



Original Article

Effects of lower leg muscle quality on gait variability in community-dwelling older and healthy young adults

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Abstract. [Purpose] We aimed to determine whether lower leg muscle echo intensity, an indicator of muscle quality, is a useful predictor of gait variability after examining the relationship between physical activity and gait variability in community-dwelling older and healthy young adults. [Participants and Methods] This study comprised two tasks. In the first task, 18 older and 25 young adults were included as participants. We examined the relationship between the amount of physical activity and gait variability in both groups. In the second task, muscle echo intensity related to gait variability in each group was measured using ultrasound echoes after identifying common factors related to gait variability in 19 older and 19 younger adults, and trends were compared. [Results] In the first task, gait variability was significantly higher in the younger group than in the older group. A significant negative correlation was found between the amount of physical activity and gait variability in both groups. In the second task, multiple regression analysis was performed for gait variability, and lower leg muscle echo intensity was identified as a significant factor. There was no difference in the correlation coefficient between gait variability and lower leg muscle echo intensity between the two groups. [Conclusion] Lower leg muscle quality was one of the causes of gait variability, suggesting that it is a useful predictor of gait sway status.

Key words: Physical activity, Gait variability, Muscle quality

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INTRODUCTION

Physical activity does not only improve physical and mental function, it also has the potential to reverse the effects of chronic disease; however, participation in physical activity among the older adults is usually inadequate¹). As humans age, their anatomical and physiological functions decline. Consequently, skeletal muscle disorders are a common negative event in the older adults²). As sarcopenia is a core component of the frailty cycle³), some form of assessment and intervention for the skeletal muscles is essential. In older adults, the variability of spatial (stride length and step distance), mechanical (gait speed), and temporal (gait cycle) parameters of gait cause more negative changes than noted in younger people⁴). The flexibility and muscle weakness associated with aging are thought to cause a gait with a large degree of sway. Co-contraction⁵), a postural control strategy related to gait, is higher in the older than in the young adults, and increased co-contraction is a type of strategy for maintaining postural stability^{6, 7}). However, excessive co-contraction inhibits a smooth gait and increases the energy cost of motion⁸).

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Older adults may experience a decrease in physical activity due to fewer opportunities to go outside. Thus, it is meaningful to evaluate physical activity and gait variability from a preventive perspective to maintain future health. We focused on muscle quality in relation to co-contraction. Muscle quality is affected by the infiltration of non-contractile tissues, such as adipose tissue, into the muscles⁹⁾, which can now be easily assessed by muscle echo intensity (MEI) using ultrasound equipment. Generally, the somatosensory system, including the intrinsic sensory system, accounts for a high percentage of human postural control strategies¹⁰⁾. In older adults with reduced skeletal muscle mass, the sensitivity of muscle spindles and other proprioceptors that are selectively distributed in the lower limbs is reduced and postural control is impaired¹¹⁾. While the function of Ia inhibition and alpha motor neurons in antagonist muscles is reduced in the older adults, the infiltration of intramuscular fat also reduces the percentage of contractile tissue that produces muscle strength and decreases proprioceptor sensitivity. This is speculated to be accompanied by a loss of Ia inhibition, leading to excessive co-contraction. Thus, it is likely that the degree of intramuscular fat infiltration increases gait variability. By examining the relationship between muscle qualities in gait variability, a new index for gait can be created from a preventive perspective. Moreover, if muscle quality is determined as a factor influencing gait variability, effective exercise therapy and assessment can be provided to those with low physical activity.

This study aimed to examine the relationship between physical activity and gait variability in community-dwelling older and healthy young adults, to identify common factors and their influence on gait variability, and to determine whether MEI is associated with gait variability. We then verified whether MEI was a predictor of gait variability.

