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Associations between Lower-Limb Motor Coordination, Muscle Strength, and Fall Risk in Older Adults: A Cross-Sectional Study

Sasithorn Putfak, M.Sc.[1,2], Pakwipa Julphunthong, Ph.D.[1], Olan Isariyapan, M.Sc.[1,2], Orawan Keeratisiroj, Ph.D.[3], Waroonnapa Srisoparb, Ph.D.[1,2]

[1]Department of Physical Therapy, Faculty of Allied Health Sciences, Naresuan University, Mueang, Phitsanulok 65000, Thailand.
[2]Exercise and Rehabilitation Sciences Research Unit, Faculty of Allied Health Sciences, Naresuan University, Mueang, Phitsanulok 65000, Thailand.
[3]Department of Community Health, Faculty of Public Health, Naresuan University, Mueang, Phitsanulok 65000, Thailand.

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Abstract:

Objective: This study investigated the associations between lower-limb motor coordination, assessed using the Foot Tapping Test (FTT) and Four Square Step Test (FSST), and muscle strength, measured by the Five Times Sit-to-Stand Test (FTSST), with functional performance and fall risk classification in community-dwelling older adults.

Material and Methods: A total of 200 community-dwelling adults aged 60 years and older were recruited. Fall risk was evaluated using the Timed Up and Go (TUG) Test as the primary outcome measure. Participants were assessed for lower-limb motor coordination using the FTT and FSST, and for muscle strength using the FTSST. Multiple logistic regression analysis was performed to determine the independent contributions of coordination and strength measures (FTT, FSST, and FTSST) to the classification of high fall risk.

Results: Two models were analysed. Model 1 included the FTT and FTSST, while Model 2 included the FSST and FTSST. In Model 1, the FTT showed an adjusted odds ratio (AOR) of 0.803 (95% CI: 0.720–0.896), and the FTSST had an AOR of 1.702 (95% CI: 1.322–2.191). In Model 2, the FSST showed an AOR of 1.455 (95% CI: 1.197–1.770), and the FTSST had an AOR of 1.546 (95% CI: 1.195–2.001). All findings were statistically significant (p-value<0.001).

Conclusion: These findings suggest that the coordination and strength of lower extremity muscles are associated with fall risk in older adults and may help indicate or reflect the likelihood of mobility impairment related to falling.

Keywords: Aged, coordination, falling, lower extremity, muscle strength

Contact: Waroonnapa Srisoparb, Ph.D.
Department of Physical Therapy, Faculty of Allied Health Sciences, Naresuan University, Mueang, Phitsanulok 65000, Thailand.
E-mail: waroonnapas@nu.ac.th

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Introduction

Falls are a common geriatric syndrome resulting from age-related biological changes and health status shifts. With the growing global population of older adults, falls have emerged as a major health concern, affecting quality of life and potentially leading to disabilities worldwide[1]. These falls are often triggered by various risk factors, including intrinsic factors related to the natural deterioration of the body[2] and a history of falls[3]. External risk factors, also known as extrinsic factors, pertain to elements within the living environment of older adults[4]. The primary internal risk factors for falls among older adults include reduced leg muscle strength, balance dysfunction, and gait problems[5]. Leg muscle strength and balance are key factors related to the frequency of falls among older adults[6]. Additionally, muscle strength is essential for performing daily activities, such as walking, rising from a chair, and performing routine activities[7]. Unfortunately, older adults often experience a decline in muscle strength due to decreased size and a decrease in muscle mass along with selective atrophy of type II muscle fibres[8]. As older adults age, they experience a decline in muscle composition, contractile properties, and tissue characteristics, along with changes in tendon and muscle size. These factors lead to decreased muscle strength, power, and function, ultimately resulting in diminished mobility, lower physical fitness, and an increased risk of falls and frailty[9,10].

Furthermore, lower-limb motor coordination plays an important role in walking performance, as coordinated movements of the foot and ankle joints contribute to effective locomotor function during gait[11]. The link between coordination and fall risk lies in how impaired intra- and intersegmental coordination disrupts gait stability. Altered coordination, especially in the hip-knee and ankle-knee joints, leads to inconsistent joint movements, increasing the likelihood of balance loss and falls. Studies show that older adults with a history or fear of falling exhibit greater coordination variability, indicating compromised neuromuscular control and higher fall risk[12]. Previous studies have demonstrated a strong correlation between lower-limb coordination and walking ability in older adults. However, their study measured interlimb coordination using an advanced system, such as Vicon®. While Vicon® provides highly accurate data on lower-limb coordination, it is not practical for use in field assessments or community settings[13]. This highlights the need for simple, accessible tools that can evaluate motor coordination in older populations outside laboratory environments.

