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# Examination of the Factor Structure of Center of Foot Pressure Movement and Cross-validity

Tamotsu Kitabayashi[1], Shinichi Demura[2] and Masahiro Noda[3]

1) Kanazawa University Graduate School of Natural Science and Technology
2) Kanazawa University Faculty of Education
3) Jin-ai University

**Abstract:** This study aimed to determine the factor structure of the center of foot pressure (CFP) movement during static upright posture, and to objectively categorize and summarize parameters to evaluate CFP movement. The subjects were 220 healthy young males and females. The measurement of CFP was carried out 3 times with 1 min rest and the mean of trials 2 and 3 was used for the analysis. The measurement device was an Anima's stabilometer G5500. The data sampling frequency was 20 Hz. Thirty-four parameters with high reliability were selected from the following 6 domains except for the center position which is a fundamental attribute: distance, distribution of amplitude, area, velocity, power spectrum, and body sway vector. Factor analysis (principal factor method and promax rotation) was applied to a correlation matrix consisting of 32 parameters. Four factors abstracted were interpreted as follows; unit time sway, front and back sway, left and right sway and high frequency band of power spectrum. The reliability coefficient (ICC=0.89–0.95) and the congruence coefficient ($\phi$=0.80–0.97) between factors abstracted from the original and the cross-validity groups were very high. It was considered that the CFP movement consists of the above 4 factors that evaluate the amount of body sway and can be synthetically evaluated by them. *J Physiol Anthropol Appl Human Sci 22 (6): 265–272, 2003* http://www.jstage.jst.go.jp/en/

**Keywords:** center of foot pressure (CFP), factor analysis, static upright posture

## Introduction

People with balance function disorders show particular characteristics in center of foot pressure (CFP) movement during static upright posture. For example, it has been determined that people with unilateral labyrinth disability show mediolateral body sway, people with bilateral labyrinth disability, brainstem disability and neuroparalysis show anteroposterior body sway, and people with subfolium disability show diffuse body sway. Therefore, CFP movement has been used clinically as one way to diagnose giddiness or balance function disorder (Baker et al., 1998; Goldie et al., 1989; Geurts et al., 1993; Woolley et al., 1993). Until now, parameters representing the following domains(distance, center average, distribution of the amplitude, area, velocity, power spectrum, and body sway vector)have been used to evaluate the CFP of disordered people (see Table 2). However, effective evaluation parameters for healthy people have not been sufficiently examined. Individual differences of body sway in healthy people are very small, and they do not show characteristic body sway such as with disordered people. It is difficult to properly evaluate their body sway characteristics by only a few parameters. Therefore, it is necessary to synthetically evaluate their CFP movement based on plural parameters (Tokita et al., 2001; Demura et al., 2001; Savelberg et al., 1999; Pyykko, 2000; Collins, 1995). Tokita et al. (2001) pointed out that each parameter measuring CFP movement has a respective original test aim, but they evaluated only a part of the body-sway characteristic, therefore it is necessary to look at it synthetically based on multiple measurement values. Pyykko (2000) and Collins (1995) indicated sway area, sway path, root mean square value of sway amplitude, power spectra, sway velocity, and performance ratio as CFP movement domains, and pointed out that CFP movement with several posture-keeping strategies cannot be synthetically understood by a single domain. Evaluation parameters of CFP movement are theoretically categorized into the following 7 domains from characteristics of the CFP trajectory: distance, center average, distribution of the amplitude, area, velocity, power spectrum, and body sway vector (Demura et al., 2001; Mizuta et al., 1993). Demura et al. (2001) and Kitabayashi et al. (2002) examined, after compiling 114 parameters used so far in many studies, the trial-to-trial and day-to-day reliabilities, interrelationships between parameters and gender differences, and reported that the characteristics of CFP movement can be synthetically understood from 36 parameters representing the above-stated 7 domains. However, these parameters are basically categorized based on a theoretical hypothesis, and are compound parameters calculated from the two-dimensional coordinates of the center position of X (right-left) and Y (front-back) in evaluating the amount of body sway. Demura et al. (2001) and Goldie et al. (1989) reported that center position parameters do not show significant relationships with other parameters evaluating the amount of body sway, and they have different unique characteristics from the latter ones. Therefore, center position parameters are valid to use distinct from other parameters.

There are close relationships between parameters representing each domain, and this suggests that parameters with the same characteristics exist (Kitabayashi et al., 2002). Body sway is the result of various afferent signals and various factors are involved in the information transmission process. Therefore, it is assumed that some common latent characteristics exist behind their parameters. Namely, there is a high possibility that CFP parameters are categorized objectively and synthetically into some domains different from theoretical domains (i.e. factors), based on connections between parameters.

Factor analysis is an effective analysis procedure to achieve the above-stated purpose. The purpose of this study was to determine the factor structure of CFP movement using factor analysis and to examine the reliability and cross-validity of interpreted factors.

