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Anterior and mediolateral dynamic gait stabilities attributed to different gait parameters in different age groups

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Abstract

The margin of stability (MoS) is a gait stability index with good validity. MoS is computed in the anterior and mediolateral directions. However, their relationship has not been well investigated. Furthermore, previous studies have little investigated the differences in MoS between distinct age groups. Inter-age comparisons reveal age-specific walking characteristics and their effects on stability. In this study, we used multiple indicators and multiple causes model, which is a type of structural equation modeling, to investigate the statistical relationships between various types of gait parameters and MoSs for each of the healthy participant groups over 60 and in their 20s. For the analysis, data from 120 individuals were obtained from a gait database. The model for the younger group showed that the MoSs in the anterior and mediolateral directions were mostly separated. The stability in the anterior direction was independent of the stability in the mediolateral direction. In contrast, some gait parameters simultaneously affected the two MoSs in the elderly group. The stability in the anterior and mediolateral directions was interdependent. For example, forward walking speed influenced the anterior and mediolateral MoSs in the elderly group, whereas it influenced only the anterior MoS in the younger group. These findings suggest that the age of people must be considered when discussing gait characteristics that contribute to stability.

Keywords : Margin of stability, Multiple indicators and multiple causes model, Age

1. Introduction

Gait stability indices, which quantify the risk of falling, are expected to reduce the number of falls by providing an early warning. Among the many stability indices (Bruijin et al., 2013; Balance Project, 2014), the margin of stability (MoS) (Hof et al., 2005) is one of the most widely used gait stability indices. The MoS is based on the biomechanical principle of an inverted pendulum and has excellent construct validity (Bruijin et al., 2013). Furthermore, MoSs are computed in the mediolateral and anterior directions, thus enabling an analysis of stability in different directions (Akiyama et al. 2023). The relationships between MoSs and gait parameters, including walking speed, stride length, step width, and cadence, have been investigated to understand the determinants of gait stability. However, these relationships have been found to be inconsistent (Hak et al., 2012; Hak et al., 2013; Hallesmans et al., 2018; Alamoudi et al., 2020; Iwasaki et al., 2021, 2022). For example, several studies have suggested that anterior walking speed is a predictor of MoSs in the mediolateral and anterior directions and that anterior walking speed impairs stability in the mediolateral direction (Alamoudi et al., 2020; Gill et al., 2019; Ohtsu et al., 2019; Iwasaki et al., 2022). However, according to Hak et al. (2013) and Hallesman et al. (2018), the correlation between mediolateral MoS and walking speed is weak. Furthermore, the mediolateral MoS does not change at different walking speeds according to Caterby et al. (2014). They suggested that an increase in walking speed does not lead to a decrease in gait stability because, as walking speed increases, the mediolateral width between steps increases and stability is maintained. These inconsistencies in the effects of gait parameters on MoSs may be attributed to differences in the experimental conditions and participants. Furthermore, research on the relationship between mediolateral and anterior MoSs is rare. For example, Hak et al. (2013) and Alamoudi et al. (2020) investigated the relationships between gait parameters and mediolateral and anterior gait stabilities. However, they separately discussed the MoSs in two directions. Therefore, the MoSs in different directions must be analyzed using a single statistical model. The risk of falling in the anterior direction differs from that of falling in the mediolateral direction. Modeling the anterior and mediolateral MoSs and various gait parameters in a single statistical model will enable an analysis of gaits that are stable in both directions.