Ankle dorsiflexion muscle coordination reflects the central nervous system's ability to regulate movement and muscle function efficiently. Compared with adolescents, older adults often show reduced control and performance during ankle dorsiflexion. Furthermore, research on ankle function and balance in older adults evaluating both weight-bearing (such as in the lunge test) and non-weight-bearing movements revealed that restricted ankle dorsiflexion is negatively associated with fall risk and overall balance. However, it showed a statistically significant positive correlation with balance during movement, indicating that while limited dorsiflexion can compromise stability, it may also enhance dynamic balance in certain contexts[14]. The lower extremity motor coordination test revealed a significant relationship with walking ability in stroke patients. Poor coordination was associated with slower walking speeds. Interestingly, individuals with good muscle strength, defined as a manual muscle testing score of Grade 4 or higher, still exhibited slow walking speed, suggesting that factors beyond strength may contribute to their reduced gait performance. Furthermore, decreased walking speed contributes to an increased risk of falling[15]. Moreover, slower walking is particularly associated with a greater fall risk in older adults[16]. These findings suggest that lower-limb coordination, as evaluated through field assessment tools, may be closely related to fall risk in this population. The Four

Square Step Test (FSST), which requires participants to step rapidly in four directions over obstacles, is a widely used field-based assessment of dynamic balance and interlimb coordination. Prior studies support its validity and reliability for identifying older adults at an increased risk of falling[17,18]. In contrast, the Foot Tap Test (FTT) offers a simple, low-cost method to evaluate unilateral ankle dorsiflexion speed in a seated, non-weight-bearing position[19,20]. Although the FTT has been used to measure neuromuscular control in older adults, there is currently limited evidence directly linking FTT performance to fall risk. It is important to note that both FTT and FSST assess lower-limb coordination through different mechanisms. While the FTT evaluates ankle dorsiflexion speed, the FSST assesses dynamic balance and interlimb coordination. These tests are complementary, as they both provide valuable information about lower-limb coordination, which is crucial for assessing fall risk. Depending on the specific goals of the evaluation, either test may be selected to assess coordination performance.

This study therefore aimed to address this gap by investigating whether lower-limb motor coordination, measured by the FTT and FSST, together with muscle strength, is associated with functional performance and fall risk classification in community-dwelling older adults, providing valuable insights for tailored health promotion strategies.

Material and Methods

The study protocol was approved by the Institutional Review Board of Naresuan University (NU-IRB P1-0022/2567) and Thai Clinical Trials Registry (TCTR) number TCTR20241031006. All processes were performed in accordance with the Declaration of Helsinki.

Study design and population

This study employed a cross-sectional design, with data collected in July and August 2024. Participants were recruited from the Mueang District, Phitsanulok Province, Thailand, using a convenience sampling method. Eligible individuals were aged 60 years or older, able to walk independently for at least 10 meters, and proficient in speaking, listening, reading, and writing Thai. Cognitive screening was performed using the Thai Mental State Examination T10 (MSET10), with a cut-off score of >22, which is commonly used to indicate normal cognitive function in older Thai populations[21]. The participants voluntarily agreed to take part in the research project and provided written consent. The sample size was determined via the formula $n=100 + 50i$[22], where i represents the number of independent variables in the prediction model. In this study, i is 2, representing lower-limb strength and coordination. Consequently, the required sample size was calculated to be 200. Data collection was conducted at an elderly club situated within Buddhachinaraj Hospital, Phitsanulok, Thailand. Although located on hospital grounds, the club functions as a community-based centre where older adults regularly engage in non-clinical activities.

Outcome measures

Data on participant characteristics related to fall risk among older adults were collected through face-to-face interviews conducted by a physiotherapist. Participants provided information on age, dominant leg (identified as the leg they would naturally use to kick a ball)[23], body mass index (BMI), marital status, fall history, use of walking aids, musculoskeletal disorders, urinary retention, sleep issues, dizziness, the presence of handrails at home, and the use of three or more medications. After the interviews, the participants underwent field tests to assess both the dependent and predictor variables. These tests were administered by experienced physiotherapists, who worked independently and followed a designated sequence.