## Methods

### *Subjects*

Subjects were 220 healthy young adults. They had no evidence or known history of a gait, posture, or skeletal disorder. In addition, 50 healthy young adults were selected at random from the 220 subjects to examine cross validity. Table 1 shows the characteristics of both groups. Before the measurements, the purpose and procedure of this study were explained in detail to subjects. Informed consent was obtained from all subjects.

### *Experimental instrument*

The measurement instrument used was an Anima's stabilometer G5500. This instrument can calculate 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 sampling frequency was recorded at 20 Hz.

### *Experimental procedure*

The measurement procedure followed a method prescribed in the standardized stabilometry test (the Japan Society for Equilibrium, 1994). Subjects held a static upright posture with closed feet (Romberg posture) for 1 min, and after that were instructed to watch a circular achromatic target placed at eye level. Measurement was started after the subject's posture and eyes were stable. The CFP movement was measured 3 times with a 1 min rest period. During the testing, the subjects stood bare-footed with their arms held comfortably and their eyes open. Subjects were instructed not to change the position of their feet on the plate during a rest period in a sitting position.

### *Evaluation parameters*

We examined all parameters used before from the viewpoints of theoretical validity, reliability (ICC) and their relationships, and selected thirty-four effective parameters representing the following 6 domains: distance (4 parameters), area (3 parameters), velocity (3 parameters) and the amplitude distribution (4 parameters), the power spectrum (6 position parameters and 6 velocity parameters) and the vector (4 position parameters and 4 velocity parameters) (see Table 2) (Demura et al., 2001; Yamaji et al., 2001; Kitabayashi et al., 2002).

### *Data Analysis*

Trial-to-trial reliability was examined by the intraclass correlation coefficient (ICC), and relationships between parameters were done by Pearson's product-moment correlation coefficient. The mean of trials 2 and 3 was used as a representative value for the analysis. Factor analysis used the principal factor method and oblique solution by promax-rotation. Factor scores were calculated by the complete estimation method, and the reliability of each factor was examined. The same factor analysis was applied to the correlation matrix made up from the data of the cross-validity group to examine cross validity, and the congruence coefficient was calculated between factors (Harry H. Harman, 1976).

## Results

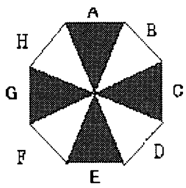
Table 2 shows means, standard deviations and reliability coefficients (ICC) of 34 CFP movement parameters and Table

**Table 1** Characteristics of original and cross-validity groups

| | original group (n=220) | | cross-validity group (n=50) | |
|---|---|---|---|---|
| | Male (n=108) | Female (n=112) | Male (n=25) | Female (n=25) |
| Age (yr) | 20.1±1.6 | 19.6±1.4 | 20.8±1.6 | 19.8±1.1 |
| Height (cm) | 173.3±5.5 | 161.0±5.8 | 174.3±5.9 | 160.4±5.8 |
| Weight (kg) | 67.0±7.9 | 54.3±6.1 | 67.6±7.8 | 53.8±6.0 |

