

Association of Lower-Limb Muscle Strength and Range-of-Motion Asymmetry with Motor Performance Indices in Older Adults: A Cross-Sectional Study

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Original Article

Abstract

Introduction: Motor function decline is a key contributor to reduced independence in older adults. This study examined associations between lower-limb muscle strength and range of motion (ROM) asymmetry with motor performance and functional limitations in the elderly.

Materials and Methods: In this cross-sectional study, 67 older adults (mean age: 71.01 ± 4.80 years) were recruited via convenience sampling from the Kahrizak Charity Foundation in Tehran City, Iran. Lower-limb muscle strength was measured with a handheld dynamometer, and joint ROM was assessed using a goniometer; asymmetry indices were then calculated. Motor performance was assessed using the Timed Up and Go (TUG) test, 10-Meter Walk Test (10MWT), the Balance Error Scoring System (BESS), and the Tinetti Performance-Oriented Mobility Assessment (POMA). Falls and functional limitations were evaluated via a fall-frequency questionnaire and basic/instrumental activities of daily living (BADLs/IADLs) measures, respectively. Associations between variables were analyzed using Pearson's and Spearman's correlation coefficients, with statistical significance set at $P < 0.05$.

Results: Lower-limb muscle strength asymmetry showed no significant association with motor performance or functional limitations ($P > 0.05$). Most ROM asymmetry indices were also not significantly associated with functional outcomes. However, hip adduction ROM asymmetry correlated significantly with walking speed ($r = -0.668$, $P = 0.001$), fall frequency ($r = 0.606$, $P = 0.001$), static balance ($r = 0.285$, $P = 0.019$), and dynamic balance ($r = -0.424$, $P = 0.001$). Hip extension ROM asymmetry was also significantly associated with walking speed ($r = 0.268$, $P = 0.029$) and functional limitations ($r = 0.254$, $P = 0.038$).

Conclusion: Lower-limb muscle strength asymmetry was not significantly associated with the functional outcomes examined, whereas hip adduction and extension ROM asymmetries were associated with several functional measures. These findings suggest that the functional significance of lower-limb asymmetry may vary according to the type of joint movement.

Keywords: Older adults; Lower limb; Muscle strength; Joint range of motion; Motor performance; Rehabilitation

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Introduction

Increasing life expectancy and the growing older adult population have made the preservation of function and independence a major priority for health systems and rehabilitation services. Aging is accompanied by

gradual changes in the nervous, muscular, and skeletal systems, which can lead to reduced muscle strength, restricted joint ROM, impaired postural control, and decreased ability to perform activities of daily living (1, 2). These changes are associated with reduced gait

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speed, impaired balance, increased fall risk, and functional dependence, thereby affecting the quality of life of older adults (3, 4). Therefore, one of the primary goals of geriatric rehabilitation is to identify factors contributing to declines in motor function and to design effective interventions to maintain functional independence, prevent disability, and promote social participation (5).

Motor function in older adults is a multidimensional phenomenon resulting from the complex interaction of neural, muscular, skeletal, sensory, and cognitive systems. It is typically evaluated using indicators such as gait speed, balance, functional mobility, and the ability to perform daily activities (6). In recent years, rehabilitation specialists have increasingly focused not only on traditional measures such as muscle strength and ROM but also on lower-limb symmetry, as coordinated performance of both lower limbs is essential for maintaining balance, safe weight transfer, control of the center of mass, and a normal gait pattern (7).

Lower-limb asymmetry refers to functional differences between the right and left limbs in characteristics such as muscle strength, ROM, neuromuscular control, or movement patterns. Increased asymmetry may alter gait patterns, increase mechanical loading on one limb, reduce motor stability, and increase the risk of falls (8, 9). Accordingly, some researchers have proposed asymmetry as a potential indicator for functional assessment and rehabilitation planning, suggesting that its measurement may provide clinicians with information beyond strength or ROM assessments alone (10).

Nevertheless, existing evidence regarding the association between lower-limb asymmetry and motor function in older adults remains inconsistent. Some studies have reported that increased muscle strength or ROM asymmetry is associated with reduced gait speed, impaired balance, and increased risk of falls (11, 12). Conversely, other studies have found no significant association between asymmetry and functional indicators, suggesting that older adults, particularly healthy community-dwelling individuals, may maintain their functional abilities despite some degree of asymmetry through neuromuscular compensatory mechanisms and altered motor control strategies (13, 14). This variability in findings suggests that the effects of asymmetry on motor function may depend on factors such as the measured indicator, the joint being assessed, sample characteristics, physical activity level, and assessment methods.