Dependent variable

The dependent variable in this study was fall risk, which was assessed via the timed up and go (TUG) test, which is known for its good to excellent test–retest reliability[24] and has also been validated as a predictor of fall risk in older adults[25]. For the test, the participants sat in a chair with a 43–cm–high backrest and armrests. Upon the researcher's verbal cue of "Go!", timing began. Participants were instructed to stand up without using their arms, walk 3 meters at a normal pace, turn around, walk back, and sit down with their back against the backrest, at which point the timing stopped. Each participant completed the test twice, and the average time was used for analysis[26]. A completion time of 15 seconds or more indicates a high fall risk in older adults[27]. While the TUG is a widely accepted indicator, it reflects performance–based risk and is not a direct measure of actual fall events.

Predictor variables

Lower–limb motor coordination was assessed via the Foot Tapping Test (FTT) and the Four Square Step Test (FSST). Both tests measure lower–limb coordination, but they offer different perspectives and have different applicability to various populations. The FTT measures the speed of ankle dorsiflexion movements and has demonstrated good to excellent test–retest and interrater reliability[19]. The participants were seated in a chair with their hips and knees bent at 90 degrees and instructed to tap the ball of their foot (forefoot) up and down, touching the floor without lifting their heel, for 10 seconds. This motion was repeated three times with a one–minute rest between each trial. The number of repetitions on the dominant foot across the three trials was averaged for analysis[20]. The FSST, which also evaluates balance, was used as an additional measure of lower–limb coordination and has shown good to excellent test–retest reliability. The participants walked through a square obstacle pattern, first in a clockwise direction and then in a counterclockwise direction. The stopwatch started as the participant stepped into the second square and stopped when the second foot returned to the first square. Each participant completed two trials with a two–minute rest between attempts, and the fastest time was recorded for analysis[28]. While the FSST assesses coordination through dynamic, weight–shifting movements and requires participants to follow a set stepping sequence, it imposes higher cognitive and physical demands. In contrast, the FTT is a simpler, seated test suitable for individuals with limited mobility or balance deficits. Including both tests ensures broader applicability across functional levels and informs appropriate test selection in future studies.

Lower–limb muscle strength was evaluated via the Five Times Sit–to–Stand Test (FTSST)[29], which has demonstrated excellent intrarater and test–retest reliability, with reliability scores ranging from 0.98–0.99[30]. During the test, the participants sat upright in the center of a chair positioned against a wall to ensure stability, with their feet flat on the floor, shoulder width apart, and their hands clasped over their chest. Upon the researcher's cue to "start," timing began as the participants stood up and sat down five times at their own pace. The timer stopped when the participant's hips touched the chair after the final repetition, ensuring that they fully extended their knees while standing before each sit–back[31]. Three measurements were taken with a three–minute rest between each, and the average time across all three trials was used for analysis[32].

Statistical analysis

All analyses were conducted via Statistical Package for the Social Sciences software version 31. The normality of quantitative variable distributions was assessed with the Kolmogorov–Smirnov test and appropriate graphical methods (Q–Q plots and P–P plots). Summary statistics for predictor variables are presented separately for participants

classified as having high fall risk and low fall risk. Normally distributed variables are reported as the means with standard deviations, whereas abnormally distributed variables are presented as medians with interquartile ranges. Categorical variables are summarized as frequencies and percentages.

To identify the significant differences (p-value<0.05) between the high- and low-fall-risk groups, t-tests were used for continuous variables, and chi-square tests were used for categorical variables. Spearman correlations and chi-square tests were performed between pairs of variables to identify similarities and minimize overlap.

Multiple logistic regression analyses were conducted to evaluate independent predictors (lower-limb motor coordination, lower-limb strength, and other factors such as gender, age, BMI, marital status, fall history, use of walking aids, urinary retention, sleep issues, dizziness, presence of handrails at home, and use of three or more medications) of high fall risk (TUG >15s). All variables were initially included in the model with an inclusion threshold of p-value<0.05. The models were developed based on the literature and the relevant clinical relevance of these factors in contributing to fall risk. Variables that were not statistically significant (p-value>0.05) were subsequently removed to optimize model fit and sample size, with odds ratios (ORs) and 95% confidence intervals (CIs) reported for significant predictors.