Note) mean±SD

**Table 2** Means, Standard deviations and ICCs of 34 CFP parameters

| Domains | | Parameters | Properties | M | SD | ICC |
|---|---|---|---|---|---|---|
| Distance | 1 | Mean path length (cm/sec) | Mean length of center of foot pressure (CFP) path | 1.1 | 0.27 | 0.97 |
| | 2 | Root mean square (cm) | Equation: $\sqrt{[1/N\{\Sigma(Xi-Xmean)^2+\Sigma(Yi-Ymean)^2\}]}$ : Dispersion from CFP | 0.8 | 0.27 | 0.92 |
| | 3 | Root mean square of X-axis (cm) | Equation: $\sqrt{\{1/N\,\Sigma(Xi-Xmean)^2\}}$ | 0.5 | 0.15 | 0.94 |
| | 4 | Root mean square of Y-axis (cm) | Equation: $\sqrt{\{1/N\,\Sigma(Xi-Xmean)^2\}}$ | 0.6 | 0.26 | 0.86 |
| Area | 5 | Area surrounding mean path length (1/cm) | Total path length was broken within the circumference area | 22.5 | 9.03 | 0.92 |
| | 6 | Area surrounding maximal amplitude rectangle ($cm^2$) | Area surrounding maximal amplitude rectangle for each axis | 7.9 | 4.76 | 0.93 |
| | 7 | Area surrounding root mean square ($cm^2$) | Area of the circle making the actual effective radius value | 2.2 | 1.82 | 0.90 |
| Velocity | 8 | Mean velocity of X-axis (cm/sec) | Mean velocity of X-, Y-axis for body-sway | 0.7 | 0.18 | 0.96 |
| | 9 | Mean velocity of Y-axis (cm/sec) | | 0.6 | 0.15 | 0.96 |
| | 10 | Root mean square of sway velocity (cm/sec) | Root mean square of sway velocity | 1.5 | 0.37 | 0.96 |
| Distribution of amplitude | 11 | Standard deviation of X-axis (cm) | Equation: $Sx=\sqrt{(1/N\,\Sigma(Xi-Xmean)^2)}$ | 0.5 | 0.15 | 0.94 |
| | 12 | Standard deviation of Y-axis (cm) | Equation: $Sy=\sqrt{(1/N\,\Sigma(Yi-Ymean)^2)}$ | 0.6 | 0.26 | 0.86 |
| | 13 | Standard deviation of X-axis velocity (cm/sec) | Standard deviation of X- and Y-axis velocity | 1.1 | 0.30 | 0.96 |
| | 14 | Standard deviation of Y-axis velocity (cm/sec) | | 0.9 | 0.25 | 0.96 |
| Power spectrum | 15 | Ratio of A domain for power spectrum of X-axis (%) | Power spectrum area by the fournier translate 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; above 2 Hz | 29.6 | 6.37 | 0.82 |
| | 16 | Ratio of C domain for power spectrum of X-axis (%) | | 14.0 | 3.63 | 0.82 |
| | 17 | Ratio of A domain for power spectrum of Y-axis (%) | | 33.3 | 6.55 | 0.72 |
| | 18 | Ratio of C domain for power spectrum of Y-axis (%) | | 16.7 | 4.84 | 0.73 |
| | 19 | Ratio of A domain for power spectrum of R-axis (%) | | 27.3 | 6.42 | 0.80 |
| | 20 | Ratio of C domain for power spectrum of R-axis (%) | | 15.8 | 3.65 | 0.89 |
| | 21 | Ratio of A domain for power spectrum of X-axis velocity (%) | Power spectrum area by the furier translate 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 | 5.2 | 1.56 | 0.91 |
| | 22 | Ratio of C domain for power spectrum of X-axis velocity (%) | | 25.2 | 3.80 | 0.93 |
| | 23 | Ratio of A domain for power spectrum of Y-axis velocity (%) | | 5.9 | 1.70 | 0.90 |
| | 24 | Ratio of C domain for power spectrum of Y-axis velocity (%) | | 27.0 | 3.60 | 0.95 |
| | 25 | Ratio of A domain for power spectrum of R-axis velocity (%) | | 8.7 | 1.49 | 0.88 |
| | 26 | Ratio of C domain for power spectrum of R-axis velocity (%) | | 43.5 | 3.99 | 0.94 |
| Vector | 27 | Mean vector length of A direction sway (cm) | Mean distance of body-sway in 8 directions (A to H) | 0.8 | 0.33 | 0.82 |
| | 28 | Mean vector length of C direction sway (cm) |  | 0.6 | 0.20 | 0.87 |
| | 29 | Mean vector length of E direction sway (cm) | | 0.8 | 0.33 | 0.83 |
| | 30 | Mean vector length of G direction sway (cm) | | 0.6 | 0.22 | 0.84 |
| | 31 | Mean vector length of A direction velocity (cm/sec) | | 0.9 | 0.24 | 0.95 |
| | 32 | Mean vector length of C direction velocity (cm/sec) | | 1.1 | 0.28 | 0.95 |
| | 33 | Mean vector length of E direction velocity (cm/sec) | | 0.9 | 0.24 | 0.95 |
| | 34 | Mean vector length of G direction velocity (cm/sec) | Mean distance of body-sway velocity in 8 directions (A to H) | 1.1 | 0.29 | 0.95 |



Note) M: mean , SD: standard deviation , ICC: Intraclass correlation coefficient , CFP: center of foot pressure

3 shows their correlation coefficients (N=220). Almost all ICCs had a very high value of over 0.80 except some power spectrum parameters.

Correlation coefficients between parameters in each domain were generally significant and very high, and the coefficients between parameters representing domains except the power spectrum were significant (see Table 3).

As a result of factor analysis, 4 factors with an eigen value over 1.0 were extracted. Eliminating two parameters with very low factor loading and communality (Ratio of A domain for position and velocity powers on Y-axis: see Table 2), factor analysis was again applied to the correlation matrix. An oblique factor pattern matrix shown in Table 4 was obtained. Table 5 shows the correlations coefficients between interpreted factors. The coefficient (r=0.48) between the second and third factors was the highest, and they were significant but moderate except for the value (r=−0.18) between the second and fourth factors. Table 6 shows reliability coefficients of each factor and relationships between factor scores calculated by the complete estimation method in the original and the cross-validity groups. Reliability (ICC=0.89–0.95) of the 4 factors was very high. To examine cross validity, the same factor analysis was applied to the correlation matrix obtained from the cross-validity group. As a result, 4 factors with the same name were extracted. The congruence coefficient ($\phi$=0.80–0.97) and correlation coefficients (r=0.83–0.89) between the factors obtained in both groups were very high (see Table 6).