Moreover, a review of the literature shows that most previous studies have focused on asymmetry in

muscle strength, isokinetic torque, or gait parameters. In contrast, the role of joint ROM asymmetry, particularly in the lower limbs, has received less attention. Furthermore, most of these studies have examined only one or two functional outcomes, such as gait speed or balance. Few have simultaneously evaluated the associations between muscle strength and ROM asymmetry and a comprehensive set of functional indicators, including gait speed, static balance, dynamic balance, fall history, and functional limitations (10–14). Consequently, it remains unclear which asymmetry indicators may be more valuable for assessing functional performance in older adults.

Given this research gap, the simultaneous examination of muscle strength and ROM asymmetry across various dimensions of motor function may provide a more comprehensive understanding of the factors associated with functional decline in older adults. Therefore, this study aimed to investigate the associations of lower-limb muscle strength and ROM asymmetry indicators with motor performance outcomes, including gait speed, static balance, dynamic balance, fall history, and functional limitations, in older adults.

Materials and Methods

Study design and Participants: This cross-sectional study aimed to examine the associations between lower-limb muscle strength and ROM asymmetry indicators and motor performance and functional limitations in older adults.

The study population consisted of older men and women residing at the Kahrizak Charity Foundation (a center for the care, education, and rehabilitation of individuals with disabilities and older adults) in Tehran, Iran. A total of 67 older adults (mean age: 71.01 ± 4.80 years) participated in the study. Participants were selected using convenience sampling.

The sample size was calculated using G*Power software (version 3.1.9.6, freeware, University of Düsseldorf, Düsseldorf, Germany) based on a Pearson correlation test, with an expected effect size, 80% statistical power, and a significance level of 0.05.

The inclusion criteria were age ≥ 60 years, the ability to walk independently without assistive devices, the ability to understand and follow instructions for the motor performance tests, and provision of informed consent to participate. These criteria were established based on previous studies assessing gait, balance, and lower-limb asymmetry in older adults (8, 15).

The exclusion criteria included a history of lower-limb or orthopedic surgery within the previous six

months, acute musculoskeletal injury during the preceding six months, or neurological conditions affecting movement, such as Parkinson's disease or stroke. In addition, individuals who were unable to complete the functional tests or cooperate adequately during the assessment were excluded (8, 15).

Outcome Measures

Timed Up and Go (TUG) Test: Functional mobility was assessed using the TUG test, a valid and reliable tool for evaluating functional mobility in older adults (16, 17). Participants started from a seated position on a standard armless chair with a seat height of approximately 45 cm, stood up, walked 3 meters, turned around, returned to the chair, and sat down. Participants were instructed to perform the test at their maximum safe speed without running. The total completion time was recorded in seconds.

10-Meter Walk Test (MWT): Gait speed was assessed using the 10-meter walk test, a valid and reliable measure of walking performance in older adults (18, 19). Participants walked along a straight 10-meter course at their maximum safe speed. The completion time was recorded, and gait speed was calculated in meters per second. Each participant performed the test twice, and the best performance was used for the final analysis.

Balance Error Scoring System (BESS): Static balance and postural control were assessed using the Balance Error Scoring System, which has acceptable validity and reliability for evaluating postural control in various populations (20, 21). The test consisted of three stances: double-leg stance, tandem stance, and single-leg stance, each performed on firm and foam surfaces, with eyes open and closed. Each stance was maintained for 20 seconds, and the number of postural errors observed under each condition was recorded. The total error score was used for analysis.

Tinetti Performance-Oriented Mobility Assessment (POMA): Dynamic balance and fall-related motor function were assessed using the Tinetti test, which has good validity and reliability for evaluating balance, gait, motor performance, and fall risk in older adults (22, 23). The test comprises 16 items organized into two subsections: balance (9 items) and gait (7 items). Each item is scored on a 3-point scale ranging from 0 to 2, with a total possible score of 0 to 28. Higher scores indicate better balance and motor performance and a lower risk of falls.

Functional Variables Questionnaire: Functional limitations were assessed using a multidimensional questionnaire covering various domains, including basic activities of daily living, instrumental activities, social and leisure activities, lower-limb mobility, and

general physical activities. Participants reported their level of difficulty or inability to perform 19 functional activities on a 3-point scale: "no difficulty," "some difficulty," or "unable to perform." Functional limitation was defined as reporting any difficulty or inability in at least one of the assessed activities (24, 25).

Muscle Strength Assessment: Isometric muscle strength of the lower limbs was measured using a portable handheld dynamometer. The reliability and validity of handheld dynamometry for assessing isometric muscle strength in older adults have been reported in previous studies (26, 27). The device used could measure muscle force up to 300 pounds. In each trial, participants performed a maximal voluntary isometric contraction for 5 seconds against the device's applied resistance. Three repetitions were performed for each muscle group, with a 2-minute rest interval between repetitions to minimize fatigue. A familiarization session was conducted before testing. The mean of the three trials was used as the final value for each muscle group in the statistical analysis.