PARTICIPANTS AND METHODS

This study was divided into two tasks (Fig. 1). In Task 1, an interview was conducted among 18 community-dwelling older adults and 25 healthy young adults. In order to identify the characteristics of the older population as a whole, we did not classify the older adults by gender for this task. The interview obtained data regarding participant characteristics (gender, age, and medical history). Next, after measuring the participants' height, the body mass index (BMI) was calculated by measuring their body weight using a body component analyzer (Inbody 270: Inbody Japan Inc., Tokyo, Japan). The young group was then assessed using the International Physical Activity Questionnaire (IPAQ). For the older group, the Physical Activity Questionnaire for Elderly Japanese (PAQ-EJ), which is adapted to the lifestyle of elderly Japanese, was used. The two scores were calculated using a prescribed formula to obtain the total amount of physical activity^{12, 13)}. Gait variability was evaluated using a triaxial accelerometer (ATR-Promotions, Inc., Kyoto, Japan) to measure the change in trunk acceleration along the horizontal axis. The measurement method was the same as for the 10-m walking test, but with a 3-m front-back aided zone. The changes in the horizontal axis were extracted as the root-mean-square (RMS). RMS was divided by the square of the gait speed to obtain the normalized root-mean-square (NRMS). The triaxial accelerometers were firmly attached to the third lumbar spinous process, which is considered to reflect the center of gravity, using a velcro belt.

Participants for Task 2 were 19 community-dwelling older adults and 19 healthy young adults matched in terms of gender ratio. The same method was used for participant characteristics (gender, age, medical history, height, weight, and BMI) as in Task 1. In addition, the skeletal muscle mass index (SMI) was calculated. Next, grip strength (GRIP-D, Takei Kiki Kogyo Co., Ltd., Niigata, Japan) was measured twice on both sides, and the bilateral averages were used. Ankle plantar flexor and dorsiflexor muscle strength were measured using a multipurpose device for evaluating muscle function (BIODEX System 4, Sakai Medical Co., Ltd., Tokyo, Japan). The measurement protocol consisted of 5 seconds of isometric contraction, a 10-second rest period, and 5 seconds of dorsiflexion. This was performed for a total of two sets, and the results were averaged. A diagnostic ultrasound device (SonoSite iViz, FUJIFILM, Tokyo, Japan), a linear probe (L38v/5-10 MHz, FUJIFILM), and ultrasound jelly (F JELLY Ultrasound Gel MIDDLE, FUJIFILM) were used to measure MEI in the lower legs. The measurement point was the medial head of the gastrocnemius muscle at 30% proximal to the length of the lower leg, since the role of the triceps muscle is an important determinant in gait¹⁴⁾. Pixels in the measurement area were quantified using

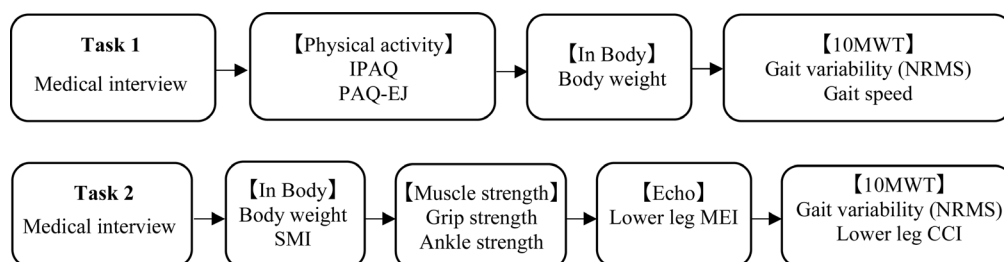


Fig. 1. Overview of protocols for Task 1 and Task 2.

10MWT: 10 m walk test; IPAQ: International Physical Activity Questionnaire; PAQ-EJ: Physical Activity Questionnaire for Elderly Japanese; SMI: Skeletal muscle mass index; MEI: Muscle echo intensity; CCI: Co-contraction index.