**Table 3** Correlation coefficients between 34 parameters

| Domains | | Parameters | Distance | | | | Area | | | Velocity | | | Distribution of amplitude | | | | Power spectrum | | | | | | | | | | | | Vector | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| Distance | 1 | Mean path length (cm/sec) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 2 | Root mean square (cm) | 0.462 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 3 | Root mean square of X-axis (cm) | 0.580 | 0.687 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Root mean square of Y-axis (cm) | 0.337 | 0.948 | 0.429 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Area | 5 | Area surrounding mean path length (1/cm) | −0.288 | −0.791 | −0.674 | −0.708 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6 | Area surrounding maximal amplitude rectangular ($cm^2$) | 0.629 | 0.907 | 0.784 | 0.804 | −0.729 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Area surrounding root mean square ($cm^2$) | 0.409 | 0.958 | 0.591 | 0.931 | −0.648 | 0.879 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Velocity | 8 | Mean velocity of X-axis (cm/sec) | 0.952 | 0.422 | 0.549 | 0.302 | −0.273 | 0.578 | 0.365 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 9 | Mean velocity of Y-axis (cm/sec) | 0.907 | 0.480 | 0.571 | 0.361 | −0.329 | 0.652 | 0.437 | 0.755 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 10 | Root mean square of sway velocity (cm/sec) | 0.993 | 0.474 | 0.594 | 0.347 | −0.316 | 0.648 | 0.421 | 0.959 | 0.906 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Distribution of amplitude | 11 | Standard deviation of X−axis (cm) | 0.580 | 0.687 | 0.988 | 0.429 | −0.674 | 0.784 | 0.591 | 0.549 | 0.571 | 0.594 | | | | | | | | | | | | | | | | | | | | | | | | |
| | 12 | Standard deviation of Y-axis (cm) | 0.337 | 0.948 | 0.429 | 0.982 | −0.708 | 0.804 | 0.931 | 0.302 | 0.361 | 0.347 | 0.429 | | | | | | | | | | | | | | | | | | | | | | | |
| | 13 | Standard deviation of X-axis velocity (cm/sec) | 0.950 | 0.421 | 0.551 | 0.300 | −0.274 | 0.580 | 0.365 | 0.998 | 0.754 | 0.960 | 0.551 | 0.300 | | | | | | | | | | | | | | | | | | | | | | |
| | 14 | Standard deviation of Y−axis velocity (cm/sec) | 0.909 | 0.483 | 0.570 | 0.365 | −0.330 | 0.654 | 0.442 | 0.760 | 0.998 | 0.910 | 0.570 | 0.365 | 0.759 | | | | | | | | | | | | | | | | | | | | | |
| Power spectrum | 15 | Ratio of A domain for power spectrum of X-axis (%) | −0.155 | 0.295 | 0.452 | 0.176 | −0.481 | 0.292 | 0.236 | −0.218 | −0.020 | −0.148 | 0.452 | 0.176 | −0.214 | −0.025 | | | | | | | | | | | | | | | | | | | | |
| | 16 | Ratio of C domain for power spectrum of X-axis (%) | 0.012 | −0.041 | −0.008 | −0.062 | 0.143 | −0.082 | −0.029 | −0.027 | −0.004 | −0.017 | −0.008 | −0.062 | −0.033 | 0.006 | −0.339 | | | | | | | | | | | | | | | | | | | |
| | 17 | Ratio of A domain for power spectrum of Y-axis (%) | −0.110 | 0.296 | 0.151 | 0.325 | −0.382 | 0.259 | 0.249 | −0.075 | −0.124 | −0.103 | 0.151 | 0.325 | −0.078 | −0.125 | 0.284 | −0.140 | | | | | | | | | | | | | | | | | | |
| | 18 | Ratio of C domain for power spectrum of Y-axis (%) | −0.059 | 0.083 | −0.065 | 0.124 | −0.016 | −0.031 | 0.054 | −0.052 | −0.135 | −0.090 | −0.065 | 0.124 | −0.054 | −0.128 | −0.096 | 0.188 | −0.388 | | | | | | | | | | | | | | | | | |
| | 19 | Ratio of A domain for power spectrum of R-axis (%) | −0.232 | 0.506 | 0.221 | 0.531 | −0.580 | 0.350 | 0.453 | −0.251 | −0.149 | −0.226 | 0.221 | 0.531 | −0.251 | −0.152 | 0.469 | −0.149 | 0.497 | −0.066 | | | | | | | | | | | | | | | | |
| | 20 | Ratio of C domain for power spectrum of R-axis (%) | 0.154 | −0.271 | −0.222 | −0.249 | 0.446 | −0.247 | −0.244 | 0.124 | 0.070 | 0.107 | −0.222 | −0.249 | 0.118 | 0.066 | −0.372 | 0.256 | −0.403 | 0.393 | −0.534 | | | | | | | | | | | | | | | |
| | 21 | Ratio of A domain for power spectrum of X-axis velocity (%) | −0.198 | 0.198 | 0.346 | 0.105 | −0.438 | 0.244 | 0.159 | −0.274 | −0.004 | −0.175 | 0.346 | 0.105 | −0.270 | −0.010 | 0.822 | −0.145 | 0.201 | −0.174 | 0.404 | −0.373 | | | | | | | | | | | | | | |