Range of Motion Assessment: Active joint ROM of the lower limbs was measured using a standard goniometer. The reliability and validity of this instrument for assessing joint ROM have been established (28, 29). Measurements were performed according to standard procedures, with the goniometer aligned with the joint axis and its arms aligned with the adjacent bony segments. Participants performed their maximum active ROM for each movement. Each movement was repeated twice, and the average of the two measurements was used for statistical analysis.

Asymmetry Assessment: Asymmetry indices for muscle strength and ROM were calculated using the following formula, expressing the difference between the stronger and weaker limbs as a percentage of the stronger limb value. A value of 0% indicated perfect symmetry between the two limbs (30).

Ethical Considerations: This study was approved by the Ethics Committee of the Sport Sciences Research Institute of Iran (ethics code: IR.SSRC.REC.1401.057). All participants provided written informed consent after receiving a full explanation of the study objectives and procedures. Participants' personal information was kept confidential, and all research procedures were conducted in accordance with ethical principles.

Statistical Analysis: All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to assess the normality of the data distribution. Normally distributed continuous variables are presented as mean

± standard deviation, whereas non-normally distributed variables are presented as median and interquartile range. Categorical variables are presented as frequencies and percentages.

To examine the associations between lower-limb muscle strength and ROM asymmetry indices and functional variables, Pearson's correlation coefficient was used for normally distributed variables, and Spearman's correlation coefficient for non-normally distributed variables. The significance level was set at $P < 0.05$ for all tests.

Results

The demographic and anthropometric characteristics of the participants, including age, height, weight, body mass index, and lower-limb length, are presented in Table 1. These results describe the baseline characteristics of the study participants.

Table 1. Descriptive statistics of the demographic characteristics of the sample (n = 67)

Characteristic	Mean ± SD
Age (years)	71.01 ± 4.80
Height (m)	1.68 ± 0.06
Weight (kg)	66.20 ± 5.04
Body mass index (kg/m ²)	23.50 ± 2.75
Lower-limb length (cm)	89.96 ± 3.36

The normality of the data distribution was assessed using the Kolmogorov–Smirnov test. Variables with normal distributions were analyzed using parametric

tests, whereas variables with non-normal distributions were analyzed using non-parametric tests. Static balance, dynamic balance, and functional limitations, which had non-normal distributions, were analyzed using non-parametric tests. To examine the associations between muscle strength and range-of-motion asymmetry indices and functional variables, Pearson's or Spearman's correlation tests were used based on the distribution of the data. The significance level was set at 0.05 for all tests.

The results of Pearson's correlation test showed that there was no significant association between muscle strength asymmetry indices and walking speed ($P > 0.05$) (Table 2).

Pearson's correlation results showed a significant positive association between hip extension ROM asymmetry and gait speed ($r = 0.268$, $P = 0.029$). Additionally, a significant negative association was observed between hip adduction ROM asymmetry and gait speed ($r = -0.668$, $P = 0.001$). The coefficient of determination (R^2) indicated that 7.18% to 44.62% of the variance in gait speed was explained by hip extension and hip adduction ROM asymmetry indices. No significant associations were found between gait speed and ROM asymmetry indices for ankle dorsiflexion, ankle plantarflexion, knee flexion, hip abduction, or hip flexion ($P > 0.05$) (Table 3).

Pearson's correlation results showed no significant association between any lower-limb muscle strength asymmetry index and the number of falls ($P > 0.05$) (Table 4).

Table 2. Pearson's correlation results for the association between the lower-limb muscle strength asymmetry index and gait speed

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexion strength asymmetry index (%)	Gait speed (m/s)	0.126	0.0158	0.311
Ankle plantarflexion strength asymmetry index (%)	Gait speed (m/s)	0.115	0.0132	0.352
Knee flexion strength asymmetry index (%)	Gait speed (m/s)	-0.039	0.0015	0.753
Knee extension strength asymmetry index (%)	Gait speed (m/s)	0.112	0.0125	0.368
Hip adduction strength asymmetry index (%)	Gait speed (m/s)	-0.069	0.0047	0.580
Hip hamstring strength asymmetry index (%)	Gait speed (m/s)	0.030	0.0009	0.807
Hip quadriceps strength asymmetry index (%)	Gait speed (m/s)	0.100	0.0100	0.420
Hip abductor strength asymmetry index (%)	Gait speed (m/s)	-0.101	0.0102	0.414

