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Research article

Influence of motor capacity of the lower extremity and mobility performance on foot plantar pressures in community-dwelling older women

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ABSTRACT

Objectives: To investigate the associations of motor capacity of the lower extremity and mobility performance in daily physical activities with peak foot plantar pressures during walking among older women.

Methods: Using the data collected among 58 community-dwelling older women (68.66 ± 3.85 years), Pearson correlation and multiple linear regression analyses were performed to analyze the associations of motor capacity of the lower extremity (the 30-s chair stand test, the timed one-leg stance with eyes closed, and the Fugl-Meyer assessment of lower extremity), mobility performance in daily physical activities (the average minutes of moderate to vigorous physical activity every day and the metabolic equivalents), and foot plantar pressures (peak force and peak pressure) with the age and body fat percentage as covariates.

Results: (1) The motor capacity of the lower extremity has higher explanatory power for peak foot plantar pressures compared with the mobility performance in daily physical activities. (2) Higher body fat percentage was positively associated with peak force and pressure, while a lower score on the Fugl-Meyer assessment of lower extremity was negatively associated with both of them. (3) The metabolic equivalents were positively associated with the peak force, while the 30-s chair stand test was negatively associated with it.

Conclusions: Mobility performance in daily physical activities can be significant predictors for peak foot plantar pressures among older women. The significant predictor variables include the Fugl-Meyer assessment of lower extremity, the 30-s chair stand test, and metabolic equivalents.

1. Introduction

The foot, in direct contact with the ground, plays a crucial role in supporting the musculoskeletal system, bearing weight,

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cushioning impact forces, generating forward force, and maintaining stability during locomotor activities. A comprehensive analysis of pressure distribution beneath the foot [1] holds significant potential to enhance sports performance, prevent injuries [2], understand human gait and motion [3], assess fall risks [4], monitor balance and postural control [5,6], diagnose diseases and pains [7], and improve foot healthcare and footwear design [8]. Consequently, the analysis of foot plantar pressures has gained considerable attention across various fields, including biomechanics [9], biomedicine [3], gait biometrics [8], and other sport-related research.

For older individuals, the analysis of foot plantar pressure becomes particularly important due to age-associated changes in foot structure, which may alter loading patterns [10]. Atypical loading patterns increase the risk of foot pains, discomfort, and injuries during walking, limiting the engagement of older individuals in physical activities [11,12]. Previous studies have shown the association between higher peak values of plantar pressures and various foot conditions, such as foot injuries, pains, discomfort, and falls among older individuals [13,14]. Consequently, an increased focus on peak foot plantar pressures is crucial for the well-being of older individuals [15].

Currently, plantar pressure sensing technology utilizes platform systems or in-shoe systems [3] to measure peak foot plantar pressures [16]. These systems have good stationarity [3] and portability [4,17], respectively. However, accessibility to plantar pressure measurement equipment remains limited. In cases where professional measurement devices are unavailable, exploring alternative methods, such as describing changes in body functional abilities, becomes essential.

Assessing body functional abilities can occur in two distinct environments: a standardized environment and daily life [18,19]. What a person can physically do in a standardized environment, such as a laboratory, is named as motor capacity (MC) assessment while what a person actually does in daily lives is named as mobility performance (MP) assessment [20]. Understanding the associations between capacity assessed in a controlled environment and actual daily life, with peak foot plantar pressures, may offer insights into addressing the aforementioned challenge.

Several studies have examined the association between MP and peak foot pressures, focusing mainly on adolescents and children [21,22], rather than older adults. Similarly, studies exploring the association between MC and peak foot pressures in older adults have often concentrated on specific populations, such as those with fall experiences [23], chronic diseases [24,25], or foot problems [26], typically in individuals aged above 75 years old [23–25]. Notably, there is a lack of research focusing on healthy young older adults (60–74 years old [27]), despite the rapidly growing population of this demographic [28]. Previous studies used measures of MC, such as the weight-bearing lunge test [29], the paper grip test [30], the 30-sec chair stand [31], the 2-min step test [31], and the 8-foot up-and-go test [31], to assess joint flexibility [29], muscle strength of toes [30] or lower limb [31], endurance [31], and balance [31], respectively. For younger seniors, the ability to independently perform various daily life activities and participate in society without relying on assistive devices is crucial, as they often still need to care for themselves. Therefore, examining the association between MC of the lower limb and peak plantar pressures is valuable.