| | 22 | Ratio of C domain for power spectrum of X-axis velocity (%) | 0.090 | −0.065 | −0.072 | −0.051 | 0.179 | −0.079 | −0.062 | 0.009 | 0.040 | 0.020 | −0.072 | −0.051 | 0.006 | 0.044 | −0.164 | 0.381 | −0.027 | 0.153 | −0.146 | 0.255 | −0.269 | | | | | | | | | | | | | |
| | 23 | Ratio of A domain for power spectrum of Y-axis velocity (%) | −0.270 | 0.173 | 0.073 | 0.201 | −0.346 | 0.149 | 0.137 | −0.204 | −0.271 | −0.241 | 0.073 | 0.201 | −0.197 | −0.271 | 0.285 | −0.158 | 0.722 | −0.204 | 0.398 | −0.349 | 0.314 | −0.175 | | | | | | | | | | | | |
| | 24 | Ratio of C domain for power spectrum of Y-axis velocity (%) | 0.150 | −0.028 | −0.037 | −0.031 | 0.157 | −0.078 | −0.017 | 0.140 | −0.011 | 0.081 | −0.037 | −0.031 | 0.136 | −0.012 | −0.160 | 0.188 | −0.176 | 0.299 | −0.097 | 0.391 | −0.261 | 0.483 | −0.356 | | | | | | | | | | | |
| | 25 | Ratio of A domain for power spectrum of R-axis velocity (%) | −0.093 | 0.082 | 0.073 | 0.071 | −0.141 | 0.114 | 0.089 | −0.080 | −0.006 | −0.040 | 0.073 | 0.071 | −0.064 | 0.001 | 0.158 | −0.190 | −0.018 | −0.046 | 0.123 | −0.166 | 0.250 | −0.395 | 0.143 | −0.284 | | | | | | | | | | |
| | 26 | Ratio of C domain for power spectrum of R-axis velocity (%) | 0.173 | −0.142 | −0.163 | −0.119 | 0.336 | −0.200 | −0.130 | 0.152 | 0.007 | 0.092 | −0.163 | −0.119 | 0.140 | 0.009 | −0.304 | 0.342 | −0.187 | 0.263 | −0.228 | 0.435 | −0.472 | 0.633 | −0.400 | 0.653 | −0.542 | | | | | | | | | |
| Vector | 27 | Mean vector length of A direction sway (cm) | 0.327 | 0.869 | 0.421 | 0.909 | −0.660 | 0.751 | 0.853 | 0.295 | 0.344 | 0.335 | 0.421 | 0.909 | 0.293 | 0.349 | 0.178 | −0.040 | 0.296 | 0.190 | 0.444 | −0.185 | 0.089 | −0.018 | 0.188 | −0.038 | 0.038 | −0.035 | | | | | | | | |
| | 28 | Mean vector length of C direction sway (cm) | 0.460 | 0.471 | 0.767 | 0.254 | −0.518 | 0.559 | 0.391 | 0.443 | 0.443 | 0.474 | 0.767 | 0.254 | 0.452 | 0.440 | 0.375 | −0.021 | 0.066 | −0.089 | 0.130 | −0.197 | 0.310 | −0.165 | 0.084 | −0.026 | 0.097 | −0.239 | 0.233 | | | | | | | |
| | 29 | Mean vector length of E direction sway (cm) | 0.341 | 0.872 | 0.453 | 0.895 | −0.678 | 0.772 | 0.840 | 0.301 | 0.371 | 0.351 | 0.453 | 0.895 | 0.303 | 0.370 | 0.192 | −0.079 | 0.372 | −0.006 | 0.476 | −0.306 | 0.156 | −0.062 | 0.256 | −0.029 | 0.109 | −0.148 | 0.700 | 0.323 | | | | | | |
| | 30 | Mean vector length of G direction sway (cm) | 0.478 | 0.541 | 0.811 | 0.331 | −0.538 | 0.633 | 0.476 | 0.443 | 0.470 | 0.478 | 0.811 | 0.331 | 0.436 | 0.470 | 0.398 | −0.025 | 0.265 | −0.125 | 0.179 | −0.209 | 0.305 | 0.007 | 0.113 | −0.046 | −0.028 | −0.263 | 0.363 | 0.548 | 0.348 | | | | | |
| | 31 | Mean vector length of A direction velocity (cm/sec) | 0.883 | 0.449 | 0.536 | 0.340 | −0.311 | 0.626 | 0.405 | 0.745 | 0.957 | 0.880 | 0.536 | 0.340 | 0.740 | 0.956 | −0.022 | −0.017 | −0.102 | −0.125 | −0.159 | 0.074 | −0.018 | 0.029 | −0.242 | −0.013 | −0.038 | 0.012 | 0.324 | 0.407 | 0.349 | 0.460 | | | | |
| | 32 | Mean vector length of C direction velocity (cm/sec) | 0.920 | 0.448 | 0.562 | 0.332 | −0.314 | 0.613 | 0.390 | 0.964 | 0.733 | 0.930 | 0.562 | 0.332 | 0.968 | 0.736 | −0.171 | −0.076 | −0.047 | −0.056 | −0.216 | 0.097 | −0.234 | −0.008 | −0.143 | 0.100 | −0.070 | 0.101 | 0.313 | 0.455 | 0.346 | 0.439 | 0.719 | | | |
| | 33 | Mean vector length of E direction velocity (cm/sec) | 0.886 | 0.458 | 0.552 | 0.338 | −0.298 | 0.616 | 0.415 | 0.739 | 0.954 | 0.878 | 0.552 | 0.338 | 0.736 | 0.958 | −0.042 | 0.028 | −0.124 | −0.120 | −0.153 | 0.086 | −0.044 | 0.089 | −0.283 | 0.014 | −0.042 | 0.070 | 0.311 | 0.425 | 0.364 | 0.470 | 0.909 | 0.719 | | |
| | 34 | Mean vector length of G direction velocity (cm/sec) | 0.939 | 0.372 | 0.524 | 0.249 | −0.236 | 0.534 | 0.314 | 0.966 | 0.777 | 0.949 | 0.524 | 0.249 | 0.969 | 0.780 | −0.229 | −0.013 | −0.108 | −0.065 | −0.299 | 0.131 | −0.257 | −0.015 | −0.230 | 0.113 | −0.061 | 0.111 | 0.261 | 0.435 | 0.246 | 0.411 | 0.761 | 0.921 | 0.759 | |