Table 3. Pearson's correlation results for the association between lower-limb joint ROM asymmetry index and gait speed

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexion ROM asymmetry index (%)	Gait speed (m/s)	0.151	0.0228	0.224
Ankle plantarflexion ROM asymmetry index (%)	Gait speed (m/s)	0.102	0.0104	0.410
Knee flexion ROM asymmetry index (%)	Gait speed (m/s)	0.168	0.0282	0.173
Hip abduction ROM asymmetry index (%)	Gait speed (m/s)	-0.019	0.0003	0.880
Hip flexion ROM asymmetry index (%)	Gait speed (m/s)	-0.068	0.0046	0.587
Hip extension ROM asymmetry index (%)	Gait speed (m/s)	0.268	0.0718	0.029*
Hip adduction ROM asymmetry index (%)	Gait speed (m/s)	-0.668	0.4462	0.001*

*Significant at $P < 0.05$

Table 4. Pearson's correlation results for the association between lower-limb muscle strength asymmetry index and number of falls

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexor strength asymmetry index (%)	Number of falls	-0.132	0.0174	0.287
Ankle plantar flexor strength asymmetry index (%)	Number of falls	-0.153	0.0234	0.216
Knee flexor strength asymmetry index (%)	Number of falls	0.044	0.0019	0.723
Knee extensor strength asymmetry index (%)	Number of falls	-0.075	0.0056	0.547
Hip adductor strength asymmetry index (%)	Number of falls	-0.002	0.0001	0.989
Hip hamstring strength asymmetry index (%)	Number of falls	0.025	0.0006	0.838
Hip quadriceps strength asymmetry index (%)	Number of falls	-0.068	0.0046	0.587
Hip abductor strength asymmetry index (%)	Number of falls	0.127	0.0161	0.306

Pearson's correlation results showed a significant positive association between hip adduction ROM asymmetry and the number of falls ($r = 0.606$, $P = 0.001$). The coefficient of determination (R^2) indicated that this relationship accounted for 36.72% of the variance in the number of falls. No significant associations were found between the number of falls and ROM asymmetry indices for ankle dorsiflexion, ankle plantarflexion, knee flexion, hip abduction, hip flexion, or hip extension ($P > 0.05$) (Table 5).

Spearman's correlation results showed no significant association between any lower-limb muscle strength asymmetry index and static balance score ($P > 0.05$) (Table 6).

Spearman's correlation results showed no significant association between any lower-limb muscle strength asymmetry index and dynamic balance score

($P > 0.05$) (Table 7).

Spearman's correlation results showed a significant positive association between hip adduction ROM asymmetry and static balance ($r = 0.285$, $P = 0.019$). The coefficient of determination (R^2) indicated that this relationship accounted for 8.12% of the variance in static balance. No significant associations were found between static balance and ROM asymmetry indices for ankle dorsiflexion, ankle plantarflexion, knee flexion, hip abduction, hip flexion, or hip extension ($P > 0.05$) (Table 8).

Spearman's correlation results showed a significant negative association between hip adduction ROM asymmetry and dynamic balance ($r = -0.424$, $P = 0.001$). The coefficient of determination (R^2) indicated that this relationship accounted for 17.97% of the variance in dynamic balance.

Table 5. Pearson's correlation results for the association between lower-limb joint ROM asymmetry index and the number of falls

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexion ROM asymmetry index (%)	Number of falls	-0.049	0.0024	0.695
Ankle plantarflexion ROM asymmetry index (%)	Number of falls	-0.136	0.0184	0.272
Knee flexion ROM asymmetry index (%)	Number of falls	-0.057	0.0032	0.645
Hip abduction ROM asymmetry index (%)	Number of falls	0.074	0.0054	0.549
Hip flexion ROM asymmetry index (%)	Number of falls	0.154	0.0237	0.214
Hip extension ROM asymmetry index (%)	Number of falls	-0.133	0.0176	0.282
Hip adduction ROM asymmetry index (%)	Number of falls	0.606	0.3672	0.001*

*Significant at $P < 0.05$

Table 6. Spearman's correlation results for the association between lower-limb muscle strength asymmetry index and static balance

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexor strength asymmetry index (%)	Static balance (errors)	0.052	0.0027	0.679
Ankle plantarflexor strength asymmetry index (%)	Static balance (errors)	-0.041	0.0016	0.741
Knee flexor strength asymmetry index (%)	Static balance (errors)	-0.065	0.0042	0.602
Knee extensor strength asymmetry index (%)	Static balance (errors)	0.035	0.0012	0.776
Hip adductor strength asymmetry index (%)	Static balance (errors)	-0.038	0.0014	0.760
Hip hamstring strength asymmetry index (%)	Static balance (errors)	-0.117	0.0136	0.345
Hip quadriceps strength asymmetry index (%)	Static balance (errors)	-0.074	0.0054	0.553
Hip abductor strength asymmetry index (%)	Static balance (errors)	-0.046	0.0021	0.709