Results

Characteristic data

A total of 217 older adults were initially interviewed during the screening process. Health conditions that did not meet the inclusion criteria were identified at this stage, resulting in the exclusion of 17 individuals: 7 due to musculoskeletal issues, 4 due to neurological problems, and 6 due to other health concerns. These exclusions were made to ensure that only participants meeting the predefined eligibility criteria proceeded to the evaluation phase. Consequently, 200 participants were deemed eligible for further assessment. Table 1 presents the characteristics of all the participants, who were divided into no-risk-of-falling (n=167) and risk-of-falling (n=33) groups. The majority of the participants were female (77%), with a median age of 69 years and an average BMI of 24.27 kg/m^2. Among these participants, 42.5% were single, 21% had a history of falls, and 8% used walking aids. Additionally, 32.5% reported urinary incontinence, 63.5% experienced insomnia, and 22% were taking three or more medications. Dizziness was reported by 43.5% of the participants, and 26% lived in homes without handrails. The median MSET10 score was 26 points.

Lower-limb coordination and muscle strength

Among the 200 volunteers, the median (IQR) and mean (S.D.) TUG scores were 10.17 (8.40, 12.10) and 10.81 (3.53) seconds, respectively. Lower-limb motor coordination in the dominant leg, as assessed by the FTT, was 24.67 (19.75, 30.00) and 24.76 (7.13) repetitions. The FSST scores were 9.58 (8.08, 12.00) and 10.77 (4.61) seconds, respectively. The FTSST results for lower-limb strength were 10.36 (8.75, 12.32) and 10.95 (3.30) seconds, as shown in Table 2.

Correlations among risk factors

Owing to the nonnormal data distribution, relationships between fall-risk factors were assessed via the Spearman rank correlation for interval-scale variables (FTT, FSST, TUG, FTSST, MSET10, age, and BMI) and the chi-square test for categorical variables (gender, marital status, history of falls, urinary incontinence, insomnia, dizziness, use of walking aids, and use of more than three medications). The correlations between variables did not exceed 0.80, indicating that there was no multicollinearity among the independent variables, and thus all the variables were retained in the analysis of fall-risk factors.

Table 1 Participant characteristics by Timed Up and Go (TUG) Test score

Characteristic	Number of participants (N=200)	Number of participants by fall risk category		p-value
		No risk of falling TUG <15 s (N=167)	Risk of falling TUG >15 s (N=33)	
Gender[a]: number (%)				0.789
Male	46 (23)	39 (23.4)	7 (21.2)	
Female	154 (77)	128 (76.6)	26 (78.8)	
Age[b]: year median (IQR)	69 (65.00, 74.75)	68 (65.00, 73.00)	75 (71.00, 82.00)	<0.001*
BMI[b]: kg/m^2 median (IQR)	24.27 (21.63, 26.72)	24.06 (21.48, 26.35)	24.49 (21.94, 28.19)	0.246
Marital status[a]: number (%)				0.707
Single	85 (42.5)	70 (41.9)	15 (45.5)	
Married	115 (57.5)	97 (58.1)	18 (54.5)	
History of falls[a]: number (%)				0.333
Yes	42 (21)	33 (19.8)	9 (27.3)	
No	158 (79)	134 (80.2%)	24 (72.7%)	
Usage of walking aids[a]: number (%)				<0.001*
Yes	16 (8)	5 (3)	11 (33.3)	
No	184 (92)	162 (97)	22 (66.7)	
Urinary incontinence[a]: number (%)				0.911
Yes	65 (32.5)	54 (32.3)	11 (33.3)	
No	135 (67.5)	113 (67.7)	22 (66.7)	
Insomnia[a]: number (%)				0.986
Yes	127 (63.5)	106 (63.5)	21 (63.6)	
No	73 (36.5)	61 (36.5)	12 (36.4)	
Taking 3 or more medications[a]: number (%)				0.085
Yes	44 (22)	33 (19.8)	11 (33.3)	
No	156 (78)	134 (80.2)	22 (66.7)	
Dizziness[a]: number (%)				0.891
Yes	87 (43.5)	73 (43.7)	14 (42.4)	
No	113 (56.5)	94 (56.3)	19 (57.6)	
Indoor handrails[a]: number (%)				0.262
Yes	148 (74)	121 (72.5)	27 (81.8)	
No	52 (26)	46 (27.5)	6 (18.2)	
MSET10[a]: median (IQR); number (%)	26 (22.00, 28.00)	–	–	<0.001*
No formal education	17 (16, 20)	10 (6.0)	3 (9.1)	
Primary education	24 (21.25, 27.00)	92 (55.1)	28 (84.8)	
Higher than primary education	28 (27.00, 28.00)	65 (38.9)	2 (6.1)	