image analysis software (Image J software, National Institute of Health, Bethesda, MD, USA) with an 8-bit grayscale (256 grayscale levels), with values of 255 and 0 designating white and black, respectively¹⁵). The area for analysis in the image was analyzed as a region of interest with the vertical axis being the largest area, not including the fascia, and the horizontal axis being the center three-quarters of the image. Gait variability was evaluated with the same method as in Task 1. To evaluate the muscle contraction index, the lower leg co-contraction was calculated based on the muscle activity obtained from the 10-m walk test at the same time as the evaluation of gait variability. Thereafter, the lower leg co-contraction index (CCI) was calculated using a specified formula¹⁶). Measurements were made using a surface electromyograph (TeleMyo 2400T G2, NORAXON U.S.A., Scottsdale, AZ, USA) with electrodes (Blue Sensor M-00-S, Metts, Tokyo, Japan) affixed to the tibialis anterior muscle and the medial head of the gastrocnemius muscle. The electrode for tibialis anterior muscle was placed on the proximal third of the line connecting the tip of the fibula to the tip of the medial capsule, and the electrode for the medial head of the gastrocnemius muscle was placed along the lower leg of the maximum bulge of the gastrocnemius muscle (Nihon Kohden Co., Ltd., Tokyo, Japan). Before applying the electrodes, the skin at the measurement site was treated with a pretreatment agent for biological signal monitoring (SkinPure, Nihon Kohden Co., Ltd.) and with alcohol to lower the impedance¹⁷). The sampling frequency of the surface electromyograph was 1,500 Hz, and a bandpass filter (frequency range: 20–500 Hz) was applied to the data. The raw waveforms were smoothed (RMS: 50 ms window) and then normalized by the peak value during gait¹⁸). A foot switch that can be synchronized with the electromyograph was used to identify one gait cycle. The foot switch is a sensor that can display an electrical signal based on heel contact pressure. Data on five stable gait cycles were extracted and utilized. The muscle activity obtained was calculated using the CCI as the degree of simultaneous contraction of the lower leg muscles during one gait cycle¹⁶).

IBM® SPSS® version 27 and Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA) were used for the statistical analyses. For Task 1, the unpaired t-test was used for between-group comparisons of height, weight, BMI, and gait speed, and the Mann–Whitney U test was used to compare age and NRMS. The χ^2 test was used to compare gender. Spearman's rank correlation analysis was used to examine the association of NRMS with IPAQ and PAQ-EJ in each group, and correlation coefficients were calculated. For Task 2, for intergroup comparisons between the young and older groups, uncorrelated t-tests were performed for height, weight, SMI, ankle plantar flexor strength, ankle dorsiflexor strength, mean grip strength, lower leg MEI, and lower leg CCI, whereas the Mann–Whitney U test was performed for age, BMI, and NRMS. Subsequently, Spearman's rank correlation analysis was used to calculate correlation coefficients for the following indices: age, BMI, SMI, ankle plantar flexion muscle strength, ankle dorsiflexion muscle strength, average grip strength, lower leg CCI, and lower leg MEI for NRMS. Multiple regression analysis was performed on the combined population of both groups, with the relevant indices as explanatory variables and NRMS as the dependent variable. The forced entry method was used for each variable. After conducting multiple regression analysis, the variance inflation factor (VIF) was set to 10, and if it exceeded 10, the variable was excluded because of the strong influence of multicollinearity. Thereafter, to compare the trends of the items extracted by multiple regression analysis between the young and older groups, Spearman's rank correlation analysis and a test of difference in correlation coefficients were used to determine any differences in correlation coefficients. The significance level was set at 5%. This study was approved by the ethics committee of the International University of Health and Welfare (approval No. 21-Ig-10). For the recruitment of participants in this study, permission was obtained from a senior manager to attend a meeting of the older adults organized by a local municipality in Kanagawa Prefecture. After distributing the recruitment guidelines and explaining the study to the potential research participants, we confirmed their willingness to participate and obtained their written consent.