Furthermore, earlier studies have rarely studied the differences in MoSs during steady walking between different age groups, despite young and elderly groups being investigated separately. One exceptional study was conducted by Yamaguchi and Masani (2022). They performed an inter-age comparison of gait parameters and gait stability indices including MoS. They showed that the step width and mediolateral MoS increased with age and found other age-related differences in gait characteristics. Hallesmans et al. (2018) and Hak et al. (2013) studied MoSs in children and young people, respectively. Brodie et al. (2018) measured MoSs during disrupted walking in healthy adults aged approximately 30 years. Ohtsu et al. (2019) investigated the balance strategies of healthy young people using MoSs. Iwasaki et al. (2022) analyzed mediolateral MoSs during normal walking in the elderly. These earlier studies did not compare MoSs and their relationships with gait parameters between different age groups. Furthermore, other researchers focused on age-related differences in MoSs for gait conditions with disturbances. For example, Roeles et al. (2018) investigated the anterior and mediolateral MoSs of perturbed gait in young and elderly individuals and reported no significant differences between the two age groups. Martelli et al. (2017) suggested that the backward MoSs of elders were lower than those of young adults during and at the end of an early compensatory reaction under slip conditions. Other studies have also compared MoSs during compensatory steps after perturbation in young and old adults (Bierbaum et al., 2010; Carty et al., 2011). Age-related differences in gait stability have also been studied using another representative index, the Lyapunov exponent (Buzzi et al., 2003; Kang et al., 2009; Terrier et al., 2015). However, MoSs and Lyapunov exponents are largely independent (Inagaki et al., 2023). Furthermore, Cromwell et al. (2004) compared the gait stability ratios calculated from the walking velocity and cadence between young and elderly adults. Similarly, Rogers et al. (2008) compared the balance abilities during walking on compliant grounds between young and elderly individuals. Moreover, Dean et al. (2007) and Schrager et al. (2008) concluded that older people adopt greater step widths to maintain lateral stability in challenging walking conditions; however, these researchers did not discuss stability indices. Thus far, the comparison of MoSs between the young and elderly during normal gait has been rarely conducted.

Therefore, this study investigated the relationship between MoSs along the anterior and mediolateral directions and typical gait parameters during steady walking in young adults (20–30 years old) and older adults (60–78 years old) using the multiple indicators and multiple causes (MIMIC) model and structural equation modeling technique. We used an open database as our source of gait motion data (Kobayashi et al., 2019). Unlike the aforementioned studies that separately discussed the two types of MoSs, the MIMIC model explains the two types of MoSs using latent and common variables called constructs, which are formed by the linear combination of several gait parameters. The results will enable us to discuss the effects of age on gait strategies in terms of gait parameters and dynamic stability. This study is based on our earlier work (Kuroda et al., 2022), in which only the elderly were analyzed, and focuses on the comparison between the elderly and young.

2. Methods

2.1. Margin of stability (MoS)

MoS is the margin against falling at any instant during walking. As shown in Fig. 1, MoS is defined as the distance between the prospective position of the center of mass (CoM) of the human body in the near future and the endpoints of the base of support (BoS). Despite the MoS being computable for all-round directions (Akiyama et al., 2023), the anterior and mediolateral directions are primarily discussed for straight walking. The prospective position of the CoM was estimated using velocity of CoM in the mediolateral and anterior directions. MoS is defined as

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

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

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

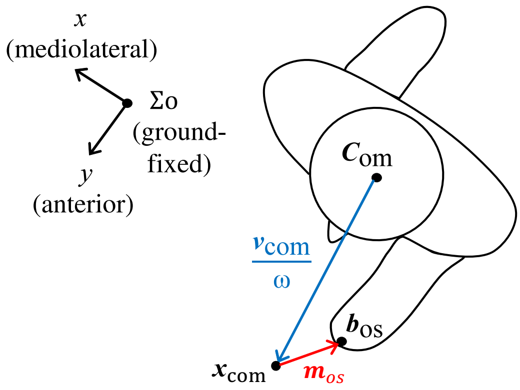

Fig. 1 Computation of margin of stability along the anterior and mediolateral direction.