Note) ⁘ means high correlation coefficients ($r>0.80$)
The parameter number corresponds to the number in Table 2

**Table 4** Oblique factor pattern matrix of 32 parameters

| No | Parameter | F1 | F2 | F3 | F4 | Communality |
|---|---|---|---|---|---|---|
| 10 | Root mean square of sway velocity | 0.987 | 0.012 | −0.033 | −0.047 | 0.979 |
| 34 | Mean vector length of G direction velocity | 0.967 | −0.048 | −0.088 | −0.042 | 0.948 |
| 1 | Mean path length | 0.959 | 0.010 | −0.010 | 0.055 | 0.923 |
| 13 | Standard deviation of X-axis velocity | 0.937 | 0.008 | −0.074 | −0.001 | 0.884 |
| 8 | Mean velocity of X-axis | 0.935 | 0.011 | −0.074 | 0.010 | 0.880 |
| 32 | Mean vector length of C direction velocity | 0.894 | 0.041 | −0.055 | −0.020 | 0.805 |
| 14 | Standard deviation of Y-axis velocity | 0.872 | 0.025 | 0.054 | −0.087 | 0.771 |
| 9 | Mean velocity of Y-axis | 0.869 | 0.019 | 0.061 | −0.088 | 0.767 |
| 31 | Mean vector length of A direction velocity | 0.854 | 0.011 | 0.042 | −0.087 | 0.739 |
| 33 | Mean vector length of E direction velocity | 0.835 | 0.012 | 0.069 | −0.019 | 0.702 |
| 12 | Standard deviation of Y-axis | 0.000 | 0.979 | −0.180 | 0.018 | 0.991 |
| 4 | Root mean square of Y-axis | 0.000 | 0.979 | −0.180 | 0.018 | 0.991 |
| 27 | Mean vector length of A direction sway | 0.008 | 0.855 | −0.117 | 0.057 | 0.748 |
| 7 | Area surrounding root mean square | 0.079 | 0.808 | 0.032 | 0.040 | 0.661 |
| 29 | Mean vector length of E direction sway | 0.054 | 0.795 | −0.070 | −0.057 | 0.644 |
| 2 | Root mean square | 0.098 | 0.785 | 0.150 | 0.074 | 0.654 |
| 19 | Ratio of A domain for power spectrum of R-axis | −0.512 | 0.539 | 0.257 | −0.060 | 0.622 |
| 6 | Area surrounding maximal amplitude rectangle | 0.361 | 0.532 | 0.245 | −0.047 | 0.475 |
| 5 | Area surrounding mean path length | 0.005 | -0.484 | −0.413 | 0.104 | 0.416 |
| 15 | Ratio of A domain for power spectrum of X-axis | −0.379 | −0.056 | 0.866 | −0.049 | 0.899 |
| 3 | Root mean square of X-axis | 0.324 | 0.003 | 0.822 | 0.124 | 0.795 |
| 11 | Standard deviation of X-axis | 0.324 | 0.003 | 0.822 | 0.124 | 0.795 |
| 21 | Ratio of A domain for power spectrum of X-axis velocity | −0.324 | −0.106 | 0.754 | −0.211 | 0.729 |
| 30 | Mean vector length of G direction sway | 0.256 | −0.015 | 0.695 | 0.118 | 0.563 |
| 28 | Mean vector length of C direction sway | 0.302 | −0.093 | 0.655 | 0.024 | 0.529 |
| 26 | Ratio of C domain for power spectrum of R-axis velocity | −0.045 | −0.018 | −0.031 | 0.908 | 0.828 |
| 22 | Ratio of C domain for power spectrum of X-axis velocity | −0.120 | 0.014 | 0.087 | 0.730 | 0.555 |
| 24 | Ratio of C domain for power spectrum of Y-axis velocity | −0.076 | 0.024 | 0.068 | 0.721 | 0.531 |
| 16 | Ratio of C domain for power spectrum of X-axis | −0.071 | −0.008 | 0.024 | 0.442 | 0.201 |
| 25 | Ratio of A domain for power spectrum of R-axis velocity | 0.026 | 0.031 | −0.020 | −0.485 | 0.237 |
| 20 | Ratio of C domain for power spectrum of R-axis | 0.190 | −0.182 | −0.249 | 0.398 | 0.289 |
| 18 | Ratio of C domain for power spectrum of Y-axis | −0.201 | 0.224 | −0.113 | 0.391 | 0.256 |
| | Contributions | 9.455 | 5.471 | 4.108 | 2.773 | 21.808 |
| | Contribution rate | 27.808 | 16.092 | 12.084 | 8.157 | 64.141 |