Prior studies have reported that women are more likely to have functional limitations [32] and high foot pressures [33] compared to men, attributed to higher rates of overweight and obesity [34], and discomfort caused by wearing high-heeled shoes. Additionally, the disease survival years of older women are longer than those of older men [35], emphasizing the need for special consideration of foot plantar pressure issues in older women for healthy aging. Thus, by involving young old women as participants and exploring the associations between the two assessments and peak foot plantar pressures, respectively, this study primarily aims to explore the different explanatory power of the two assessments for foot plantar pressures. Secondly, it aims to identify significant predictor variables from the two assessments for foot plantar pressures. The ultimate goal is to facilitate the development of early foot risk assessment in primary-level healthcare, providing a reference for addressing the specific needs of older women and promoting healthy aging.

2. Methodology

2.1. Study design

The study adopted a cross-sectional study design, and the majority of measurements were carried out at the Innovation Laboratory of Integration of Sport and Medicine at Peking University. Before the assessments, each participant received informed consent and an introduction to the study. Following informed consent, descriptive variables, MC of the lower extremity, and foot plantar pressures were assessed within a controlled experimental environment, all on the same day. Subsequently, daily MP during physical activities was measured over one week using a 3-D accelerometer in participants' actual living environments. All laboratory tests were conducted by well-trained testers with the support of Peking University.

The laboratory maintained an average temperature of 22.4 °C and an average humidity of 39.3%, meeting the requirements for all instruments used in the study (Footscan® pressure measurement system: operating temperature range +15 °C to +30 °C, storage temperature range +0 °C to +40 °C, relative humidity 20%–80% non-condensing; In-body 270: operating temperature range +10 °C to +40 °C, storage temperature range +0 °C to +40 °C, relative humidity 30%–80% non-condensing).

2.2. Participants

Female participants aged 60–74 years were recruited from 2 communities in the Haidian District of Beijing. The recruitment process utilized the household registration system with the assistance of two community workers. The study sample size was determined based on the total number of older residents aged 60–74 years in the communities. By setting the sampling proportion at 20%, as opposed to the suggested 15% [36], to account for the anticipated attrition of 5%, a total of 70 older women were recruited from a pool of 341 female residents aged 60–74 years.

Inclusion criteria were established as follows (1) *Lawton Instrumental Activities of Daily Living (IADL) Scale score* $\geq$ 6 [37], ensuring participants' ability to walk independently, (2) no significant trauma, surgery, or operations on the lower extremities in the past two years, given the potential impact of each conditions on foot plantar pressures and prior studies which reported individuals may take two years to return to sport after operation or recovery [38] [39], (3) no severe endocrine, neurological, bone, joint conditions for similar reasons. A total of 8 participants were excluded, and an additional 4 did not provide 7-day MP data, resulting in a final enrollment of 58 participants for the study.

2.3. Measures

2.3.1. Descriptive variables

Descriptive variables included age (years), body fat (%), muscle mass of the two lower extremities (kg), and shoe size (EU). In-body 270 (Korea In-body Co. Ltd., Seoul, Republic of Korea) was used to examine the body fat and muscle mass of the two lower extremities.

Age and Body fat were considered covariates in multiple regressions. Muscle mass of the two lower extremities determined extremity dominance, essential for tests such as the timed one-leg stance with eyes closed and foot plantar pressures. Shoe size, provided by participants, served as a required input for the Footscan® pressure measurement system.

2.3.2. Measures of MC of the lower extremity

The **30-s chair stand test (30-s CST)**, developed by Rikli and Jones, is widely employed to assess the ability of older individuals to transition from a seated to a standing position without assistance [40–42]· It has demonstrated good test-retest reliability in healthy older individuals [43]. During the test, participants were instructed to cross their arms over their chests and sit on a chair with a straight back and no armrests (Seat height: 0.46 m). Upon the “start” command, participants stood up fully and returned to a fully seated position. The number of complete stand-to-sit cycles performed within the 30-s time frame was recorded. A higher number of cycles indicates a better ability to shift body positions. Participants were allowed to practice trials, and the formal test was administered after their heart rate returned to the common range with a 10-min rest.

