

# Examination of the impact of strength and velocity of the knee and ankle on gait speed in community-dwelling older adults

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## Article

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# Abstract

Muscle strength of knee extension and ankle plantarflexion plays a crucial role in determining gait speed. Recent studies have shown that no-load angular velocity of the lower limb joints is essential for determining the gait speed. However, no study has compared the extent to which lower limb functions such as knee extension strength, knee extension velocity, plantarflexion strength, and plantarflexion velocity impact gait speed. Therefore, this study aimed to examine the relative importance of maximum strength and no-load angular velocity on gait speed in older adults. Overall, 164 community-dwelling older adults participated in this study. We measured maximum gait speed and lower limb function (strength and velocity of knee extension and plantarflexion). Multiple linear regression analysis was performed with gait speed as the dependent variable and age, sex, and lower-limb function as independent variables. Plantarflexion velocity (standardized  $\beta = 0.25$ ) and plantarflexion strength (standardized  $\beta = 0.21$ ) were noted to be significant predictors of gait speed. These findings indicate that no-load plantarflexion velocity is more important than the strength of plantarflexion and knee extension as a determinant of gait speed, suggesting that improvement in plantarflexion velocity may be expected to increase gait speed.

## Introduction

Gait speed is a useful index for evaluating locomotion, and it is known to decline with age. The decline in gait speed can reach 12–16% per decade starting at the age of 60 years<sup>[1–5]</sup>. Slow gait speed has been shown to be a good predictor of disability, hospitalization, falls, the requirement for a caregiver, and mortality in older adults in several epidemiological studies<sup>[1–4]</sup>. Gait speed is affected by various factors such as health status, muscle function, sensory and perceptual function, pain, motivation, cognitive status, and the environment<sup>[6]</sup>.

Lower limb muscle strength is a major determinant of gait speed<sup>[7–11]</sup>. Knee extension strength is strongly correlated with gait speed of community-dwelling women as reported in a study by Load et al<sup>[7]</sup>. Bendall et al. reported that plantarflexion strength is related to gait speed in older adults<sup>[9]</sup>. Furthermore, decline in both knee extension and plantarflexion strength with aging causes a decrease in gait speed<sup>[12]</sup>. Thus, knee extension and plantarflexion strength are critical determinants of gait speed in older adults.

Lower limb muscle power is also involved in determining gait speed. Bean et al. reported that muscle power is more closely associated with gait speed than muscle strength in older adults<sup>[13]</sup>. As muscle power is the product of velocity and strength (power = velocity  $\times$  strength), both components are relevant determinants of muscle power. Therefore, the concept of angular velocity have gained attention. Recent studies in older adults have shown a relationship between gait speed and angular velocity of the upper limbs<sup>[14, 15]</sup>, lower limbs<sup>[16–18]</sup>, and trunk<sup>[19–21]</sup>. Regarding the lower limb, the angular velocity of knee extension<sup>[16, 17]</sup> and ankle plantarflexion<sup>[18]</sup> have been shown to correlate with gait speed in older adults. Thus, the angular velocity of knee extension and ankle plantarflexion greatly contribute to the gait speed.

As stated above, muscle strength and angular velocity as the function and knee and ankle joints as the region, all have been found to play a crucial role in determining gait speed in older adults. However, no study has compared the extent to which knee extension strength, knee extension velocity, plantarflexion strength, and plantarflexion velocity contribute to gait speed. The purpose of this study was to comprehensively examine the importance of each of the four aforementioned lower limb functions in determining gait speed in older adults. By clarifying the relative importance of lower-limb muscle strength and angular velocity in gait speed, this study could provide useful information regarding effective interventions for improving gait speed in older adults.

## Results

Figure 1 shows the flowchart of recruitment and exclusion of study participants. Seven of the initially selected 164 participants did not meet the inclusion criteria and were excluded from the study. Thus, 157 participants (41 men and 116 women) were included in the final analysis. Table 1 shows the characteristics corresponding participants. The mean age, height, and weight of our study population were  $72.9 \pm 5.0$  years,  $156.0 \pm 8.0$  cm, and  $54.8 \pm 9.2$  kg, respectively.