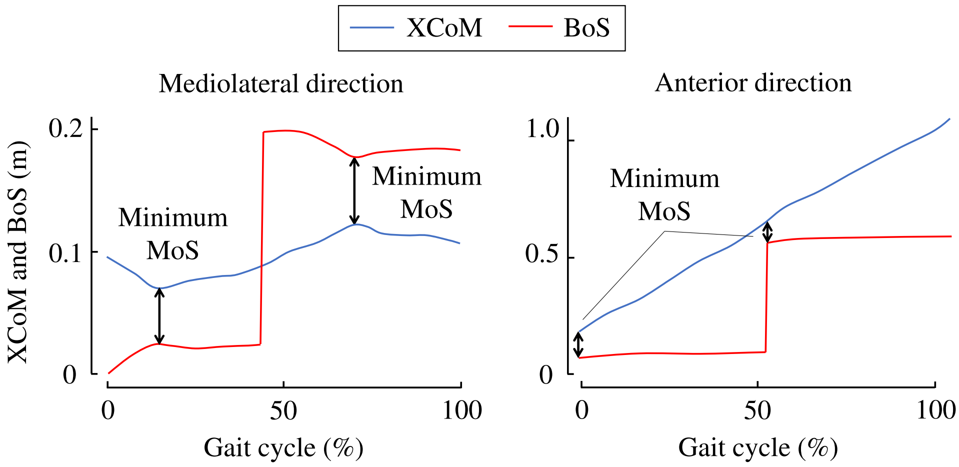

Fig. 2 Example of the time evolution of XCoM and BoS. Adapted from (Kuroda et al., 2022).

where $\boldsymbol{b}_{\mathrm{os}}$ and $\boldsymbol{c}_{\mathrm{om}}$ are the position vectors of the BoS endpoint and CoM, respectively, on the x-y plane, as shown in Fig. 1. $\boldsymbol{v}_{\mathrm{com}}$ denotes the velocity vector of 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.

Figure 2 shows examples of temporal changes in the prospective CoM (XCoM) and BoS along the mediolateral and anterior directions. The horizontal axis represents the gait cycle, and the vertical axis represents the positions of the XCoM and BoS. The gait cycle presents the normalization of two successive steps. At 0% of the gait cycle, the right heel contacts the ground, and the double-support phase begins. Subsequently, left toe is off the ground and left heel contacts at approximately 50%. Successively, the next right heel contact occurs at 100% of the gait cycle.

Greater mediolateral and anterior MoSs indicate more stable walking in each direction. MoS is always computed during gait, and the minimum value during a gait cycle corresponds to the most unstable moment. The minimum values were considered in this study.

The value of the mediolateral MoS is defined by

$$\boldsymbol{m}_{\mathrm{os}}^{(x)} = |\boldsymbol{b}_{\mathrm{os}}^{(x)} - \boldsymbol{x}_{\mathrm{com}}^{(x)}| \tag{4}$$

and its minimum value is typically observed at approximately 10 or 60% of the gait cycle. This is the most critical condition for balance loss in the mediolateral direction. The XCoM is usually located inside the BoS, and mediolateral MoS is positive. A larger MoS indicates more stable walking in the mediolateral direction.

The value of the anterior MoS is defined by

$$\boldsymbol{m}_{\mathrm{os}}^{(y)} = \boldsymbol{b}_{\mathrm{os}}^{(y)} - \boldsymbol{x}_{\mathrm{com}}^{(y)} \tag{5}$$

Table 1 Mean ± standard deviation of the MoSs for the elder and young adults.

	Elder adults	Young adults
Mediolateral MoS (m)	0.033 ± 0.011	0.022 ± 0.011
Anterior MoS (m)	−0.033 ± 0.031	−0.032 ± 0.035

Table 2 Means and standard deviations of the gait parameters, height, and weight for the elder and young adults.

	Mean value for elders	Mean value for young adults
Maximal mediolateral CoM speed (m/s)	0.12 ± 0.025	0.11 ± 0.030
Maximal anterior CoM speed (m/s)	1.44 ± 0.16	1.50 ± 0.18
Step width (m)	0.15 ± 0.027	0.12 ± 0.033
Stride length (m)	1.26 ± 0.089	1.36 ± 0.10
Swing duration (%)	85.0 ± 6.7	86.0 ± 3.3
Mediolateral MoS min Timing (%)	9.04 ± 5.10	7.81 ± 5.51
Anterior MoS min Timing (%)	0.34 ± 0.89	0.34 ± 0.85
Height (m)	159.62 ± 7.58	164.88 ± 7.94
Weight (kg)	60.57 ± 9.33	58.55 ± 9.79

and its minimum absolute value is observed at approximately 0 or 50% of the gait cycle, that is, immediately after the heel contact. This corresponds to the most critical condition in the anterior direction. During a large part of the gait cycle or its entirety, the position of the XCoM is in front of the BoS, which is the toe of the leading foot. Thus, the anterior MoS is generally negative. The smaller value of the anterior MoS indicates a riskier condition in the anterior direction.