The **timed one-leg stance with eyes closed (TOLS-EC)** measures the time an individual can maintain their body's center of gravity on a single-foot support surface with their eyes closed [44]. Widely used in assessing balance and postural control abilities for older people, participants were instructed to stand on the dominant leg with the other leg lifted and arms outspread [45–48]. The tester recorded the time when the participant either moved their supporting foot or their lifted foot touched the ground. A longer time reflects a greater capacity for postural control and maintaining balance. Two approaches were used to identify the dominant foot. (1) The side with more muscle mass. (2) The participant was asked about the dominant side. If the muscle mass values of the two sides were equal, the determination was based on the participant's self-report. Practice trials were consistent with those described above.

The **Fugl-Meyer assessment of lower extremity (FMA-LE),** a subscale of the Fugl-Meyer Assessment (FMA) developed by Fugl-Meyer and colleagues, offers a comprehensive evaluation of the participant's sensorimotor capacity in the lower extremity [49]. The sensorimotor capacity is integral to neuromuscular coordination in daily physical activities. The FMA-LE comprises 17 items across 7 categories: reflex activity, hyperreflexia, flexor synergy, extensor synergy, movement combining synergies, movement out of synergy, and heel-knee-shin test. Each item receives a score from 0 to 2, with a score of 0 indicating inability to perform, a score of 1 indicating partial performance, and a score of 2 indicating full performance. The total score is 34, with a higher score indicating better sensorimotor capacity in the lower extremity.

2.3.3. Measures of MP in daily physical activities

Various methods are available for assessing MP, encompassing a wide range of activities such as different forms of locomotion (e.g. walking, running), and leisure activities (e.g. hiking, climbing, games, sports) [18,50]. Recent studies highlight wearable sensors equipped with a 3D accelerometer as effective tools for collecting data to assess MP [51,52]. These sensors provide a convenient and objective means to capture movement patterns, offering valuable insights into an individual's physical activity levels. By analyzing the data, researchers can evaluate MP in daily physical activities.

ActiGraph GT9X Link (dimensions: 0.035 $\times$ 0.035 $\times$ 0.01 m; weight: 0.014 kg; sampling frequency range: 30–100 Hz; maximum service time: 14 days; data storage capacity: 240 days/4 GB; gyro dynamic range: $\pm$ 2000 deg/sec; accelerometer dynamic range: $\pm$ 16 G; magnetometer dynamic range: $\pm$ 4800 micro-Tesla; connection type: USB, Bluetooth® LE), produced by ActiGraph LLC., Pensacola, FL, USA, is one of the leading commercially available devices widely used for monitoring daily physical activities [53]. Numerous studies have demonstrated its high reliability and validity [54–56]. Equipped with a solid three-axis accelerometer and a unique data filtering algorithm, it collects and records high-resolution human activity information [57]. The ActiLife software is utilized for data collection. The data were first processed into cut-point values based on a 60-s epoch length and then measured using the Freedson Adult model [58]. The levels were categorized as 0–99 for Sedentary, 100–1951 for Light, 1952–5724 for Moderate, and 5725–9498 for Vigorous, representing counts per minute regardless of the file's epoch length.

All participants were instructed to wear the ActiGraph GT9X Link on their arms continuously for seven days (5 weekdays and weekends), throughout the day and night. **The main variables measured were the average minutes of moderate to vigorous physical activity (MVPA) every day and the metabolic equivalents (METs)**, capturing a wide range of one-day MP as described by the WHO [18].