Table 1  
Characteristics of participants (n = 157).

	mean	±	SD	range	
Characteristic					
Age (years)	72.9	±	5.0	65	- 89
Sex (M/F)	41 / 116				
Height (cm)	156.0	±	8.0	140.5	- 176.0
Weight (kg)	54.8	±	9.2	37.8	- 83.8
Gait					
Fast gait speed (m/s)	1.90	±	0.28	1.23	- 2.97
Lower limb function					
Knee extension strength (Nm/kg)	1.60	±	0.37	0.33	- 2.55
Knee extension velocity (°/s)	367.7	±	36.3	260.2	- 459.1
Ankle plantarflexion strength (kgf/kg)	0.86	±	0.27	0.22	- 1.72
Ankle plantarflexion velocity (°/s)	754.8	±	157.0	351.9	- 1261.0
SD: standard deviation, M: male, F: female					

Table 2 shows the Pearson's correlation coefficients between gait speed and lower limb function. Gait speed was significantly positively correlated with all four lower limb functions. Table 3 presents the results of multiple regression analysis, which revealed that the independent variables accounted for 31% of the variance in gait speed (adjusted  $R^2 = 0.31$ ,  $p < 0.001$ ). The ankle plantarflexion angular velocity (standardized  $\beta$ -regression coefficient = 0.25,  $p < 0.01$ ), ankle plantarflexion muscle strength (standardized  $\beta$ -regression coefficient = 0.21,  $p < 0.01$ ), age (standardized  $\beta$ -regression coefficient = - 0.19,  $p < 0.01$ ), and sex (standardized  $\beta$ -regression coefficient = - 0.16,  $p < 0.05$ ) were noted as significant predictors of gait speed.

Table 2  
Correlation between gait speed and lower limb functions.

	Gait speed	Knee strength	Knee velocity	Ankle strength	Ankle velocity
Gait speed (m/s)	1.000	0.399**	0.409**	0.389**	0.394**
Knee extension strength (Nm/kg)		1.000	0.644**	0.534**	0.221**
Knee extension velocity (°/s)			1.000	0.386**	0.278**
Ankle plantarflexion strength (kgf/kg)				1.000	0.261**
Ankle plantarflexion velocity (°/s)					1.000
**; $p < 0.01$					

Table 3  
The results of multiple regression analysis.

Characteristic	Gait speed (m/s)		
	Standardized $\beta$	p-value	VIF
Age	-0.19	0.01	1.2
Sex	-0.16	0.04	1.3
Knee extension strength (Nm/kg)	0.10	0.28	2.1
Knee extension velocity (°/s)	0.11	0.23	1.9
Ankle plantarflexion strength (kgf/kg)	0.21	0.01	1.4
Ankle plantarflexion velocity (°/s)	0.25	< 0.01	1.2
Adjusted $R^2 = 0.31$			
$\beta$ : regression coefficient, VIF: variance inflation factor			

## Discussion

This is the first study to comprehensively examine the relationship between gait speed and lower limb function (muscle strength and angular velocity of the knee and ankle) in older adults. The results of the study indicated two points: (1) the ankle function had a greater influence on gait speed than knee function, and (2) plantarflexion velocity was the most significant factor in determining gait speed.

The importance of ankle function can be explained by differences in the roles of each joint during gait. Knee extension mainly provides shock absorption during the loading response and controls body stability during mid-stance<sup>[22-26]</sup>. However, ankle plantarflexion provides forward propulsion during push-off in the late stance<sup>[22, 23, 27, 28]</sup>, accounting for 67% of the total propulsion power during the gait<sup>[29]</sup>. The forward propulsion is a major factor in determining gait speed. The ankle function, which provides most of the propulsion, has a greater impact on gait speed compared to knee function.

This study showed that the plantarflexion velocity is particularly crucial to gait speed. Angular velocities in various regions have a significant impact on mobility in older adults as suggested by previous studies<sup>[16-18,30-32]</sup>. Sayers et al. demonstrated that movement velocity in the leg press exercise is a stronger predictor of performance than muscle strength in lower-intensity tasks such as gait<sup>[31]</sup>. Furthermore, Yamamoto et al. reported that knee extension velocity is more influential than knee extension strength as a determinant of gait speed in older adults<sup>[32]</sup>. Our results that angular velocity is essential for gait speed are in line with the results of these studies.