Table 7. Spearman's correlation results for the association between lower-limb muscle strength asymmetry index and dynamic balance

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexor strength asymmetry index (%)	Dynamic balance (score)	0.020	0.0004	0.873
Ankle plantarflexor strength asymmetry index (%)	Dynamic balance (score)	0.078	0.0060	0.529
Knee flexor strength asymmetry index (%)	Dynamic balance (score)	0.048	0.0023	0.702
Knee extensor strength asymmetry index (%)	Dynamic balance (score)	0.006	0.0001	0.963
Hip adductor strength asymmetry index (%)	Dynamic balance (score)	-0.056	0.0031	0.651
Hip hamstring strength asymmetry index (%)	Dynamic balance (score)	0.057	0.0032	0.649
Hip quadriceps strength asymmetry index (%)	Dynamic balance (score)	0.032	0.0010	0.796
Hip abductor strength asymmetry index (%)	Dynamic balance (score)	-0.059	0.0034	0.936

Table 8. Spearman's correlation results for the association between lower-limb joint ROM asymmetry index and static balance

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexion ROM asymmetry index (%)	Static balance (errors)	-0.160	0.0256	0.197
Ankle plantarflexion ROM asymmetry index (%)	Static balance (errors)	0.024	0.0005	0.845
Knee flexion ROM asymmetry index (%)	Static balance (errors)	-0.067	0.0044	0.591
Hip abduction ROM asymmetry index (%)	Static balance (errors)	-0.053	0.0028	0.669
Hip flexion ROM asymmetry index (%)	Static balance (errors)	-0.019	0.0003	0.878
Hip extension ROM asymmetry index (%)	Static balance (errors)	-0.240	0.0576	0.051
Hip adduction ROM asymmetry index (%)	Static balance (errors)	0.285	0.0812	0.019*

*Significant at P<0.05

No significant associations were found between dynamic balance and ROM asymmetry indices for ankle dorsiflexion, ankle plantarflexion, knee flexion, hip abduction, hip flexion, or hip extension ($P > 0.05$) (Table 9). Spearman's correlation results showed no significant association between any lower-limb muscle strength asymmetry index and functional limitations ($P > 0.05$) (Table 10).

Spearman's correlation results showed a significant positive association between hip extension ROM asymmetry and functional limitations ($r = 0.254$, $P = 0.038$). Additionally, a significant negative association was observed between hip adduction ROM asymmetry and functional limitations ($r = -0.410$,

$P = 0.001$). The coefficients of determination (R^2) indicated that these relationships accounted for 6.45% and 16.81% of the variance in functional limitations, respectively. No significant associations were found between functional limitations and ROM asymmetry indices for ankle dorsiflexion, ankle plantarflexion, knee flexion, hip abduction, or hip flexion ($P > 0.05$) (Table 11).

Discussion

This study aimed to examine the associations of lower-limb muscle strength asymmetry and joint ROM asymmetry with motor performance indicators and functional limitations in community-dwelling older adults.

Table 9. Spearman's correlation results for the association between lower-limb joint ROM asymmetry index and dynamic balance

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexion ROM asymmetry index (%)	Dynamic balance (score)	0.217	0.0470	0.078
Ankle plantarflexion ROM asymmetry index (%)	Dynamic balance (score)	0.132	0.0174	0.288
Knee flexion ROM asymmetry index (%)	Dynamic balance (score)	0.129	0.0166	0.298
Hip abduction ROM asymmetry index (%)	Dynamic balance (score)	0.071	0.0050	0.568
Hip flexion ROM asymmetry index (%)	Dynamic balance (score)	-0.027	0.0006	0.830
Hip extension ROM asymmetry index (%)	Dynamic balance (score)	0.236	0.0556	0.054
Hip adduction ROM asymmetry index (%)	Dynamic balance (score)	-0.424	0.1797	0.001*

*Significant at P<0.05

Table 10. Spearman's correlation results for the association between lower-limb muscle strength asymmetry index and functional limitations

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexor strength asymmetry index (%)	Functional limitations (score)	0.028	0.0007	0.823
Ankle plantar flexor strength asymmetry index (%)	Functional limitations (score)	0.063	0.0039	0.611
Knee flexor strength asymmetry index (%)	Functional limitations (score)	0.046	0.0021	0.713
Knee extensor strength asymmetry index (%)	Functional limitations (score)	0.014	0.0001	0.912
Hip adductor strength asymmetry index (%)	Functional limitations (score)	-0.040	0.0016	0.749
Hip hamstring strength asymmetry index (%)	Functional limitations (score)	0.072	0.0051	0.561
Hip quadriceps strength asymmetry index (%)	Functional limitations (score)	0.028	0.0007	0.820
Hip abductor strength asymmetry index (%)	Functional limitations (score)	-0.060	0.0036	0.631