Note) The parameter number corresponds to the number in Table 2

**Table 5** Correlations between interpretated factors

| Factor | F1 | F2 | F3 | F4 |
|---|---|---|---|---|
| F1: unit time sway factor | 1.000 | | | |
| F2: front-back sway factor | 0.310 | 1.000 | | |
| F3: left-right sway factor | 0.296 | 0.481 | 1.000 | |
| F4: high frequency band power spectrum factor | 0.194 | −0.118 | −0.290 | 1.000 |

## Discussion

Evaluation parameters of CFP movement are theoretically categorized into 7 domains, and the characteristics of CFP movement can be synthetically understood from 36 parameters representing the above-stated 7 domains (Demura et al., 2001; Mizuta et al., 1993; Yamaji et al., 2001; Kitabayashi et al., 2002). We determined that these parameters have high reliability and validity (Demura et al., 2001; Kitabayashi et al., 2002). However, among 7 domains, the X and Y direction parameters of the center position domain are used as standards when examining the qualitative characteristics of CFP movement, such as pattern classification, and they are considered to be qualitatively different from parameters evaluating the amount of body sway.

This study aimed to determine the common characteristics (factors) measured by parameters evaluating the amount of CFP movement based on their interrelationships, and to

**Table 6** Reliability coeffecients of each factor and relationships between $FS_{original}$ and $FS_{cross\text{-}validity}$

| | | | coefficient of congruence | | | | correlation coefficient | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Factor | ICC | F1 | F2 | F3 | F4 | F1 | F2 | F3 | F4 |
| $FS_{cross\text{-}validity}$ | F1:Unit time sway factor | 0.89 | 0.966 | 0.271 | 0.451 | 0.229 | 0.877 | 0.011 | −0.002 | 0.072 |
| | F2:Front-back sway factor | 0.90 | 0.361 | 0.916 | 0.444 | 0.230 | −0.159 | 0.890 | −0.159 | 0.103 |
| | F3:Left-right sway factor | 0.95 | 0.448 | 0.352 | 0.906 | 0.524 | 0.119 | −0.239 | 0.890 | 0.276 |
| | F4:High frequency band power spectrum factor | 0.92 | 0.348 | 0.203 | 0.323 | 0.798 | 0.066 | −0.015 | 0.207 | 0.827 |

Note) ICC: Reliability coefficients were calculated from the intraclass correlation coefficient
Coefficients of congruence were calculated by Harman's equation
Correlation coefficients were calculated using Pearson's product-moment correlation
$FS_{original}$: Factor scores were calculated by the complete estimation method in the original group
$FS_{cross\text{-}validity}$: Factor scores in the cross-validity group were calculated using the above estimation made up in the original group

objectively summarize theoretically categorized parameters.

Reliability coefficients of CFP parameters were very high and similar to those in previous studies (Demura et al., 2001; Kitabayashi et al., 2002), and were beyond the standard (beyond or higher than 0.7) proposed by Fleiss (1981). Therefore, the reliability of the CFP parameters selected in this study is judged to be high.

The relationships between parameters, especially in each domain, were high. The above results suggest that some parameters with common characteristics exist in the background and spread over each theoretically categorized domain. Factor analysis extracted 4 factors to explain about 64% of the total variance.

The first factor can be interpreted as the unit time sway (sway-velocity) factor, because it is defined mainly by sway velocity parameters, dividing movement distance by unit time. These parameters are effective in judging people with a decline of posture control function (Tokita et al., 2001; Okawa et al., 1998), which is an undeveloped stage in infants and a marked decline stage in old people. Therefore, this factor will be effective to examine the change of CFP movement with aging and to judge the posture disorder for healthy elderly.