2.2. Gait parameters

In this study, seven gait parameters were used. These gait parameters include the maximum velocity of the CoM in mediolateral and anterior directions, step width, stride length, swing duration, and timing at which the mediolateral and anterior MoSs are minimized in the gait cycle.

Step width is the distance between the left and right feet in the mediolateral direction during walking. Stride length is the distance between two successive steps of the same foot. Swing duration is the proportion of the swing phase in the gait cycle. These gait parameters potentially relate to the MoSs according to earlier studies (Alamoudi et al., 2020; Hak et al., 2012; Hak et al., 2013; Hallesmans et al., 2018; Iwasaki et al., 2022; Yamaguchi and Masani, 2022). Step widths and stride lengths were normalized to the body height of each participant.

In addition to the aforementioned gait parameters, we considered the timing of the minimum mediolateral and anterior MoS values to be observed. This value indicates the timing at which the MoS reached its minimum in a gait cycle and is expressed as a cycle percentage from 0 to 100%. One gait cycle includes two steps, and the minimum MoS value during a gait cycle is observed either at the first or second step. When this timing was above 50%, 50% was subtracted from the value to cancel laterality. Such timing has rarely been considered in earlier gait stability analyses. The timing of the MoS value to become minimum largely depends on the prospective position of the center of mass, which is the XCoM calculated from the CoM position and velocity. Individual differences in the kinematics of CoM produce those in the timing at which the MoS value is critical. Thus, the timing at which the MoS reaches its minimum may pertain to the MoSs. Despite no previous studies exploring the relationship between the timing at which the MoS reaches a minimum and the gait stability indices, we adopted these timings as gait parameters.

2.3. Gait database

We used a gait database from AIST (Kobayashi et al., 2019) for the three-dimensional time-series coordinates of the body features during walking. In each sample, a participant walked 10 m straight barefoot at a comfortable speed, and one gait cycle in the middle of the walk was recorded. An optical motion capture system was used to measure the positions of body segments. We refer to the center of the second and third metatarsal bone as the toe.

In this study, we used samples from 30 healthy men and 30 healthy women aged 60–78 years as the elderly group and 30 healthy men and 30 healthy women aged 20–30 years as the young adult group. Five gait cycles were analyzed for each individual, starting from heel contact with the right foot. A total of 600 samples were used for the study: 300 samples each from elderly and young adults. Tables 1 and 2 show the mean values of the MoSs and gait parameters for elderly and young adults, respectively. Typical reduction in the stride length and anterior speed and increase in the step width for elders (Dean et al., 2007; Schrager et al., 2008; Ko et al., 2010) are seen in the samples used in this study.

