Verifying the Independence of Anterior and Mediolateral Margin of Gait Stability Indices

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***Abstract*—Gait stability indices are used for the quantitative assessment of individual fall risk. The margin of stability (MoS) is a popular gait stability index. This index computes the fall risks in the anterior and mediolateral directions; however, the relationships between the anterior and mediolateral MoSs have not been studied. We analyzed the MoS values in these two directions and several gait parameters using canonical correlation analysis, and obtained the linear relationships between these two groups. The gait kinematic data of 300 strides of 60 elderlies from an open database were used for this analysis. Our analysis verified that the MoS values in the anterior and mediolateral directions exhibited a weak relationship. The anterior posture became stable as the anterior gait speed decreased or the cadence increased. Furthermore, gait motions with greater step widths exhibited higher mediolateral MoS values, indicating greater stability. These findings indicate that the anterior and mediolateral postural stabilities are independently related to different gait parameters, which can aid in understanding stable walking strategies.**

***Index Terms*—margin of stability, canonical correlation analysis, gait parameter**

I. Introduction

Gait stability indices allow the quantitative assessment of individual fall risk. The evaluation of gait stability and its applications, such as warnings of falling, have become accessible owing to inexpensive inertial measurement units. Gait stability assessment during daily life is an important field in consumer electronics. The margin of stability (MoS) [1] is a popular index to predict falling. The MoS can be computed along the anterior and mediolateral directions, and indicates the margin of falling in each direction. However, the relationships between the MoSs along the two directions and popular gait parameters, such as the gait speed, step width, and stride length, have been inconsistent in previous studies [2]–[8]. Moreover, the relationship between the anterior and mediolateral MoSs has not yet been clearly understood. For example, Hak et al. [3] researched how gait parameters pertained to the anterior and mediolateral MoSs; however, they did not target the relationship between the two directional MoSs.

We conducted canonical correlation analysis in order to clarify the relationship between the MoSs in the two directions and gait parameters. Understanding the stability against falling in the anterior and mediolateral directions helps us comprehend how stable walking is achieved. In particular, we verified if the anterior and mediolateral MoSs are mutually independent or positively or negatively correlated.

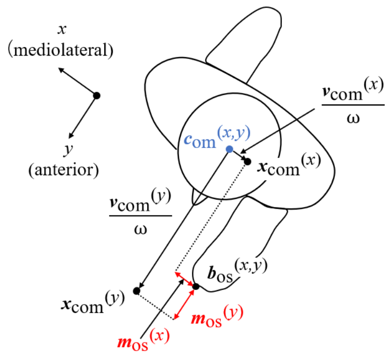

Fig. 1. Margin of stability values in the mediolateral (x) and anterior (y) directions

II. Methods

A. Margin of stability (MoS)

MoS indicates the margin against a critical condition to fall during walking. The MoS is defined as the distance between the prospective location of the center of mass (CoM) and the endpoint of the base of support (BoS) of the human body [1]. The prospective location of the CoM is estimated using the velocity in the anterior and mediolateral directions. MoS is defined as

$$\boldsymbol{m}_{\mathrm{os}} = \boldsymbol{b}_{\mathrm{os}} - \boldsymbol{x}_{\mathrm{com}} \tag{1}$$

$$\boldsymbol{x}_{\mathrm{com}} = \boldsymbol{c}_{\mathrm{om}} + \frac{\boldsymbol{v}_{\mathrm{com}}}{\omega} \tag{2}$$

$$\omega = \sqrt{\frac{g}{l}} \tag{3}$$

where $\boldsymbol{b}_{\mathrm{os}}$ and $\boldsymbol{c}_{\mathrm{om}}$ are the position vectors of the BoS endpoint and the CoM, respectively, on the x–y plane, as in Fig. 1. $\boldsymbol{v}_{\mathrm{com}}$ is the velocity vector of the CoM. $\boldsymbol{x}_{\mathrm{com}}$ is the position vector of the prospective CoM. l is the height of the CoM from the floor, and g is the gravitational acceleration. Note that the greater mediolateral MoS value indicates a more stable posture in the mediolateral direction whereas the smaller absolute value of anterior MoS indicates a more stable posture in the anterior direction.

The minimum value of mediolateral MoS and the minimum absolute value of anterior MoS during the gait cycle are used as an indicator of stability. If the mediolateral MoS is negative, it is extremely likely to fall in the mediolateral direction. Anterior MoS is generally negative. The larger the absolute value of anterior MoS, the more likely it is to fall anterior direction.

B. Gait parameters

We analyzed five popular gait parameters: the maximal mediolateral and anterior gait speeds of the CoM, step width, stride length, and cadence. The step width is the distance between the right and left toes in the mediolateral direction. The stride length is the anterior distance between two successive steps of the left foot. The cadence is the number of strides per minute. These gait parameters have been used in previous studies [2]–[4].