The plantarflexion angular velocity during heel-raising was the only method that has been shown to be related to gait speed<sup>[18]</sup>. Heel-raising is a high-load task for older adults<sup>[33]</sup>. Therefore, the angular velocity at a high-load task is greatly affected by the force component, based on the force-velocity relationship<sup>[34]</sup>. Several studies<sup>[16, 31]</sup> have suggested that lower limb angular velocity under low-load conditions is more strongly related to gait speed than that under high-load conditions. We hypothesized that the plantarflexion velocity under low-load conditions is more important for gait speed, and this study measured angular velocity under no-load conditions. As a result, the no-load plantarflexion velocity had a particularly strong relationship with gait speed in older adults.

This study has several limitations. First, the method of measuring muscle strength differed between knee extension and ankle plantarflexion. In the measurement of knee extension strength, the measured value was calculated as torque (Nm/kg) using an isokinetic dynamometer. On the other hand, in the measurement of ankle plantarflexion strength, the measured value was calculated as force (kgf/kg) instead of torque, using a handheld dynamometer. Differences in measurement methods may have affected the results of this study. Second, this examination included knee and ankle joints but did not evaluate the hip joint. The hip joint function might be related to gait speed and further studies are warranted to clarify this relationship.

In conclusion, the gait speed of community-dwelling older adults is significantly affected by the ankle plantarflexion function of the lower limb. Plantarflexion velocity is a critical determinant of gait speed. The results of this study suggest that it may be possible to increase gait speed by improving the ankle plantarflexion angular velocity.

## Methods

### Participants

In total, 164 community-dwelling older adults participated in this cross-sectional study. All participants were recruited through local newspaper advertisements and leaflets distributed at health-related events. The inclusion criteria were as follows: (1) age  $\geq 65$  years, (2) ability to walk independently without assistive devices, and (3) ability to understand and follow instructions. This study was registered in the University Hospital Medical Information Network Clinical Trials Registry (UMIN-CTR) under the number UMIN000041740. All procedures were performed in accordance with the ethical principles outlined in the Declaration of Helsinki and the study was approved by the Human Ethics Committee of Osaka Prefecture University (approval number: 2019–118). Informed consents were obtained from all patients for study participation and publication of information. The participant appearing in Fig. 2 and Fig. 3 provided additional informed consent for the publication of the identifying image in an online open-access publication.

### Measurement Data

For each participant, gait speed and lower limb function (knee extension and ankle plantarflexion) were measured in a random order on the same day. The gait speed was measured on an 8-m walkway using a photocell system (Optojump Next; Microgate, Bolzano, Italy). The initial and final 1.5m sections were not timed to allow for acceleration and deceleration, and the time taken to walk 5m in the center was measured<sup>[19]</sup>. Participants were instructed to walk as quickly as possible. The measurement was performed twice.

Measurements of lower limb function were performed unilaterally on the right side, and the maximum value was used in the analysis for all measurements. Muscle strength and angular velocity of knee extension were measured based on Van Roie's method using an isokinetic dynamometer (Biodex system3; Biodex Medical Systems, Inc, Shirley, NY, USA)<sup>[16]</sup>. Participants were seated with their hips fixed at 90° flexion, and their hips and shoulders were stabilized using safety belts. The rotational axis of the dynamometer was aligned with the transverse knee-joint axis and connected to the distal end of the tibia with a length-adjustable rigid lever arm. Knee extension muscle strength was evaluated by isokinetic movements at 60°/s in the knee flexion angle range of 90° to 20°. Participants were instructed to perform knee extension with maximal effort while sitting on the isokinetic dynamometer. Knee extension angular velocity was evaluated using a maximal unloaded knee extension test in the absence of external resistance (with the exception of the weight of the lever arm of the dynamometer) in the knee flexion

angle range of 90° to 20°. Participants were instructed to perform knee extension as quickly as possible while sitting on the isokinetic dynamometer. After the practice session, each measurement was performed in triplicate.

Ankle plantarflexion muscle strength was measured using a handheld dynamometer ( $\mu$ Tas-F100; ANIMA, Tokyo, Japan) (Fig. 2)<sup>[35]</sup>. Participants were seated on a bed in a long sitting position, with their arms crossed in front of their chest. The sensor pad of the handheld dynamometer was placed at the distal end of the metatarsal bone at the sole of the foot. Thereafter, the ankle joint was fixed in the neutral position by tightening the belt. Following a trial run, participants were instructed to perform ankle plantarflexion twice, with maximum effort for 5 s.