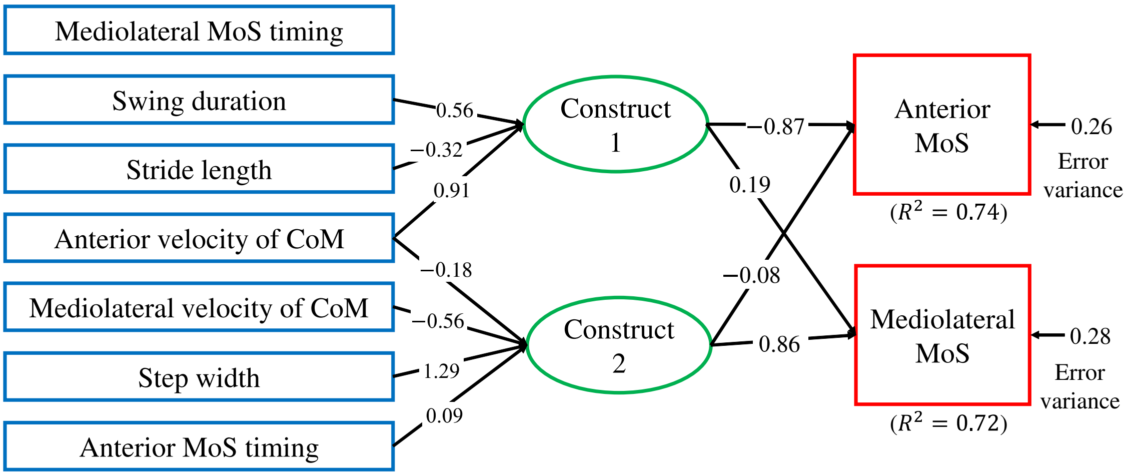

Fig. 3 MIMIC model for the young (20–30s) adult group. Square nodes are observed variables. Circular nodes are latent variables. They are normalized such that their means and standard deviations are 0 and 1, respectively. GFI = 1.0. CFI = 0.99. p = 0.04. Error variances are the variances of the prediction errors. Mediolateral MoS timing is not linked with the others. The correlation coefficients among the formative variables are not shown.

2.4. Multiple indicators and multiple causes (MIMIC) model

The MIMIC model is a type of model used in structural equation modeling (SEM). SEM analyzes the statistical validity of a hypothetical linear relationship between several variables. In MIMIC models, latent variables are defined by linear combinations of several observed variables, and they influence another set of observed variables. The latent variables are referred to as constructs. The observed variables that define the constructs are called formative indicators, and those that are affected by the constructs are called reflective indicators. Multiple formative and reflective indicators are organized into a small number of constructs.

In this study, formative variables comprised the gait parameters and reflective variables comprised the minimum MoS values along the anterior and mediolateral directions. SEM facilitates the discussion of the significance of the overall hypothetical structure and each branch. Incorporating the two types of MoSs into a single model provides a statistically valid model of the relationship between them. *lavaan* in *R* was used for analysis. We used statistically significant links between variables with p-values less than 0.05. The models for young and elderly adults were computed separately. All variables were normalized to z-scores with means and standard deviations of 0 and 1, respectively.

3. Results

3.1. MIMIC model of young adults

The MIMIC model for the younger group is shown in Fig. 3. The numbers attached to the links represent the strength of the influence of one node on another. The mean and standard deviation of the constructs are 0 and 1, respectively. The major goodness-of-fit indices were as follows: comparative fit index (CFI) = 0.99, goodness-of-fit index (GFI) = 1.00, Akaike information criterion (AIC) = 932.4, RMSE = 0.08, and χ^2 was 8.50 with a p-value of 0.04. These values largely satisfy the general standards of a valid model (McDonald & Ho, 2002).

Only the anterior velocity of the CoM affected both constructs 1 and 2, and the other gait parameters affected only one of the two latent constructs. However, the effect of anterior velocity on construct 2 was less substantial as one-fifth of that on construct 1. Constructs 1 and 2 mainly influenced the anterior and mediolateral MoSs, respectively. Conversely, the mediolateral and anterior MoSs were mostly separate from each other.

The major determinants of anterior MoS were the anterior velocity of the CoM and swing duration, followed by stride length. The decrease in the anterior velocity of the CoM and swing duration reduced the value of construct 1. A decrease in construct 1 led to an increase in the anterior MoS because the coefficient of their linkage was negative. Collectively, the model indicates that a slower walking speed, longer stride length, and shorter swing duration led to greater stability in the anterior direction.

The gait parameters that substantially affected the mediolateral MoS were the mediolateral velocity of the CoM and the step width. The large step width and slow mediolateral velocity improved latent construct 2 and stability in the mediolateral direction. Furthermore, the anterior velocity of the CoM slightly decreased construct 2, which resulted in instability along the mediolateral direction.