*=p-value<0.05, [a]χ^2 test for categorical variables, [b]Student's t-test for numeric variables, BMI=body mass index, MSET10=mental state examination T10, IQR=interquartile range

Table 2 Median and mean values for TUG, FTT, FSST and muscle strength FTSST

Variables (N=200)	Median (IQR)	Mean (S.D.)	Minimum-Maximum
TUG (second)	10.17 (8.40, 12.10)	10.81 (3.53)	5.42-27.91
FTT (repetitions)	24.67 (19.75, 30.00)	24.76 (7.13)	10.33-43.00
FSST (second)	9.58 (8.08, 12.00)	10.77 (4.61)	5.48-40.00
FTSST (second)	10.36 (8.75, 12.32)	10.95 (3.30)	5.84-27.40

TUG=Timed Up and Go Test, FTT=Foot Tapping Test, FSST=Four Square Step Test, FTSST=Five Times Sit-To-Stand Test, IQR=interquartile range

Associations between predictive variables and fall risk

Table 3 presents an analysis of the predictive variables for fall risk. The significant predictors included FTT (OR: 0.808, 95% CI: 0.748–0.872), FSST (OR: 1.685, 95% CI: 1.417–2.005), FTSST (OR: 1.797, 95% CI: 1.467–2.202), age (OR: 1.080, 95% CI: 1.025–1.139), and use of walking aids (OR: 0.062, 95% CI: 0.020–0.194). Since age and use of walking aids are significant predictors of fall risk, these factors were controlled for in the multivariate regression analysis to evaluate the primary predictors of fall risk, which focused on muscle strength and lower-limb coordination. The results indicate that, after controlling for these variables, muscle strength and lower-limb coordination remained significant predictors of fall risk. The impact of age and use of walking aids on fall risk prediction will be addressed in a separate article[33]. Variables such as gender, BMI, marital status, history of falls, urinary incontinence, insomnia, taking three or more medications, dizziness, and home handrail were not associated with fall risk, as shown in Table 3.

Predicting fall risk through lower-limb coordination and muscle strength

Two models were used to analyse lower-limb motor coordination and muscle strength in relation to fall risk in elderly individuals. In Model 1, each additional tap in the FTT was significantly associated with a 19.7% decrease in the odds of being classified in the fall-risk group (OR=0.803, 95% CI: 0.720–0.896), while a one-unit increase in the FTSST was related to a 70.25% increase in the odds of fall risk (OR=1.702, 95% CI: 1.322–2.191). In Model 2, both the FTSST and the FSST were positively correlated with fall-risk classification. Specifically, each additional second in the FTSST increased the odds of being in the fall-risk group by 45.5% (OR=1.455, 95% CI: 1.197–1.770), and each additional second in the FSST increased the odds by 54.6% (OR=1.546, 95% CI: 1.195–2.001), as shown in Table 4.

Table 3 Associations between predictive variables and fall risk

Variables	Crude OR (95% CI)	p-value
Gender	1.132 (0.456, 2.807)	0.790
Age	1.080 (1.025, 1.139)	<0.004*
Body mass index	1.080 (0.971, 1.200)	0.155
Marital status	0.866 (0.409, 1.835)	0.707
History of falls	0.657 (0.279, 1.545)	0.335
Usage of walking aids	0.062 (0.020, 0.194)	<0.001*
Urinary incontinence	0.956 (0.432, 2.112)	0.911
Insomnia	0.993 (0.457, 2.158)	0.986
Taking three or more medications	0.493 (0.217, 1.116)	0.090
Dizziness	1.054 (0.495, 2.242)	0.892
Indoor handrails	0.585 (0.227, 1.508)	0.267
FTT	0.808 (0.748, 0.872)	<0.001*
FSST	1.685 (1.417, 2.005)	<0.001*
FTSST	1.797 (1.467, 2.202)	<0.001*

*=p-value<0.05, FTT=Foot Tapping Test, FSST=Four Square Step Test, FTSST=Five Times Sit-To-Stand Test