The ankle plantarflexion angular velocity was measured using a gyroscope (45 mm×45 mm×18 mm; MicroStone Corporation, Nagano, Japan) (Fig. 3). The gyroscope was fixed on the distal end of the second metatarsal bone at the dorsum of the foot so that the axis of the sensor was aligned with the sagittal plane<sup>[18]</sup>. The data from the gyroscope were captured at a frequency of 200 Hz. Participants were seated in a long sitting position on a bed with both hands on the floor. During the test, the lower limb was fixed to the bed using a belt at the knee. They were instructed to perform ankle plantarflexion as quickly as possible at ankle angles ranging from maximum dorsiflexion to maximum plantarflexion. The maximum velocity in the range of motion from maximum dorsiflexion to 50° was used in the analysis. After two practice sessions, the measurements were performed five times. The reliability of plantarflexion angular velocity was confirmed via preliminary experiments (Supplementary Table S1-S3) performed on 10 older adults (77.0 ± 9.0 years). Informed consents were obtained from all participants for participation in preliminary experiments and publication of information in an online open-access publication. Plantarflexion velocity was measured on two different days. The intraclass correlation coefficient for the test-retest reliability was 0.93 ( $p < 0.01$ ), demonstrating excellent reliability of the measurement.

## Statistical analysis

Pearson's correlation coefficients were used to assess the relationship between gait speed and lower limb function (knee extension strength, knee extension velocity, plantarflexion strength, and plantarflexion velocity). Multiple linear regression analysis with forced entry was performed with gait speed as the dependent variable and age, sex, and limb function parameters as independent variables. The significance level was set at  $p < 0.05$ . SPSS statistical software (SPSS version 25.0; SPSS Inc., Chicago, IL, USA) was used for all statistical analyses.

## Declarations

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## Author contributions

Study conception and design: A.K., M.M., and A.I. Data collection: A.K., M.M., S.Y., T.O., M.F., T.M., and S.O. Data analysis and interpretation: A.K., M.M., S.O., and A.I. Drafting of the manuscript: A.K. Critical revision: S.Y., T.O., R.U., and A.I. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

## Data availability statement

The datasets generated or analyzed during the current study are available from the corresponding author upon reasonable request.

## Additional information

**Competing interests:** The authors declare no competing interests.

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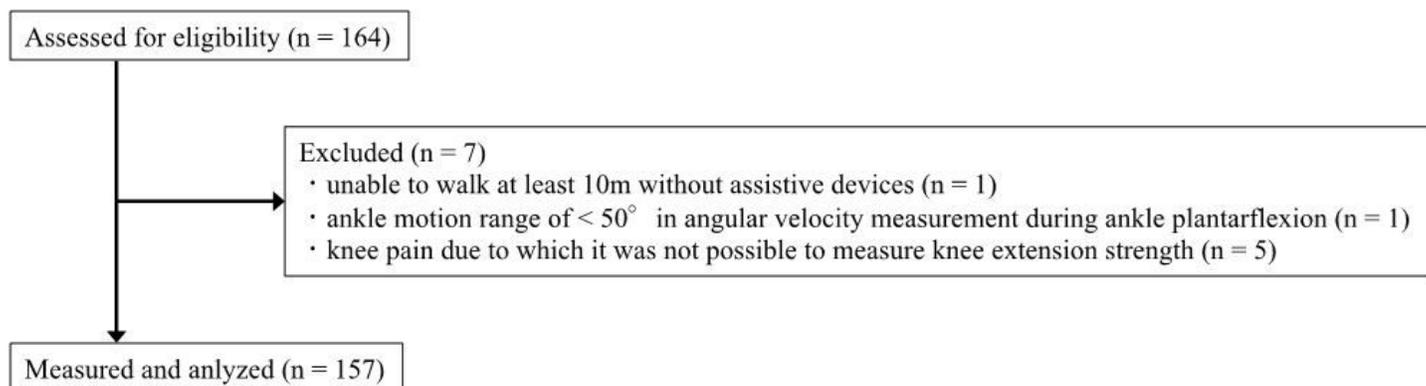
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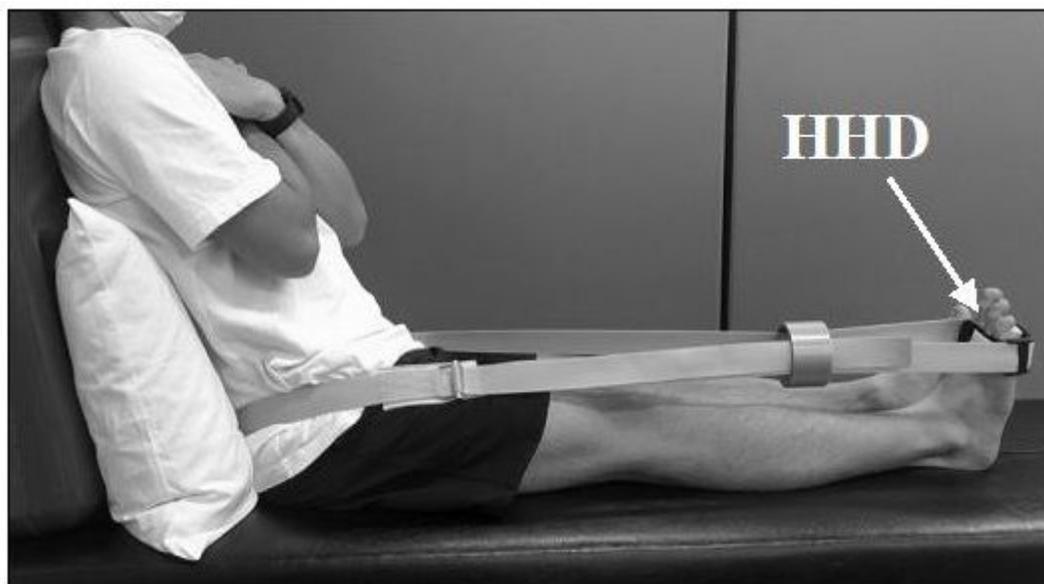
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# Figures



