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How Are Statistical Parameters of the Velocity Vector of Body Sway Distributed in Normal Human Subjects?

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The velocity vector when the human body sways has been qualitatively evaluated in clinical sessions. We quantitatively measured the velocity vector for 1 min in 89 normal subjects standing in a stable posture, and examined distributions of quantities of the velocity vector. The velocity vector was measured with a stabilometer, which visualizes the vector as magnitudes radially projected from the center to the periphery into 36 directions by 10˚. The 3 quantities we calculated from the 36 scalars of the vector per subject were the coefficient of correlation (CV), skewness and kurtosis, which were analyzed statistically. Values of skewness were normally distributed. Values of CV and kurtosis were log-normally distributed when adjusted with log transformation. Then, we calculated standardized values of the normal distributions, from which the lower and upper cutoff values in the 95% and 99% areas were available. The 3 quantities showed statistically significant correlations with one another, although the levels were low. Thus, in the present study, use of the 3 parameters enabled us to quantitatively evaluate the whole image of velocity vector, which would simplify the procedures of examination and shorten the time required for differential diagnosis.

Key words: body sway; stabilometer; statistical characteristic value; velocity vector

Human body sway has been researched from earlier (Basler, 1929; Hellebrandt, 1938). However, detailed studies on body sway have only lately become popularized after the development of the stabilometer and its introduction into clinical sessions. In examining the locus of body sway, measurement of length and area of the locus is a good method which relatively integrates qualitative and quantitative evaluations (Okawa et al., 1995; Imaoka et al., 1997). On the other hand, in the present-day clinic, the velocity vector has only been used as a reference to understanding the sway pattern at most. It is quite difficult to quantitatively evaluate the whole velocity vector with one index, when a human body sways. So, practical examinations have depended on the qualitative classification of body sway patterns and the partially quantitative analysis of Romberg's rate (Yamamoto and Komatsuzaki, 1984). Qualitative evaluation is apparently comprehensible, but the examiners' bias might spoil the objectivity of analysis. On the other hand, Romberg's rate does not reflect the whole velocity vector, but only many data related to contralateral directions among the 36 magnitudes of velocity vector.

To quantitatively evaluate the velocity vector in a more simplified manner, in this article we describe how we measured the moment-characteristic values of the velocity vector in healthy subjects, and tried to treat them statistically through analyses of their quantities.

Abbreviation: CV, coefficient of variation

Subjects and Methods

Subjects were 89 healthy adult volunteers (47 males and 42 females) in their 20's or 30's suf-

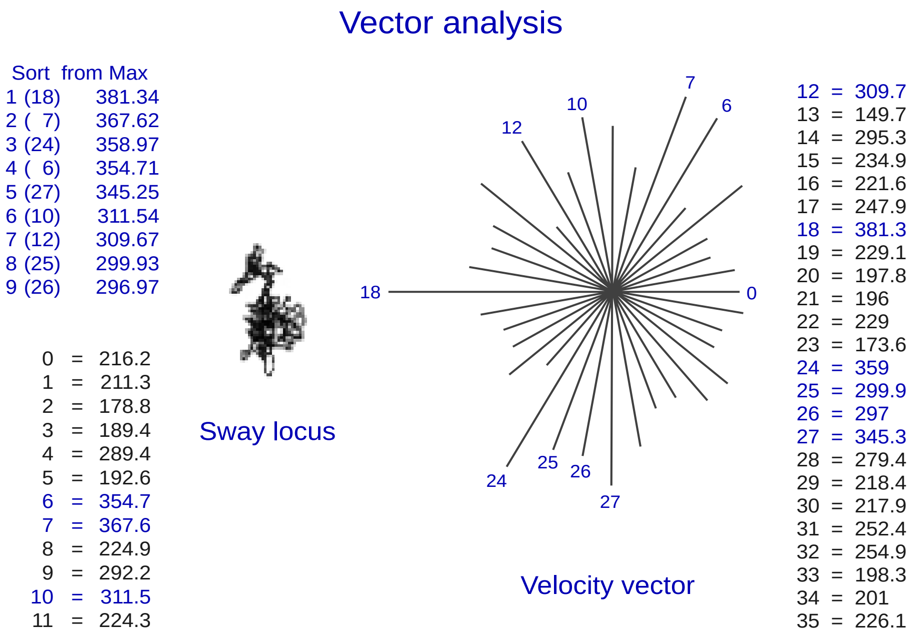

Fig. 1. Schema of vector analysis consisting of images of the sway locus (left) and the velocity vector (right). Vectors are displayed as magnitudes radially projected into 36 directions, which represent scalars. The digits from 0 to 35 on both sides are the means of scalar data obtained from the 89 healthy subjects. Upper left shows the maximum 9 scalar levels. The digit written in parentheses indicates the number of magnitude directions.