C. Gait database

We used the AIST Gait Database [9] for the time-series coordinates of each body part during walking for 30 women and 30 men aged 60 years and older. Five strides of the individual participants, starting from the right heel contact, were analyzed. Hence, a total of 300 strides were analyzed.

D. Canonical correlation analysis

Canonical correlation analysis, which determines the linear relationship between two groups of variables through latent (canonical) variables, was used to analyze the MoSs and gait parameters simultaneously. For each group, the canonical variable was determined as a linear combination of the variables in that group, such that the two obtained canonical variables exhibited a high correlation coefficient. In this study, one set of variables contained the anterior and mediolateral MoSs, and the other set contained the five gait parameters.

III. Results

We computed two pairs of canonical variables. Figs. 2 and 3 show the canonical coefficients for all variables for the first and second canonical variable pairs, respectively. The values nearby the arrows from the variables to the canonical variables indicate the canonical coefficients. The canonical variables are latent variables that represent each group of variables and are determined as linear combinations of the variables in individual groups.

As shown in Fig. 2 the first canonical correlation (correlation between the first canonical variables) was 0.88. The first canonical variable exhibited strong positive linear relationship with the mediolateral MoS and step width. A higher mediolateral MoS value indicates a more stable posture in the mediolateral direction. Thus, the higher first canonical value indicates greater stability in posture along the mediolateral direction.

The second canonical correlation was 0.80. The second canonical variable exhibited a strong negative linear relationship with the anterior MoS, and strong negative linear

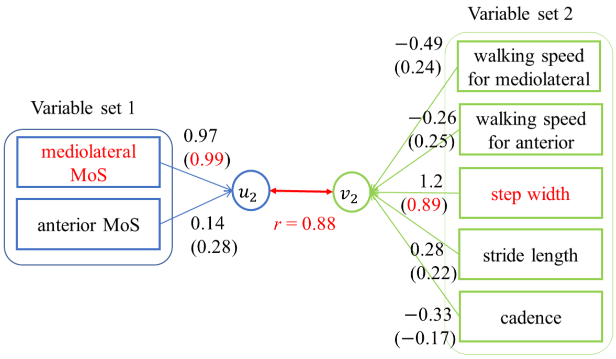

Fig. 2. The first canonical coefficients (-) for mediolateral and anterior MoSs and gait parameters. Values in parentheses are the canonical loadings.

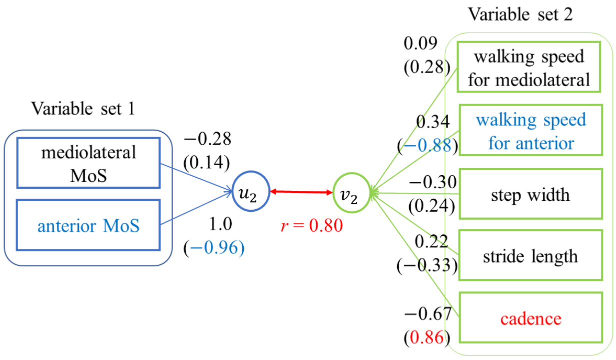

Fig. 3. The second canonical coefficients (-) for mediolateral and anterior MoSs and gait parameters. Values in parentheses are the canonical loadings.

relationship with the maximal anterior gait speed and strong positive linear relationship with cadence. A lower anterior MoS value indicates a more stable posture in the anterior direction. Thus, the higher second canonical value indicates higher stability in posture along the anterior direction.

IV. Discussion

The first and second canonical variables exhibited substantial loadings with the mediolateral and anterior MoSs, respectively, indicating that the MoS values for the two directions are largely independent. Furthermore, no gait parameters prominently related to both types of MoS values. Hence, we suggest that the mediolateral and anterior MoSs are independent of each other. To the best of our knowledge, this is the first report to demonstrate the independence of two directional MoSs.

The results of this study are not completely consistent with those of previous works. According to Hak et al. [3], cadence was positively correlated with the mediolateral MoS, whereas our analyses indicate that cadence is positively correlated with the anterior MoS, and only weakly correlated with the mediolateral MoS. Moreover, in [3], the anterior MoS increased as the stride length decreased or the walking speed increased; however, in this study, the stride length exhibited weak correlations with the anterior and mediolateral MoSs.

A possible reason behind these differences is that the gait parameters are correlated and hence their effects on the MoSs are not independent of each other.

V. Conclusion

In this study, we verified the independence of the anterior and mediolateral MoSs. Furthermore, we observed that the step width is strongly related to the mediolateral MoS, and the anterior gait speed and cadence are strongly related to the anterior MoS. Similar and extended analyses should be conducted for different cohorts in the future for generalized results.

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