**Figure 1**

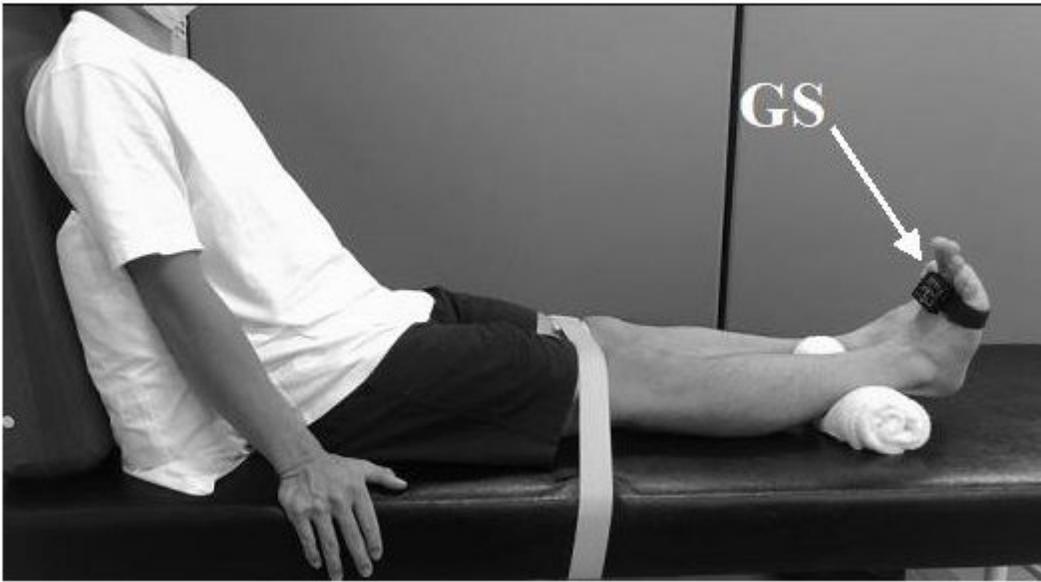
Flowchart depicting the selection of study participants.



**Figure 2**

Measurement of ankle plantarflexion muscle strength.

Participants sat on a bed with their backs against the backrest. The backrest was set to tilt backward by  $30^\circ$ . The HHD was attached to the sole and the ankle joint was fixed to the neutral position. The participant appearing in Fig.2 signed an informed consent to publish the images in an online open access publication. HDD: hand-held dynamometer.



**Figure 3**

Measurement of ankle plantarflexion angular velocity.

Participants sat on a bed with their backs against the backrest. The backrest tilted backward by  $30^\circ$ . The GS was attached to the dorsum of the feet. The participant appearing in Fig.3 signed an informed consent to publish the images in an online open access publication. GS; gyroscope.

## Supplementary Files

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