fering from no disease inappropriate to the object of this study, and with normal limbs and trunk. The mean age was 25.8 years with a range of 20 to 38 years. The velocity vector was measured with an SKG-TN-I stabilometer (Nagashima Medical Instrument, Co., Ltd., Tokyo, Japan) run on its analysis program under the guidelines determined by the Japan Society for Equilibrium Research: the subject stands on the stabilometer with both legs closed in a well-lighted environment, gazing at an indicator, while the sway of the center of gravity of the body is recorded for 1 min (Steering Committee of the Japan Society for Equilibrium Research, 1996). All subjects well understood the object of the study.

The whole image of velocity vector was visualized as 36 magnitudes radially projected from the center to the periphery, by 10˚ increments between 0˚ and 359˚ (Fig. 1). From the thus-obtained 36 scalars per patient, we calculated the coefficient of variation (CV), skewness and kurtosis in the 89 subjects, and examined types of distributions of the 3 statistics (Table 1): the CV, skewness and kurtosis respectively show the dispersion, symmetry and centrality of the distribution. In addition, histograms of the 3 statistics were examined to find out whether they were normally distributed or not.

The chi-square goodness-of-fit test, Pearson-Hartley's test and Geary's test were used to examine normality. Pearson's correlation coefficient was used in testing the correlation. Statistical significance was determined when the probability was less than 0.05.

Table 1. Definitions of statistics used

CV	$= SD/Mean$
Skewness	$= 36^{-1} \cdot \Sigma\,(Datum - Mean)^3/SD^3$
Kurtosis	$= 36^{-1} \cdot \Sigma\,(Datum - Mean)^4/SD^4$

CV, coefficient of variation.

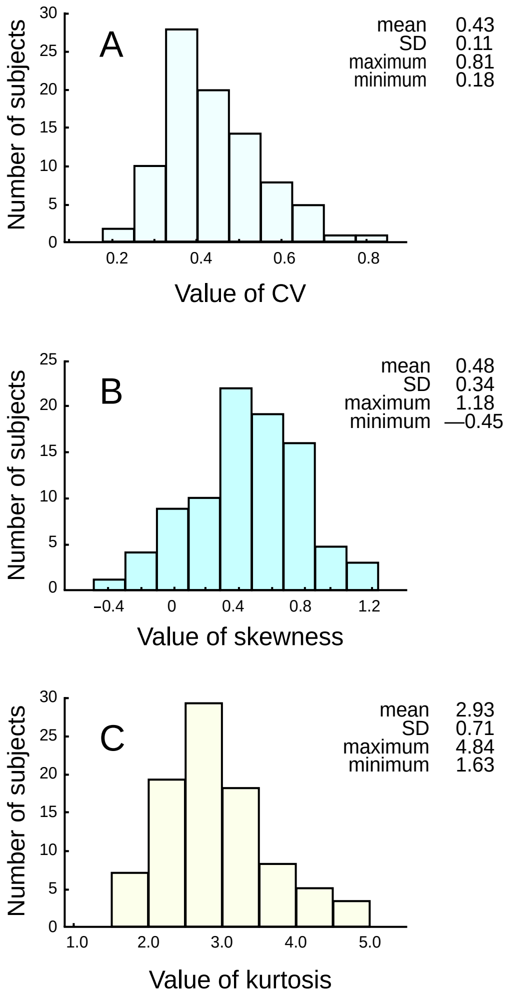

Fig. 2. Histograms of the CV (**A**), skewness (**B**) and kurtosis (**C**). Distribution is asymmetrical in **A** and **C**, and symmetrical in **B**. CV, coefficient of variation.

