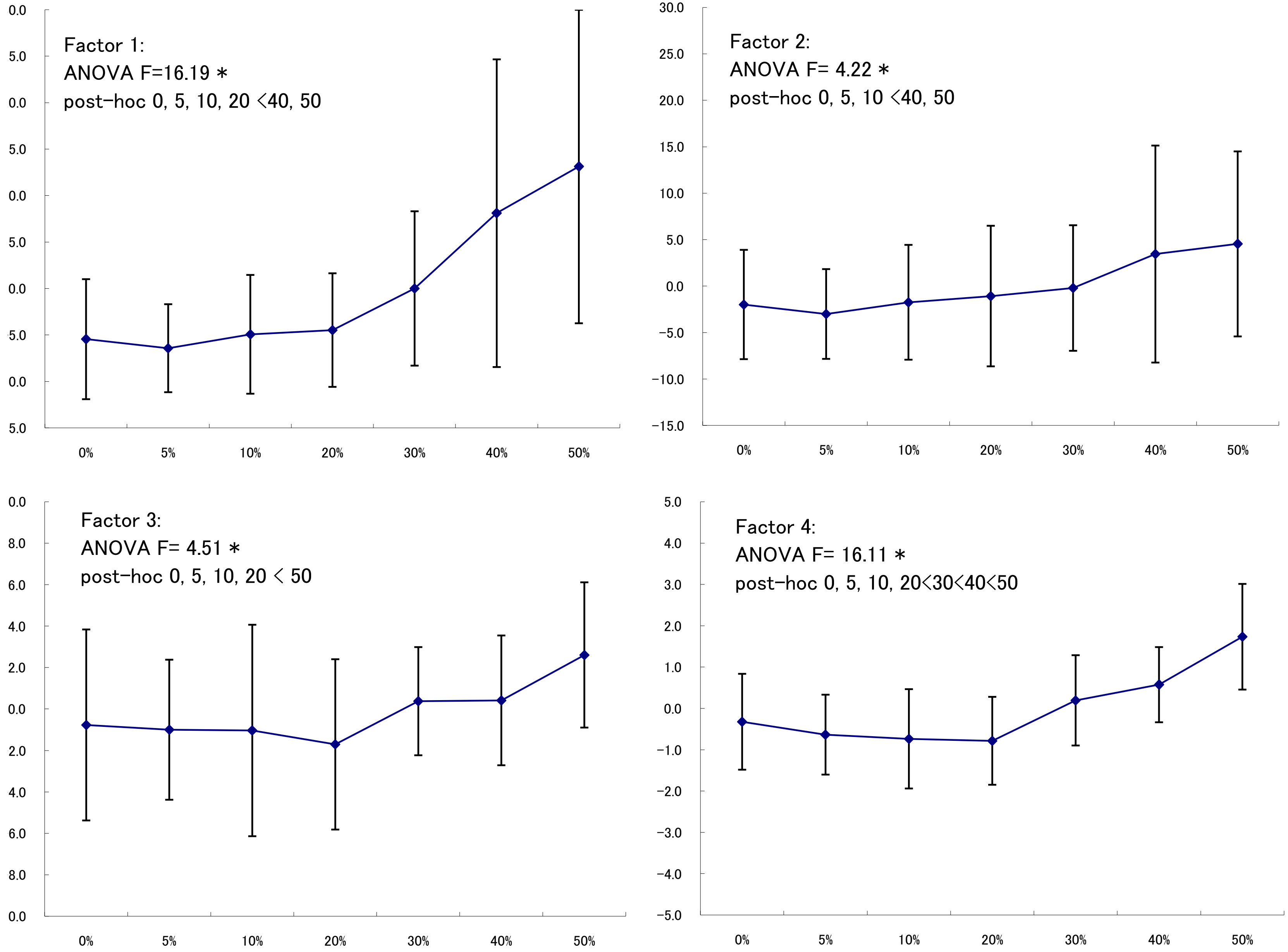
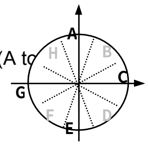

Factor 1:
ANOVA F=16.19 *
post-hoc 0, 5, 10, 20 <40, 50
Factor 2:
ANOVA F= 4.22 *
post-hoc 0, 5, 10 <40, 50
Factor 3:
ANOVA F= 4.51 *
post-hoc 0, 5, 10, 20 < 50
Factor 4:
ANOVA F= 16.11 *
post-hoc 0, 5, 10, 20<30<40<50
0%
5%
10%
20%
30%
40%
50%