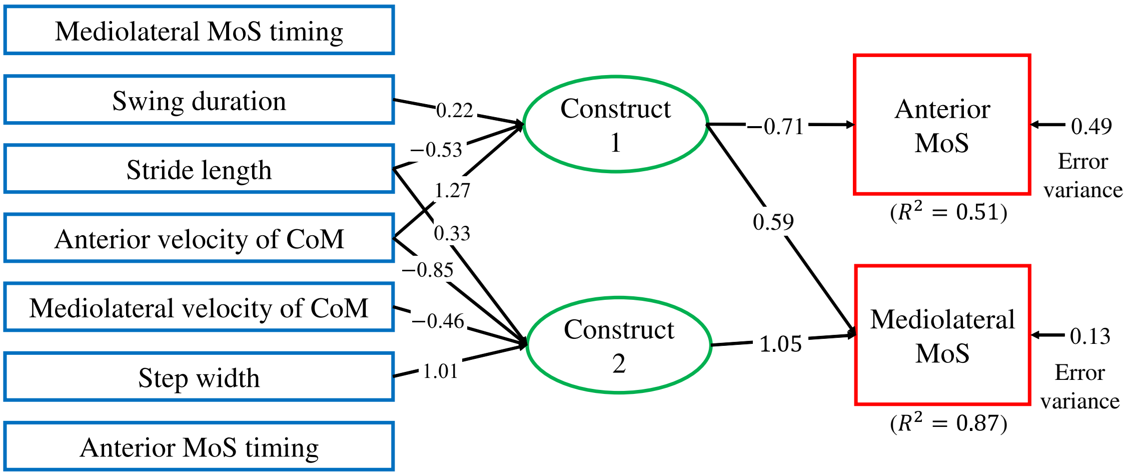

Fig. 4 MIMIC model for the elder adults aged over 60 years old. GFI = 0.99. CFI = 0.98. p = 0.003. Anterior and mediolateral MoS timings were not linked with the others. The correlation coefficients among the formative variables are not shown.

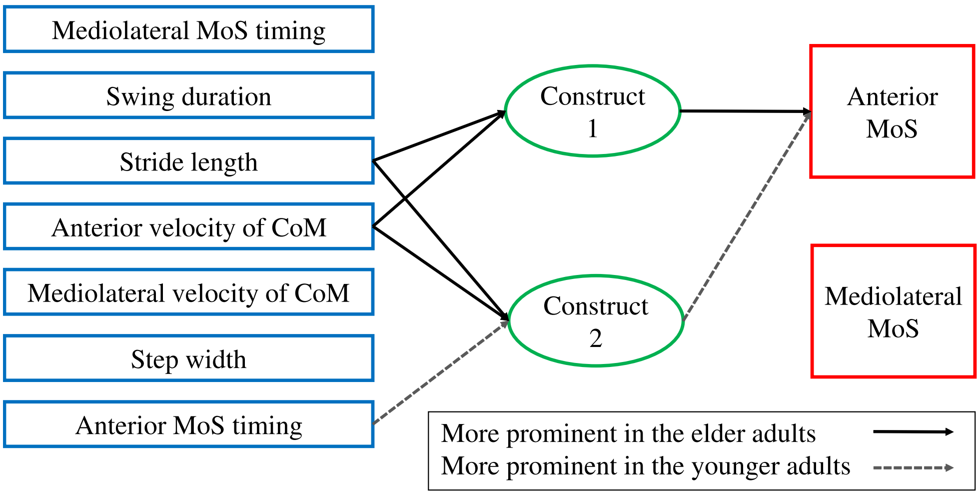

Fig. 5 The differences in the MIMIC models between the two age groups. Solid lines are connections that exist only in the elder group or whose magnitudes of the coefficients are significantly greater for the elderly than for the young adults with $p < 0.05$ by t-test. Dotted lines are those that exist only in the model of young adults.

3.2. MIMIC model of the elderly

Figure 4 illustrates the MIMIC model for adults aged 60 years and older. The goodness-of-fit indices of this model were as follows: CFI = 0.98, GFI = 0.99, AIC = 1087.82, RMSEA = 0.13, χ^2 = 11.92, for which p-value was 0.003.

The model for older adults was more complex than that for young adults. In the model of the elderly, several gait parameters affected both constructs in the model. Construct 1 had nearly equal influences on the mediolateral and anterior MoSs regarding magnitude. However, the signs of their coefficients were opposite. Construct 1 decreased the anterior MoS but increased the mediolateral MoS. Construct 2 positively affected only mediolateral MoS.