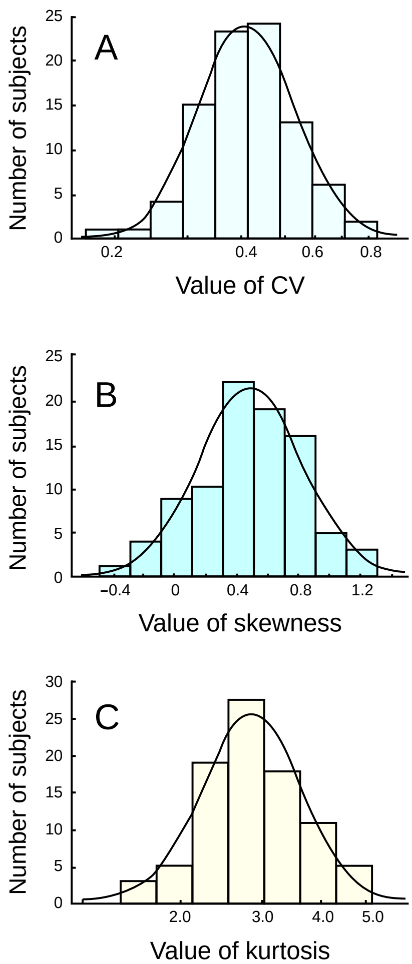

Fig. 3. Distribution curves of the CV (**A**), skewness (**B**) and kurtosis (**C**). The CV values are distributed log-normally (mean -8.73×10^{-1}, variance 7.01×10^{-2}), the skewness values normally (4.80×10^{-1}, 1.14×10^{-1}) and the kurtosis values log-normally (1.05, 5.85×10^{-2}). CV, coefficient of variation.

Results

Observed data of statistics

The CV data were distributed asymmetrically between values 0.18 and 0.81 with a mean of 0.43, an SD of 0.11 and a mode of about 0.3. The values of skewness were observed in symmetry between –0.45 and 1.18, with a mean, an SD and a mode of 0.48, 0.34 and about 0.5, respectively. The kurtosis levels were distributed asymmetrically between 1.63 and 4.84 with a mean, an SD and a mode of 2.93, 0.71 and near 3, respectively (Fig. 2).

Application of the normal distribution

In the determination of normality of distributions of the CV, skewness and kurtosis (Fig. 3), we used 2 quantities, that is, the sample mean

Table 2. Formula for calculating the cutoff values of the CV, skewness and kurtosis in the standardized normal and log-normal curves

Statistic	Formula [lower cutoff value, upper cutoff value]
Skewness†	$[X - z^*_\alpha \cdot \sigma, X + z^*_\alpha \cdot \sigma]$
CV and kurtosis‡	$[G \cdot exp(-z^*_\alpha \cdot \sigma_{ln}), G \cdot exp(z^*_\alpha \cdot \sigma_{ln})]$

CV, coefficient of variation; X, sample mean; σ, standard deviation of unbiased samples; G, geometric sample mean; σ_{ln}, log-transformed σ; z^*_α, two-sided α point in the normal distribution.
†Normally distributed.
‡Log-normally distributed.

and unbiased sample variance. As a result, the skewness was normally distributed (mean 4.80 × 10^{-1}, variance 1.14 × 10^{-1}). Conversion to logarithms achieved normality of distribution in the CV (–8.73 × 10^{-1}, 7.01 × 10^{-2}) and kurtosis (1.05, 5.85 × 10^{-2}).

Determination of the standardized values

Based on these normal distribution models, we calculated the standardized values of each statistic in 95% and 99% areas in the distribution curves (Table 2). The lower and upper cutoff CV values in the 95% area were [0.25, 0.70], and those in the 99% area were [0.21, 0.83]. As for skewness, the lower and upper cutoff values were [–0.18, 1.14] in the 95% area and [–0.39, 1.35] in the 99% area, respectively. The kurtosis values were [1.77, 4.57] in the 95% area and [1.53, 5.31] in the 99% area, respectively (Table 3).

Correlation of the statistics

Scatter diagrams were made of each pair of values of the CV, skewness and kurtosis, and their relationships were examined (Fig. 4). The CV and kurtosis data were converted to logarithms, and then Pearson's correlation coefficients were calculated. Correlation between the CV and skewness or kurtosis was significant, which was positive between the CV and skewness, and negative between kurtosis and the CV. However, their coefficient correlation values were small and the levels of their significance were low.