Table 1 Characteristics of 36 COP parameters. (Kitabayashi. T. et al., 2003)

Domains	№	Parameters	Unit	Characteristics
Factor 1: Deflection velocity	1	Mean path length	cm/s	Mean length of center of foot pressure (CFP) path
	2	Standard deviation of X-axis sway	cm/s	Equation: $S_x = \sqrt{\sum\left(X_i - \overline{X}\right)^2 / N}$
	3	Standard deviation of Y-axis sway	cm/s	Equation: $S_y = \sqrt{\sum\left(Y_i - \overline{Y}\right)^2 / N}$
	4	Mean velocity of X-axis sway	cm/s	Mean velocity of X-, Y-axis for body-sway
	5	Mean velocity of Y-axis sway	cm/s	
	6	Root mean square of velocity	cm/s	Root mean square of sway velocity
	7	Mean vector length of A direction velocity	cm/s	Mean distance of body-sway velocity in 4 directions (A to 
	8	Mean vector length of C direction velocity	cm/s	
	9	Mean vector length of E direction velocity	cm/s	
	10	Mean vector length of G direction velocity	cm/s	
Factor 2: Anteroposterior deflection	11	Root mean square	cm	Equation: $\sqrt{\left\{\left(\sum X_i - \overline{X}\right)^2 + \left(\sum Y_i - \overline{Y}\right)^2\right\} / N}$ Dispersion from CFP
	12	Root mean square of Y-axis	cm	Equation: $\sqrt{\left(\sum Y_i - \overline{Y}\right)^2 / N}$ Dispersion from CFP for Y-axis
	13	Standard deviation of Y-axis velocity	cm	Standard deviation of Y-axis velocity
	14	Area surrounding mean path length	1/cm	Circumference area divided into total path length
	15	Area surrounding maximal amplitude rectangle	cm^2	Area surrounding maximal amplitude rectangle for each axis
	16	Area surrounding root mean square	cm^2	Area of the circle making the actual effective radius value
	17	Mean vector length of A direction sway	cm	Mean distance of body-sway sway in back and forth directions (A and E)
	18	Mean vector length of E direction sway	cm	
	19	Mean CFP of Y-axis	cm	Mean displacement of CFP for Y-axis
	20	Ratio of A domain for power spectrum of Y-axis	%	Power spectrum area by the furier translate for the body-sway value (Y-, R-direction) divided A domain. A domain; 0-0.2 Hz
	21	Ratio of A domain for power spectrum of R-axis	%	
Factor 3: Lateral didrection	22	Root mean square of X-axis	cm	Equation: $\sqrt{\left(\sum X_i - \overline{X}\right)^2 / N}$ Dispersion from CFP for X-axis
	23	Standard deviation of X-axis velocity	cm	Standard deviation of X-axis velocity
	24	Ratio of A domain for power spectrum of X-axis	%	Power spectrum area by the furier translate for the body-sway and velocity value (X-direction) divided A domain. A domain; 0-0.2 Hz
	25	Ratio of A domain for power spectrum of X-axis veloci	%	
	26	Mean vector length of C direction sway	cm	Mean distance of body-sway in 4 directions (A to H)
	27	Mean vector length of G direction sway	cm	
	28	Ratio of A domain for power spectrum of Y-axis veloci	%	Power spectrum area by the furier translate for the body-sway velocity value (Y-direction) divided A domain
Factor 4: High frequency band of power spectrum	29	Ratio of C domain for power spectrum of X-axis sway	%	Power spectrum area by the furier translate for the body-sway value (X-, Y-, R-direction) divided C domain. C domain; above 2 Hz
	30	Ratio of C domain for power spectrum of Y-axis sway	%	
	31	Ratio of C domain for power spectrum of R-axis sway	%	
	32	Ratio of C domain for power spectrum of X-axis velocity	%	Power spectrum area by the furier translate for the body-sway velocity (X-, Y-, R-direction) dividedC domain. C domain; above 2 Hz
	33	Ratio of C domain for power spectrum of Y-axis velocity	%	
	34	Ratio of C domain for power spectrum of R-axis velocity	%	
	35	Mean CFP of X-axis	cm	Mean displacement of CFP for X-axis
	36	Ratio of A domain for power spectrum of R-axis velocity	%	Power spectrum area by the furier translate for the body-sway velocity (R-direction) divided A domain.