The second factor can be interpreted as the front and back sway factor, because it is defined mainly by parameters evaluating the amount of front and back sway. Also, this factor can measure the overall decline of the posture control function. Especially, it may be effective in evaluating movement characteristics to the front in old people with a marked decline in their leg muscles. It is reported that muscle groups relating to the maintenance of upright posture are mainly the backside muscles, especially the neck extensor, erector spine muscles, hamstring muscle, and sole muscle (Yabe, 1994). Muscle fatigue in a static upright posture is influenced mainly by the decline of the above stated muscle strength, and its influence is considered to also reflect on front and back CFP movement. This factor can judge dizziness and balance function disorders indicating asthenia of the spinal reflex (Tokita et al., 2001; Okawa et al., 1998). Further, this factor is also defined by area parameters such as the root mean square area and the oblong area. These parameters are important and used in many studies. In the Romberg posture of closing both legs, bearing (foot width and length) is influenced more by the longitudinal axis (Y-axis) than the side axis (X-axis) (Kitabayashi et al., 2002). In other words, area parameters (foot width×length) have strong relationships with a change in the longitudinal axis (front and back), and define the second factor as well as parameters regarding front and back sway.

The third factor can be interpreted as the left and right sway factor, because it is defined mainly by parameters evaluating left and right sway. Parameters in this factor are related to the labyrinthine righting reflex function that restores or maintains the correct position in an upright posture (Tokita et al., 2001; Okawa et al., 1998). In a nerve function decline state by factors such as leg fatigue or alcoholic intake, deviating from the normal range of body sway often occurs, and this makes the above-stated functions more active. Therefore, this factor will be effective to evaluate the sway to which labyrinthine righting reflex function strongly relates. It is reported that left and right sway is greater than front and back sway during an upright posture from the relationships with physique and bearing (Kitabayashi et al., 2002). The ankle and knee joints can easily move in the front and back directions during the Romberg posture, but hardly move in the left and right directions. Therefore, during body sway, front and back sway can be easily controlled so that the sway does not become large, but there is little control of left and right sway. From the above, this factor can evaluate individual differences in body sway reflecting the influence of physique such as joints and bearing.

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. Sway in the high frequency band beyond 1 Hz reflects the activity of propriospinal reflex (Tokita et al., 2001; Okawa et al., 1998). High frequency reflects short and quick sway. The power spectrum of CFP movement for healthy people reduces rapidly as the frequency band becomes higher (Taguchi et al., 1977). Kapten et al. (1983) reports that the power spectrum consists of a frequency band under 2.0–3.0 Hz, mainly 1.0–1.2 Hz. Namely, the sway period for many healthy people belongs to the low frequency band. Therefore, this factor can discriminate people with a sway period in the high frequency band. When each function relating to posture maintenance declines and a normal sway period cannot be maintained, the period shifts to the high frequency band. This factor is effective to discriminate such a state.

The four factors interpreted showed significant relationships except between the second and the fourth factors. CFP parameters are compound ones calculated to evaluate the amount of sway based on the center position parameters of the right and left (X) direction and the front and back (Y) direction. The significant correlation ($r=0.481$) between the second and third factors suggests that area parameters (width×length) lie between both factors, and that front-back sway and left-right sway are not independent at all.

It is valid that significant relationships were found between the 4 factors, because all parameters are derived from X and Y center position parameters, but, from the low correlations ($r=0.118$–$0.481$), each factor is considered to have respectively different sway characteristics. The present results suggest that the reliability of the 4 factors is high and the 6 domains theoretically categorized can objectively compress or summarize the 4 factors. To examine cross validity, the same factor analysis was applied to the correlation matrix obtained from the cross-validity group. Four factors explaining about 68% of total variance were interpreted with the same name. The congruence coefficient ($\phi=0.798$–$0.966$) and the correlation coefficient ($r=0.798$–$0.966$) between factors obtained in the original group and cross-validity group were very high. There were no significant differences between the mean factor scores of both groups. Therefore, it is considered that these 4 factors have high cross-validity and almost the same factors are also interpreted in different groups. Instead of using 32 parameters, the 4 factors can synthetically evaluate body sway.

In summary, 32 body sway parameters selected from 6 theoretically categorized domains were objectively compressed and summarized into the following 4 factors using factor analysis: unit time sway factor, front-back sway factor and a left-right sway factor and the high frequency band power factor. It was judged that these 4 factors have high reliability and validity, and can synthetically evaluate the CFP movement.

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Correspondence to: Tamotsu Kitabayashi, Kanazawa University Graduate School of Natural Science and Technology, Takara-machi, Kanazawa, Ishikawa 920–0934, Japan
Phone: 076–264–5610
Fax: 076–234–4120
e-mail: tamo@ed.kanazawa-u.ac.jp