Discussion

We tried to simplify the 36 moment-characteristic values which quantify the velocity vector to only 3 statistics per patient. Of the statistics, the CV represents the extent of scalar distribution, not affected by the absolute value of the vector. The CV is theoretically null if all sca-

Table 3. Cutoff values of the CV, skewness and kurtosis in 95% and 99% areas in the standardized normal and log-normal curves

	Cutoff value [lower, upper]	
	95% Area in the normal curve	99% Area in the normal curve
CV‡	[0.25, 0.70]	[0.21, 0.83]
Skewness†	[–0.18, 1.14]	[–0.39, 1.35]
Kurtosis‡	[1.77, 4.57]	[1.53, 5.31]

CV, coefficient of variation.
†Normally distributed.
‡Log-normally distributed.

lars of the velocity are equal in every direction: that is, scalar difference by direction becomes larger as the CV increases. So, we could treat the CV as an index of directional preponderance of the velocity scalar. However, it is not possible to evaluate which direction is predominant among the analyzed 36 directions of the velocity vector.

The kurtosis shows the center of magnitude distribution of the velocity vector, and is theoretically infinite if all scalars of the velocity are equal in every direction: namely, velocity scalars come to approximate one another in magnitude as kurtosis grows larger. For these, kurtosis could be an index of the absolute value-specificity of the velocity scalar.

As we observed, values of skewness were normally distributed, and those of CV and kurtosis were log-normally distributed. In the fields of medicine and biology, the standardized normal or log-normal curves are widely used as distribution models of measurements in a sample population. Besides, the 3 statistics were significantly correlated with one another, although the levels of significance were comparatively low. Therefore, we can utilize each statistic independently as an index.

The whole image of velocity vector can be quantitatively evaluated with these 3 statistics. Moreover, the statistics are hardly affected by the magnitude of the vector, because statistics are independent of measurement units. On the other hand, physiological implications of the statistics remain unclear; further, the statistics provide no information on the direction of the vector, which is a defect. The absence of units also disturbs the intuitive understanding of the statistics.

In future studies, by collecting basic data extensively, we would like to clarify the physiological significance of these statistics, and to realize the quantitative evaluation of the direction of velocity vector through correction of the defect in using statistics.

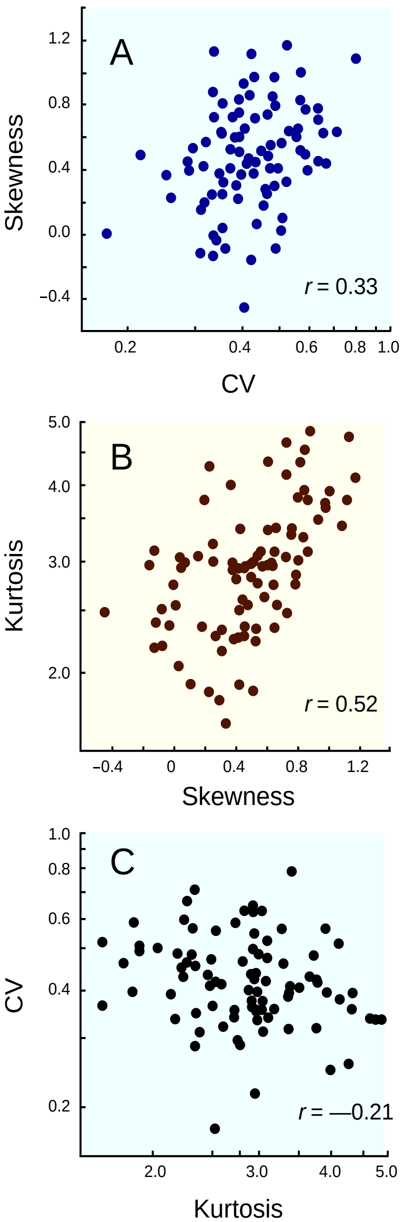

Fig. 4. Scatter diagrams of the CV and skewness (**A**), skewness and kurtosis (**B**), and kurtosis and CV (**C**). Pairs in **A** and **C** are significantly correlated lowly: the correlation is positive in **A** and negative in **C**. CV, coefficient of variation.

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