Changes in single gait parameters led to changes in both types of MoSs. For example, a decrease in the anterior velocity of the CoM increased the anterior MoS and decreased the mediolateral MoS by way of construct 1. Furthermore, the decrease in the anterior velocity of the CoM improved the mediolateral MoS using construct 2. However, the MIMIC model for the elderly shares similar characteristics with that for young people. For example, a slow walking speed, which is an anterior velocity, a large step length, and a small swing duration, led to greater stability in the walking direction. Furthermore, the large step width and slow mediolateral velocity of the CoM led to mediolateral stability.

4. Discussion

Figure 5 shows the differences between the two MIMIC models. The solid lines indicate connections that exist only in the model of the elderly or whose influences are significantly greater than those in the model of young adults with $p < 0.05$. Dotted lines represent connections that exist only in the young adult model. The differences between the two age groups are complex. Particularly, the variables that form construct 1 and their impact on the anterior MoS differ substantially. However, no differences in the influence of construct 2 on the mediolateral MoS were observed between the two age groups.

For easy access to the differences between the two MIMIC models, we computed multiple linear regression analyses with MoSs and gait parameters as objective and explanatory variables, respectively. For these analyses, we used the *stepwise* functions of MATLAB (2023a, Mathworks, Inc.), in which significant explanatory variables with $p < 0.05$ were selected using the stepwise method. All variables were standardized to ensure that the regression coefficients were comparable to those of the MIMIC models.

The regression equation for mediolateral MoS in the young group was as follows:

$$\overline{MoS}_{\mathrm{ml}}^{(\mathrm{young})} = -0.47V_{\mathrm{ml}} + 1.11W_{\mathrm{idth}} + 0.09S_{\mathrm{wing}} + 0.08T_{\mathrm{ant}} \tag{6}$$

with an adjusted coefficient of determination $\hat{R}^2 = 0.72$. That for the elderly group was as follows:

$$\overline{MoS}_{\mathrm{ml}}^{(\mathrm{elderly})} = -0.50V_{\mathrm{ml}} + 1.06W_{\mathrm{idth}} + 0.13S_{\mathrm{wing}} - 0.26V_{\mathrm{ant}} \tag{7}$$

with an adjusted coefficient of determination $\hat{R}^2 = 0.74$, where MoS_{ml}, W_{idth}, S_{wing}, and T_{ant} are the mediolateral MoS, step width, swing duration, and timing when the anterior MoS is minimized, respectively. V_{ml} and V_{ant} are the maximum speeds of the CoM in the mediolateral and anterior directions, respectively.

As shown in Figs. 3 and 4 and in the regression models, the mediolateral MoSs are largely determined by the mediolateral speed of the CoM and the step width. This is consistent with the definition of mediolateral MoS described in Section 2. According to earlier studies, step width increases mediolateral MoSs (Iwasaki et al., 2022; Young and Dingwell, 2012; Yamaguchi and Masani, 2022). In contrast, the effect of anterior walking speed on mediolateral MoS was significant only in the regression model for the elderly. This result agrees with the MIMIC model for the elderly, as shown in Fig. 4. As shown in Fig. 5, the influence of the anterior velocity of CoM on construct 2 was stronger for the elderly than for the young adults. Construct 2 largely determined the mediolateral MoS. Further, despite elderly people with fast walking speeds tending to be unstable in the mediolateral direction, the mediolateral MoS of young adults is not affected by anterior walking speed. This finding helps comprehend the inconsistencies among previous studies. Some studies have claimed that fast walking degrades the mediolateral MoS values (Gill et al., 2019; Ohtsu et al., 2019; Alamoudi et al., 2020), whereas Hak et al. (2013) and Sivakumaran et al. (2018) reported no such relationship at the time of heel contact. Our findings suggest that these incongruent reports may be because of the different participant groups involved in their studies. The effects of walking velocity on the mediolateral MoS depend on the age at which the gait strategy differs. For example, elderly fallers tend to adopt conservative gait strategies with slow speeds and small strides (Lugade et al., 2011; Monaco et al., 2009).