RESULTS

The characteristics of the young and older groups are shown in Table 1, and correlations between the median values of IPAQ and PAQ-EJ (first quartile–third quartile) and NRMS are shown in Table 2. A significant negative correlation was found between physical activity and NRMS in both the young ($r=-0.46$ [$p<0.05$] for IPAQ and NRMS) and older ($r=-0.59$ [$p<0.05$] for PAQ-EJ and NRMS) groups. NRMS was significantly lower in the young group ($p<0.05$). The characteristics of the young and older groups are shown in Table 3. Age, NRMS, lower leg CCI, and lower leg MEI were significantly lower in the younger group ($p<0.05$), whereas height and ankle plantar flexion muscle strength were significantly higher in the younger group ($p<0.05$). No significant differences were found in other indices. Mean grip strength ($r=-0.42$), lower leg CCI ($r=0.64$), and lower leg MEI ($r=0.61$) were significantly correlated with NRMS ($p<0.05$). The results of the multiple regression analysis are shown in Table 4. Multiple regression analysis was conducted using NRMS as the dependent variable and mean grip strength, lower leg CCI, and lower leg MEI as explanatory variables. Mean grip strength and lower leg CCI were not significant ($p>0.05$), whereas the standard partial regression coefficient for lower leg MEI was significant with $\beta=0.50$ ($p<0.05$) (adjusted $R^2: 0.46$, $p<0.05$). VIF was 1.86. Figure 2 shows the correlation of lower leg MEI with NRMS in the young and older groups. In the younger group, lower leg MEI ($r=0.48$) was moderately correlated with NRMS ($p<0.05$). In the older group, lower leg MEI ($r=0.59$) was moderately correlated with NRMS ($p<0.05$). A test of the difference between the two groups for the correlation coefficient showed no significant difference ($Z=0.44$ [$p>0.05$]).

Table 1. Characteristics of healthy young adults and older adults living in the community in task 1

	Young group (n=25)		Older group (n=18)
Gender (n)	Males	12	8
	Females	13	10
Age (years)**		22.3 ± 3.9	73.1 ± 4.5
Height (cm)**		164.7 ± 7.7	157.1 ± 6.9
Body weight (kg)		58.9 ± 10.3	54.6 ± 7.8
BMI (kg/m ²)		21.6 ± 2.9	22.1 ± 2.6
Gait speed (m/s)		1.43 ± 0.19	1.42 ± 0.27
IPAQ (METs*min/week)		2,208 (1,683–4,321)	
PAQ-EJ (METs*hr/week)			66.8 (42.9–98.2)
NRMS (m/s ²)*		0.70 ± 0.13	0.81 ± 0.18

Values are expressed as mean ± standard deviation or median (1st–3rd quartiles), *p<0.05, **p<0.01. BMI: Body mass index; IPAQ: International Physical Activity Questionnaire; PAQ-EJ: Physical Activity Questionnaire for Elderly Japanese; NRMS: Normalized root-mean-square.

Table 2. Relationship between physical activity and gait variability in task 1

Analysis	Median (1st–3rd quartiles)	Correlation coefficient
		NRMS
IPAQ	2,208 (1,683–4,321)	–0.46*
PAQ-EJ	66.8 (42.9–98.2)	–0.59*

Values are expressed as median (1st–3rd quartiles), *p<0.05.

IPAQ: International Physical Activity Questionnaire; PAQ-EJ: Physical Activity Questionnaire for Elderly Japanese; NRMS: Normalized root-mean-square.

Table 3. Characteristics of healthy young adults and older adults living in the community in task 2

	Young group (n=19)		Older group (n=19)
Gender (n)	Males	8	8
	Females	11	11
Age (years)**		21.4 ± 3.1	73.1 ± 4.4
Height (cm)*		163.3 ± 8.0	156.7 ± 6.7
Body weight (kg)		56.1 ± 9.4	54.5 ± 7.6
BMI (kg/m ²)		21.0 ± 2.6	22.2 ± 2.6
SMI (kg/m ²)		6.6 ± 1.1	6.5 ± 0.8
Ankle strength (ft-Lbs/kg: %)	Plantar flexion*	91.1 ± 23.3	65.2 ± 26.7
	Dorsal flexion	41.2 ± 10.0	39.0 ± 11.5
Grip strength (kgf)		30.1 ± 8.6	28.3 ± 8.3
Gait speed (m/s)		1.43 ± 0.22	1.41 ± 0.27
NRMS (m/s ²)*		0.71 ± 0.08	0.82 ± 0.18
Lower leg CCI (%)*		30.5 ± 9.8	38.6 ± 11.8
Lower leg MEI (a.u.)*		47.8 ± 8.8	68.1 ± 15.8

Values are expressed as mean ± standard deviation (SD), *p<0.05, **p<0.01.