The main findings indicated that lower-limb muscle strength asymmetry was not significantly associated with gait speed, the number of falls, static balance, dynamic balance, or functional limitations. In contrast, several ROM asymmetry indices particularly those involving the hip joint were significantly associated with functional outcomes. Specifically, hip adduction ROM asymmetry was significantly associated with gait speed, the number of falls, static balance, and dynamic balance, whereas hip extension ROM asymmetry was associated with functional limitations.

Thus, the overall pattern of our findings suggests that, in the older adult population studied, hip joint ROM asymmetry may be a more sensitive indicator than muscle strength asymmetry for identifying certain functional impairments.

Lower-Limb Muscle Strength Asymmetry and Gait Speed

In the present study, none of the asymmetry indices for ankle dorsiflexor and plantarflexor strength, knee flexor and extensor strength, hip adductor and abductor strength, or hamstring and quadriceps strength were significantly associated with gait speed. This finding is noteworthy when compared with previous studies that have reported associations between strength asymmetry and gait parameters. For example, LaRoche et al. reported that lower-limb strength asymmetry in older women was associated with increased asymmetry and variability in certain gait parameters (31). However, in that study, gait outcomes included spatiotemporal parameters and gait asymmetry, whereas the present study examined gait speed as a global indicator of walking performance.

Table 11. Spearman's correlation results for the association between lower-limb joint ROM asymmetry index and functional limitations

Independent Variable	Dependent Variable	Correlation Coefficient (r)	Coefficient of Determination (r ²)	P-value
Ankle dorsiflexion ROM asymmetry index (%)	Functional limitations (score)	0.206	0.0424	0.095
Ankle plantarflexion ROM asymmetry index (%)	Functional limitations (score)	0.140	0.0196	0.260
Knee flexion ROM asymmetry index (%)	Functional limitations (score)	0.143	0.0204	0.249
Hip abduction ROM asymmetry index (%)	Functional limitations (score)	0.075	0.0056	0.547
Hip flexion ROM asymmetry index (%)	Functional limitations (score)	-0.043	0.0018	0.732
Hip extension ROM asymmetry index (%)	Functional limitations (score)	0.254	0.0645	0.038*
Hip adduction ROM asymmetry index (%)	Functional limitations (score)	-0.410	0.1681	0.001*

*Significant at P<0.05

Therefore, strength asymmetry may affect subtler gait characteristics, such as step length, stance time, temporal symmetry, and step variability, rather than absolute gait speed.

This difference in the type of outcome assessed can also be explained by the findings of Hyeon et al. (7), who, in a study of 345 individuals aged 19–85 years, demonstrated that the association between lower-limb strength asymmetry and gait parameters depends on the joint assessed and the specific dependent variable. They found that knee extension asymmetry was associated with reduced step length in older adults, while ankle plantarflexion asymmetry was associated with certain temporal gait parameters; these relationships were not observed in younger individuals. Thus, the absence of a significant association between strength asymmetry and gait speed in our study does not necessarily imply that strength asymmetry is unimportant; rather, it may suggest that gait speed is less sensitive than spatiotemporal or symmetry-related gait parameters for detecting the functional consequences of strength asymmetry.

On the other hand, our findings are not necessarily in conflict with studies reporting a direct association between muscle strength and motor function. For instance, studies in older adults have shown that lower-limb muscle strength correlates with physical performance and mobility, but this association does not necessarily extend to limb asymmetry (26). Indeed, an individual may have sufficient overall strength to perform an activity while still exhibiting interlimb strength differences. Therefore, absolute strength and strength asymmetry are distinct neuromuscular characteristics and may have different functional implications.

Strength Asymmetry, Balance, and Falls

In the present study, none of the lower-limb muscle strength asymmetry indices were significantly associated with either static or dynamic balance. This finding differs from some existing evidence suggesting a role for strength asymmetry in postural control. For example, a study in older adults reported that lower-limb muscle strength asymmetry was associated with some measures of postural control and gait performance (33). Similarly, a 2024 study found that lower-limb strength asymmetry may be related to gait performance through alterations in static postural control (29). However, differences in balance assessment tools, methods for calculating asymmetry, study population characteristics, and functional tests may account for these discrepant findings.