Regarding the difference in the mediolateral MoS between young and older people, Yamaguchi and Masani (2022) reported an intriguing aspect. They found that the angular momentum around the center of body mass in the frontal plane was greater for older than for younger adults and that the older people appeared less stable and likely to lose balance; however, the wide step width of the older adults dominantly determined the mediolateral MoS. Hence, the older adults are more stable than the young during normal gait. Such aspects agree with the results of our study. As in Eqs. (4) and (5), the step widths were the most important predictor of the mediolateral MoS, and the velocity in the mediolateral direction, which largely determines the momentum of the body, was a secondary parameter in determining the MoS.

As shown in Fig. 5, the effects on the anterior MoSs from construct 1 are significantly different between young and elderly adults. The regression equation for the young adults was as follows:

$$\overline{MoS}_{\mathrm{ant}}^{(\mathrm{young})} = -0.74V_{\mathrm{ant}} + 0.26L_{\mathrm{ength}} - 0.50S_{\mathrm{wing}}, \tag{8}$$

where $\hat{R}^2 = 0.73$. The equation for the elderly population was as follows:

$$\overline{MoS}^{\text{(elderly)}}_{\text{ant}} = -0.88V_{\text{ant}} + 0.35L_{\text{ength}} - 0.14S_{\text{wing}} + 0.18V_{\text{ml}} - 0.14W_{\text{idth}}, \quad (9)$$

where $\hat{R}^2 = 0.52$. MoS_{ant} and L_{ength} are the anterior MoS and stride lengths, respectively. These regression equations indicate that, for both age groups, the slower the walking speed and the larger the stride length, the more stable the anterior direction. These effects are reasonable, considering the definition of the anterior MoS. In addition, the shorter the swing duration, the more stable the walking for all age groups. These characteristics were consistent between the two age groups. In contrast, for the elderly group, the maximum mediolateral velocity V_{ml} and step width W_{idth} were significant determinants of the anterior MoS. These gait parameters are calculated in the frontal plane and apparently do not pertain to the computation of the anterior MoSs. The MIMIC model shown in Fig. 4 also indicates that the parameters V_{ml} and W_{idth} influence the anterior MoSs for the elder group. These two parameters significantly influenced the mediolateral MoSs. Collectively, for the elderly, the anterior and mediolateral MoSs are not fully independent because the same gait parameters, that is, V_{ml}, V_{ant}, and W_{idth}, simultaneously influence them.

This study introduced the timing at which MoS values were minimized in the gait cycle. As shown in Fig. 3, the timing of the anterior MoS influenced construct 2 in the young adults. However, its effect was smaller than that of the other gait parameters. Hence, we did not find any meaningful relationship between these timings and MoSs.

Despite this study finding structural differences in the relationships between the MoSs and gait parameters between young and elderly adults, the root causes are unknown. Gait strategies (Lugade et al., 2011; Monaco et al., 2009) and sensory and motor abilities (Osoba et al., 2019) differ between these age groups. However, this study lacks basic data to discuss how they relate to our findings. Furthermore, we used gait data of Japanese participants. Therefore, the generalizability of this study to other ethnicities remains unclear. These aspects should be studied further in the future.

5. Conclusion

No previous study has investigated the relationship between the MoSs in two directions and gait parameters during steady walking or compared them between young and older adults. Therefore, MIMIC models were used to discuss the single statistical model involving the MoSs and gait parameters. In the young adult group, the mediolateral and anterior MoSs were mostly separated. By contrast, for the elderly group, the MoSs in the two directions interfered with each other. The gait parameters defined in the frontal plane, such as mediolateral speed and step width, affected the anterior MoSs. Furthermore, the anterior speed, which is defined in the sagittal plane, correlated with the mediolateral MoSs. Despite the elderly with fast walking tending to be unstable in the mediolateral direction, the mediolateral MoS of young adults is not affected by anterior walking speed. These findings show differences in the structure of gait stability and gait parameters between the elderly and young adults. Participant age must be considered when discussing gait stability. Nonetheless, this study did not indicate the root causes of the different variable structures between elderly and young adults, which will be studied in the future.

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