Table 4 Logistic model predicts fall risk using lower limb coordination and muscle strength

Variables	Adjusted Odds ratio (95% CI) Model FTT	Adjusted Odds ratio (95% CI) Model FSST	p-value
FTT	0.803 (0.720–0.896)	–	<0.001*
FTSST	1.702 (1.322–2.191)	1.455 (1.197–1.770)	<0.001*
FSST	–	1.546 (1.195–2.001)	<0.001*

*=p-value<0.05, indicating that the analysis controls for predictive variables, including age and the use of walking aids, increase the risk of falling. FTT=Foot Tapping Test, FSST=Four Square Step Test, FTSST=Five Times Sit-To-Stand Test

Discussion

The results of this study demonstrate a significant association between lower-limb motor coordination and muscle strength and fall risk in elderly individuals. After controlling for factors such as age and the use of walking aids, two models effectively predicted fall risk on the basis of these variables. Notably, compared with those with low FTTs, older adults with high FTTs experienced a 19.7% lower risk of falling. Specifically, for each additional tap in the FTT, the odds of being in the fall-risk group decreased by approximately 20%. Conversely, those with high FSST and FTSST scores faced an increased risk of falling relative to their counterparts with low scores.

This study is the first to report FTT values for elderly individuals, leaving uncertainty about whether these values reflect normal ranges for this age group. However, lower-limb motor coordination, assessed by the FSST, aligns with previous research on older adults without a history of falls[34]. Most participants were healthy, with nearly 80% having not fallen in the past year. The mean FSST was less than 15 s, indicating no fall risk[17,35]. Additionally, the FTSST results revealed that participants had muscle strength comparable to that of older adults who had never fallen[36]. The TUG assessment revealed that over 80% of participants were not at risk of falling, with TUG values similar to those of healthy community-dwelling elderly individuals[37]. Thus, the findings suggest that the participants were primarily healthy individuals with no significant fall risk. Our study focused on identifying fall-risk factors, rather than solely on a history of falls, to capture individuals who may not have fallen yet, but are still at risk. While fall history is a strong predictor, it doesn't account for those at risk who haven't yet fallen. Therefore, we used the TUG test as a dynamic measure to assess fall risk and identify individuals who may benefit from early intervention and prevention, even before experiencing a fall.

Lower-limb motor coordination, assessed through the frequency of ankle dorsiflexion, was associated with fall risk in older adults, as even minor ankle movements contribute to balance control during movement. While the classic "ankle strategy" is typically used during static standing to correct small balance perturbations by shifting the center of mass through ankle adjustments[38,39], this study did not directly assess static balance or ankle strategy. However, impaired ankle motor control may affect balance recovery during dynamic tasks such as walking, which also require continuous postural adjustment. Although the Foot Tap Test does not measure ankle joint range of motion, it reflects neuromuscular coordination at the ankle, which is essential for maintaining stability during movement[40]. Our findings suggest that reduced ankle coordination may impair dynamic balance and contribute to fall risk in older adults. This is supported by the observed correlation between ankle movement frequency and performance on the TUG test, which evaluates functional balance during walking. Furthermore, our results suggest that unilateral ankle motor coordination is associated with fall risk in older adults, as reflected by TUG performance. While our assessment focused on a single joint, these findings may be interpreted in the context of previous research on interlimb ankle coordination[41] and lower-limb intrajoint coordination[42], which have also been linked to balance control. Although our study did not find a direct association between fall history and fall risk, the FTT, a simple, reliable measure of ankle motor coordination[19], was associated with TUG performance and may serve as a useful tool in assessing dynamic balance and identifying individuals at a higher risk of falling.

The assessment of lower-limb motor coordination and balance by walking across square-shaped obstacles (FSSTs), which requires the coordination of both legs, better predicts fall risk in elderly individuals than assessments based solely on unilateral ankle flexion. This may be

because coordination of the lower extremity muscles is essential for effective walking. Impaired leg coordination or diminished overall body coordination can lead to stiff and awkward walking, resulting in decreased postural control, a reduced ability to adjust direction, a lower step height, and an increased risk of falls. As a result, individuals may be more prone to losing balance and experiencing trips or slips unexpectedly[43]. This can cause their center of mass to shift outside their base of support, thereby increasing the risk of falls. The findings of this study align with those of previous studies, indicating that slower walking speeds are associated with a greater risk of falling[16]. This study followed the original TUG protocol using a comfortable and safe walking pace[44]. Although some studies use a fast-paced version, this variation does not appear to affect its association with fall risk[45].