Additionally, Porto et al. (33) demonstrated that hip adductor and abductor muscle performance was

associated with certain measures of static and dynamic balance in community-dwelling older adults. Nevertheless, in their study, muscle performance was assessed in terms of strength or torque rather than interlimb differences. Thus, our finding of no significant association between hip adductor/abductor strength asymmetry and balance does not necessarily contradict the role of normal muscle function in maintaining balance; rather, it suggests that interlimb differences may not necessarily result in measurable impairments on clinical balance tests.

Regarding falls, none of the strength asymmetry indices were significantly associated with the number of falls. Falls in older adults are multifactorial and influenced by interactions among balance, gait, muscle strength, postural control, sensory function, cognitive status, medications, and environmental factors (34). Therefore, expecting a single indicator, such as strength asymmetry, to explain the occurrence of falls is likely an oversimplification. Longitudinal studies have also shown that although lower-limb muscle strength and power, particularly around the hip, are associated with fall risk, this relationship is influenced by a range of functional factors (35). Hence, the absence of a significant association between strength asymmetry and falls in our study suggests that strength asymmetry alone is insufficient to identify older adults at risk of falling.

Association of Hip ROM Asymmetry with Motor Performance

In contrast to the findings for muscle strength, the most prominent pattern observed in our study was related to hip joint ROM asymmetry. Hip adduction ROM asymmetry was significantly and negatively associated with gait speed ($r = -0.668$, $P = 0.001$). This finding is clinically important, as it indicates that a greater interlimb difference in adduction ROM was associated with slower gait speed. Moreover, hip adduction ROM asymmetry was positively and significantly associated with the number of falls ($r = 0.606$, $P = 0.001$). The observation of similar associations with two different outcomes, gait speed and falls, further highlights the potential importance of this indicator.

From a biomechanical perspective, the hip joint plays a crucial role in controlling the position of the center of mass, transferring weight between the limbs, and controlling frontal-plane body movements. The muscles surrounding the hip, particularly the adductors and abductors, contribute to pelvic stability and the control of lateral body displacement during standing and walking (33, 36). Therefore, a significant interlimb difference in adduction ROM may lead to differences

in weight transfer strategies and center-of-mass control. Such alterations may require individuals to adopt compensatory strategies and affect motor performance, particularly under conditions that require rapid weight transfer or balance maintenance. Our finding is also consistent with evidence regarding the role of lower-limb ROM in gait in older adults. Zhai et al. showed that age-related changes in trunk and lower-limb ROM were associated with altered gait patterns in older adults and that restricted motion in certain lower-limb segments was associated with changes in gait speed and other gait parameters (36). This supports the notion that, in older adults, not only muscle strength but also joint mobility and interlimb movement coordination are important for maintaining a normal gait pattern.

ROM Asymmetry and Static and Dynamic Balance

Another important finding of our study was the significant association between hip adduction ROM asymmetry and both static and dynamic balance. Hip adduction ROM asymmetry was significantly associated with increased static balance errors ($r = 0.285$, $P = 0.019$) and was significantly negatively associated with dynamic balance ($r = -0.424$, $P = 0.001$). These results are particularly noteworthy because the association was observed across both static and dynamic balance conditions, suggesting that the relationship is not limited to a single type of functional test. This finding is consistent with evidence regarding the role of the hip musculature in postural control. Porto et al., in community-dwelling older adults, reported that hip adductor and abductor muscle performance was associated with measures of static and dynamic balance and that adductor function contributed to balance control during narrow-stance conditions (33). Although their study assessed muscle strength, whereas ours assessed ROM asymmetry, both studies emphasize the importance of the hip region in postural control in older adults.

Mechanically, during standing and walking, controlling lateral center-of-mass movements and maintaining pelvic and trunk alignment are highly important. Any interlimb difference in ROM could alter the range or timing of weight transfer, thereby necessitating compensatory adjustments at other joints. This mechanism may be particularly relevant during dynamic activities that require rapid shifts in the center of mass. Therefore, the observed association between hip adduction ROM asymmetry and dynamic balance in our study is biomechanically plausible.

ROM Asymmetry and Functional Limitations

In our study, hip extension ROM asymmetry was significantly associated with functional limitations

($r = 0.254$, $P = 0.038$). Hip adduction ROM asymmetry was also significantly associated with functional limitations ($r = -0.410$, $P = 0.001$). These findings suggest that certain aspects of hip joint mobility and interlimb differences in ROM may be related to the ability to perform daily activities.