BMI: Body mass index; SMI: Skeletal muscle mass index; NRMS: Normalized root-mean-square; CCI: Co-contraction index; MEI: Muscle echo intensity.

Table 4. Results of the multiple regression analysis for normalized root-mean-square (NRMS)

	Partial regression coefficient: B	Standardized partial regression coefficient: β	Adjusted R ²	VIF
Constant	0.44			
Lower leg CCI	0.002	0.23		1.50
Lower leg MEI	0.002	0.50*	0.46*	1.86
Grip strength	0.003	–0.09		1.41

*p<0.05.

CCI: Co-contraction index; MEI: Muscle echo intensity; VIF: Variance inflation factor.

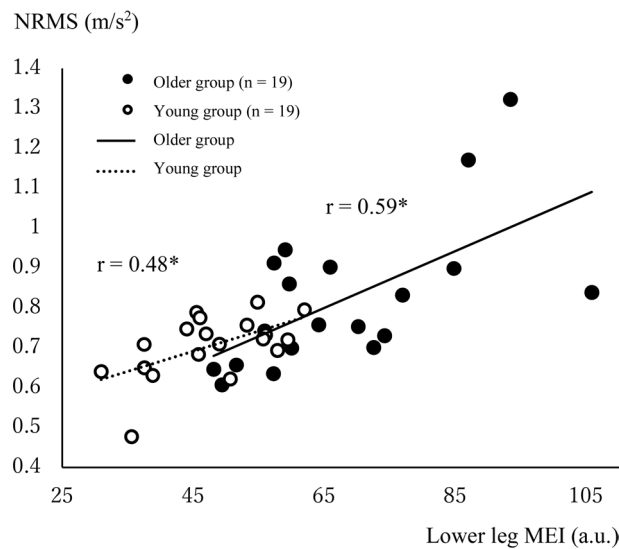


Fig. 2. Correlation between normalized root-mean-square (NRMS) and lower leg muscle echo intensity (MEI) in the younger and older groups. Spearman's rank correlation analysis was performed separately for each group.

DISCUSSION

The first task in this study aimed to determine the relationship between gait variability and the amount of physical activity in the younger and older populations, to clarify the significance of assessing gait variability in older adults living in the community. McGibbon et al.¹⁹⁾ showed that regarding gait, young persons have a lower limb control schema in which the pelvis leads the trunk, whereas older adults predominantly have a lower limb control schema in which the trunk leads the pelvis. This gait style makes it difficult for the older adults to cope with falls and stumbles. Lee et al.²⁰⁾ showed that the co-contraction of the trunk muscles is lower in the older than in younger and middle-aged participants in relation to gait. Although co-contraction has been reported to increase as a compensatory measure^{6, 7)}, the degree of co-contraction is different between the trunk and lower limbs. Therefore, the lower co-contraction of the trunk in the older adults compared to that in the young suggests that the older adults have a less stable gait. Therefore, as in the previous studies, the older participants walked with more sway even at the same gait speed compared to the younger participants. In this study, IPAQ and PAQ-EJ, which are physical activity measures, both showed a significant negative correlation with gait variability. Generally, a decrease in physical activity depresses skeletal muscle function, such as muscle weakness, both in young and older adults²¹⁾. In the case of the older population, the effects of aging also overlap, resulting in skeletal muscle disorders such as sarcopenia²²⁾. Despite the widely recognized benefits of habitual physical activity, many older adults do not meet the minimum amount of physical activity needed to stay healthy¹⁾. However, the results of this study showed that physical activity is related to gait variability, which may be one of the factors that can increase physical activity by intervening in gait variability.