In elderly people with coordination problems, joint mobility is reduced, causing the body to be unable to adapt quickly when faced with unexpected obstacles. This study did not directly measure ankle joint mobility, as the primary focus was on functional motor coordination. By emphasizing coordination performance, the findings contribute to a broader understanding of the factors affecting balance and fall risk in older adults. An incorrect posture can lead to imbalance, which increases the risk of possible falls[43]. While the FSST is a strong predictor of fall risk, some older adults may have limitations that hinder their ability to undergo the assessment, such as those who use walkers[18]. For individuals who are unable to complete the FSST or are at risk of falling during the test, the FTT may offer a safer and more feasible alternative for assessing lower-limb coordination; however, further research is needed to validate its use in this context.

Lower-limb muscle strength, as assessed by the FTSST, is a significant predictor of fall risk in elderly individuals. This finding aligns with previous research indicating that decreased leg muscle strength is a primary risk factor for falls among older adults[46]. Strong leg muscles are crucial for performing everyday activities, including walking, getting up from a chair, and navigating stairs[10]. Decreased muscle strength may negatively impact balance, coordination, and response times in older individuals[47]. Elderly individuals with weakened leg muscles often struggle with efficient weight transfer between legs, leading to instability during walking or turning. As a result, their ability to respond to external forces for maintaining balance slows down, increasing the likelihood of falls[43]. Previous studies have shown a link between fall history, reduced leg strength, and increased fall incidence. However, this association was not observed in our sample, possibly due to the distribution of TUG performance among participants[6]. Conversely, enhancing leg muscle strength is associated with a reduced risk of falls in this population[48]. Overall, this study demonstrated that assessing lower-limb muscle strength via the FTSST is effective for evaluating functional strength during movement and predicting fall risk in older adults.

A key strength of this study is that it is the first to explore the relationship between lower-limb motor coordination, assessed through unilateral ankle dorsiflexion, lower-limb muscle strength, and fall risk in elderly individuals. This assessment method holds promise for broad application in community settings aimed at improving coordination among older adults. Building on this, future studies could investigate coordination-focused exercises as a strategy to support fall prevention in this population. However, this study has certain limitations. Notably, the number of participants classified as "at risk" of falling was considerably smaller than that classified as "no risk." This imbalance between groups may affect the stability and generalizability of the logistic regression model. Future studies should aim for a more balanced sample to improve the reliability of statistical

estimates and to more accurately identify factors associated with fall risk. Additionally, the study did not consider gender differences among participants, which could impact physical performance. With a greater number of female volunteers, the results may have been affected. Although this study revealed no significant gender impact on fall risk, future investigations should either balance participant numbers by gender or focus on a single gender to better control for its influence on fall risk prediction. Furthermore, additional research should establish a cut-off value for the Foot Tap Test (FTT) to effectively screen for fall risk related to ankle movement coordination. Based on our data, the lowest FTT score among participants without fall risk (TUG ≤15 s) was 10 taps. This may serve as a tentative cut-off for adequate ankle coordination, though further research is needed to validate its accuracy. These adjustments will increase the validity and applicability of future studies in this important area. Another limitation is the sole use of the TUG test to classify fall risk. While widely used, it may not detect all at-risk individuals, particularly those with a history of falls but normal current performance. Future studies should consider combining multiple assessment tools to enhance accuracy and validity.

Conclusion

Lower-limb motor coordination and muscle strength were found to be associated with functional mobility impairment related to falls in elderly individuals. Individuals who can perform more repetitions of ankle dorsiflexion tend to have a lower risk of falling, whereas those who take longer to walk over obstacles or to sit up may be at greater risk.

However, given the multifactorial nature of falls, these measures should be interpreted as part of a broader, comprehensive assessment that may include cognitive, sensory, and environmental factors. Functional tests such as the FTT, FSST, and FTSST may be useful for identifying high-risk individuals in both clinical and community settings. Based on our findings, incorporating simple lower-limb coordination and strength exercises, such as ankle dorsiflexion tapping and sit-to-stand training, may be a practical approach to support fall prevention. Together, these strategies can contribute to broader health promotion efforts, improving mobility and reducing fall risk among older adults.

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Conflict of interest

All authors declare no conflicts of interest.

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