Hip extension is a key movement during the gait cycle, particularly during the terminal stance phase, and restriction of this motion may alter lower-limb movement patterns and lead to compensatory strategies. Anderson et al. also found that healthy older adults had reduced hip ROM and plantarflexor strength compared with younger individuals and that these differences could partially explain age-related changes in gait patterns (37). In the present study, the observed association between hip extension asymmetry and functional limitations may indicate that both an overall reduction in ROM and interlimb differences in ROM are related to daily functioning. However, because this was a cross-sectional study, it is not possible to determine whether ROM asymmetry contributed to functional limitations or whether reduced activity and functional limitations led to or exacerbated movement asymmetry. Therefore, this finding should be interpreted as an association rather than a causal relationship.

Although hip adduction and extension ROM asymmetries were associated with some functional outcomes, other ROM indices, including ankle movements, knee flexion, and hip flexion and abduction, were generally not significantly associated with functional outcomes. This pattern suggests that the functional importance of movement asymmetry is likely to be joint-, direction-, and task-specific. In older adults, restriction of motion at one joint does not necessarily lead to overt functional impairment, because the motor system can compensate, to some extent, through altered movement at other joints or at the trunk (37).

Thus, our findings support a “multi-joint motor system” perspective. Motor function in older adults results from the interplay of muscle strength, ROM, neuromuscular control, inter-joint coordination, and compensatory strategies and cannot be explained by a single variable. Accordingly, the absence of significant associations for many strength and ROM asymmetry indices should not be interpreted as indicating that these factors are unimportant; rather, it may reflect the adaptability of the neuromuscular system in older adults and their ability to use compensatory strategies to maintain functional performance.

Clinical Implications

Overall, our findings indicate that strength asymmetry and ROM asymmetry should not be

considered equivalent in terms of their functional consequences. While none of the strength asymmetry indices were significantly associated with the main study outcomes, hip adduction ROM asymmetry was associated with multiple functional indicators, including gait speed, the number of falls, and static and dynamic balance. This pattern suggests that, in community-dwelling older adults, assessment of hip joint ROM symmetry may provide valuable supplementary information alongside standard measures of motor performance. In clinical practice, functional evaluation of older adults should not focus exclusively on absolute muscle strength or strength asymmetry. However, it may also consider bilateral joint ROM, particularly at the hip, when feasible.

However, based on our findings, hip adduction or extension ROM asymmetry alone cannot be recommended as a screening tool for fall risk. A more appropriate approach would be to consider these indicators alongside gait speed, balance tests, fall history, and other relevant risk factors when assessing functional status. Finally, because this was a cross-sectional study, the observed associations should not be interpreted as causal relationships. Moreover, because multiple correlation tests were performed, individual associations, particularly those observed for only one outcome, should be interpreted with caution. In contrast, the association between hip adduction ROM asymmetry and several functional outcomes is more consistent and may provide a basis for future investigations. Longitudinal and interventional studies are needed to determine whether reducing hip ROM asymmetry, particularly in adduction and extension, can improve balance and gait and potentially reduce fall risk in older adults.

Limitations

This study had several limitations. First, the cross-sectional design precludes causal inferences regarding the associations between lower-limb asymmetry and functional outcomes. Second, participants were recruited from community-dwelling older adults via convenience sampling, and the relatively small sample size may limit the generalizability of the findings to other older adult populations, particularly those with neurological or musculoskeletal conditions. Additionally, several potential confounding factors, including physical activity level, comorbidities, and cognitive status, were not assessed or controlled for and may have influenced the observed associations.

Recommendations

Based on our findings, future studies should examine

the association between lower-limb asymmetry and motor function using longitudinal designs and larger sample sizes, which may provide stronger evidence regarding temporal and potentially causal relationships. Furthermore, the simultaneous assessment of biomechanical parameters, muscle activation patterns, sensory aspects of balance, cognitive status, and gait characteristics could contribute to a more comprehensive understanding of the role of asymmetry in functional performance among older adults. Additionally, investigating the effectiveness of rehabilitation interventions aimed at improving hip joint functional symmetry and examining their effects on balance, gait, and functional limitations could provide valuable evidence to inform the development of geriatric rehabilitation programs.

Conclusion

In summary, our findings showed that lower-limb muscle strength asymmetry was not significantly associated with motor performance, balance, the number of falls, or functional limitations in older adults. In contrast, several ROM asymmetry indicators, particularly hip adduction and extension, were significantly associated with certain functional outcomes, including gait speed and functional limitations, while hip adduction ROM asymmetry was additionally associated with static and dynamic balance, as well as the number of falls. Thus, in the studied population, the association between lower-limb asymmetry and functional outcomes was more evident for hip ROM asymmetry than for muscle strength asymmetry. Further studies with larger sample sizes and longitudinal designs are warranted to confirm these findings and clarify their clinical significance.

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Conflict of Interest

The authors did not have a conflict of interest.

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