In Task 2, a group comparison was conducted to identify differences in characteristics between the young and older groups. Thereafter, a correlation analysis and multiple regression analysis were conducted to identify the common factors that influence gait variability for both the young and the older adults. Post-hoc tests were used to compare and validate the trend of lower leg MEI against NRMS. The results showed that there were differences in NRMS, ankle plantar flexion strength, lower leg CCI, and lower leg MEI between the young and older groups, and that the older group had higher gait variability and lower physical function. These differences are related to degenerative changes due to the effects of aging. In addition, in Task 1, physical activity and gait variability were related in both the young and older groups. From these results, correlation and multiple regression analyses were conducted to identify common factors affecting gait variability. The results showed that mean grip strength, lower leg CCI, and lower leg MEI were associated with NRMS. In the subsequent multiple regression analysis with NRMS as the dependent variable, lower leg MEI was significant with $\beta=0.50$.

In the absence of sarcopenia, it is generally accepted that a person can maintain a certain degree of walking ability even when muscle mass and muscle strength are reduced²³⁾. However, the older adults are likely to have a gait that is highly unsteady due to the universal dysfunction in the skeletal muscles that occurs with aging. In terms of motor function, grip strength is related to total body muscle mass²⁴⁾, which may be related to NRMS. In addition, the older adults tend to have a short stride length and a wide step distance, indicating a conservative gait strategy²⁴⁾. Co-contraction is involved in the background of this gait strategy, and it is significantly higher in the older than in the young adults with regard to gait control strategies⁵⁾. Furthermore, patients with Parkinson's disease, which inevitably results in gait disturbance, have a strong lower

leg co-contraction²⁵). This suggests that increased co-contraction is a type of strategy for maintaining postural stability, since co-contraction is believed to enhance postural maintenance⁶ and joint stiffness⁷. However, an excess of these factors, combined with a decrease in the torque exerted during gait²⁶, prevents efficient gait. This suggests that NRMS and lower leg CCI are related, as co-contraction increases in those with greater gait variability in order to control gait variability, whether they are young or old.

Co-contraction is a common phenomenon that is related to neurological function, and it is associated with the Ia inhibitory response²⁷). The regulation of neural function is mainly performed by the visual, vestibular, and proprioceptive sensory systems, of which the somatosensory system, which includes the proprioceptive sensory system, plays a major role¹⁰). The sensory input of proprioceptors is immediately and unconsciously adjusted to unpredictable movements of the support surface²⁸). However, the older adults are often found to have reduced sensitivity²⁹) of the proprioceptive sensory system. Therefore, it is important to understand the effects of co-contraction derived from the proprioceptive system on movement. Task 2 was focused on muscle quality, which reflects the degree of non-contractile tissue within skeletal muscle. As joint stiffness may increase due to an increase in non-contractile tissue within skeletal muscle⁷), co-contraction is expected to increase in those with deteriorating muscle quality. Moreover, the older adults have more intramuscular fat infiltration compared with younger participants, which in addition to decreasing the proportion of contractile tissue, causes decreased proprioceptor sensitivity³⁰), which may have caused excessive co-contraction in association with decreased Ia inhibition. As a result, significant differences in NRMS and lower leg MEI were found between the groups, suggesting that they were associated with NRMS. We compared whether the trend of lower leg MEI, which had the greatest influence in the multiple regression analysis, differed between the young and older groups, and found that lower leg MEI was significantly associated with NRMS in both groups. The test of difference between these two correlation coefficients showed no significant difference between the two groups. Although the results do not allow us to determine a causal relationship based on correlations between the two groups, the absence of differences in the correlation coefficients and the results obtained by multiple regression analysis suggest that lower leg MEI is a factor in gait variability.

In conclusion, our results indicate that lower leg MEI had the strongest influence on NRMS and there was no difference in the correlation between NRMS and lower leg MEI by the age group. Furthermore, lower leg muscle quality is one of the causes of gait variability in the qualitative evaluation of gait, suggesting that it is a useful index for predicting the state of gait variability.

A limitation of this study is that it did not examine the middle-aged group. Since skeletal muscle mass decreases over time with age, it seemed necessary to subdivide the sample into smaller groups to obtain more detailed data.

Funding and Conflict of interest

There are no conflicts of interest and funding to disclose in this study.

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