2.3.4. Measures of peak foot plantar pressures

Peak foot plantar pressures were assessed using the Footscan® pressure measurement system (RS Scan Company, Paal, Belgium). The system comprises a 1.5 m entry-level plate (length × width × height: 1.61 × 0.47 × 0.02 m, weight: 24 kg, number of sensors: 12288, arranged in a 192 × 64 matrix, sensor dimensions: 0.00762 m × 0.00508 m, active sensor area: 1.46 m × 0.33 m, pressure range: 10000–1270000 Pa, data acquisition frequency: 200 Hz, resolution: 10 bits) and the footscan® software (version: 9). The 1.5 m entry-level plate measures plantar pressure using an X–Y matrix of resistive pressure-sensitive sensors, and the Footscan® software records and calculates peak foot plantar pressures across 10 anatomical zones, including the 1 (T1), toe 2 to toe 5 (T2-5), metatarsal 1 (M1), metatarsal 2 (M2) and metatarsal 3 (M3), metatarsal 4 (M4), metatarsal 5 (M5), midfoot (MF), medial heel (MH), and lateral heel (LH). It is considered a state-of-the-art system for recording and analyzing foot plantar pressures, recognized for its reliability and repeatability through extensive validation in previous studies [59,60].

Test variables: Peak force (N) and peak pressure (Pa) of the dominant foot were recorded as test variables. Two approaches were used to determine the dominant foot. (1) Muscle mass of two lower extremities: The side with more muscle mass was considered the dominant side. (2) Natural Walking: The side on which the participant took the first step during natural walking was considered the dominant foot. If the muscle mass values of the two sides were equal, determination based on natural walking was used.

Test requirements: To ensure consistent and standardized plantar pressure measurements, three test requirements were implemented. (1) Setup: Place the plate flat on the floor and ensure it is properly connected to the computer. (2) Barefoot Assessment: All participants removed their shoes and socks for barefoot assessments to obtain more accurate results from plantar pressure measurements [61,62]. (3) Familiarization: Participants underwent three practice trails of free walking to acclimate to the walking environment and testing procedure. (4) Formal Test: Participants were instructed to walk naturally back and forth over the plate six times, and the average of these six trials was recorded.

2.4. Statistical analysis

Data analysis was performed using Microsoft Office 2020 and SPSS 25.0 (IBM, United States). The statistical analyses comprised five components:

The Kolmogorov-Smirnov test (K–S test) [63] assessed the normal distribution of the data. Except for the FMA-LE score ($p < 0.05$), other variables adhered to the null hypothesis. A logarithmic transformation was applied to normalize the FMA-LE score.

Descriptive statistics were employed to summarize continuous variables. Mean, standard deviation (SD), minimum, and maximum values were used to describe each variable.

To prevent the influence of parameters with large value ranges on data analysis [64], the extremization method, a non-dimensionalized calculation was adopted [64]. This method normalized the data, facilitating fairer analysis across variables. The formula is as follows:

$$D_{\chi i} = (\chi_i - Min_i) / (Max_i - Min_i) \times 100, (i = 1, 2, \ldots, p)$$

where $D_{\chi i}$ is the standardized value, χ_i is the original value, Max_i is the maximum of the original value, and Min_i is the minimum of the original value.

Pearson correlation analysis analyzed the relationship between each MC or MP and peak force or peak pressure. Correlation coefficients were classified as small ($r \leq 0.25$), moderate (0.25–0.50, good (0.50–0.75), and excellent (≥0.75) [65].

6-time (3 × 2) multiple linear regression analyses were conducted to achieve two objectives. The MC of the lower extremity, MP in daily physical activities, or both were considered independent variables, with peak force or peak pressure as dependent variables. Additionally, although some potential factors have been excluded by the subject exclusion criteria, age and body fat percentage were still included as covariates due to their high correlation with foot plantar pressures, as indicated by cross-sectional studies [66,67]. To validate the regression models, multicollinearity was assessed using the variance inflation factor (VIF). Models with VIF values below

Table 1
Descriptive characteristics of study participants (n = 58).

	Mean	SD	Minimum	Maximum
Descriptive variables				
Age (years)	68.66	3.85	61.32	77.67
Body fat percentage (%)	39.13	5.24	27.80	51.12
MC of the lower extremity				
30-s CST (n)	21.57	6.62	7.00	38.00
TOLS-EC (s)	8.90	7.58	1.61	46.00
FMA-LE score	30.89	3.95	18.00	34.00
MP in daily physical activities				
Average MVPA (min/d)	132.06	61.74	10.40	316.71
METs	1.36	0.15	1.12	1.88
Foot plantar pressure				
Peak force (N)	871.04	150.21	588.52	1230.87
Peak pressure (Pa)	70855.90	11656.87	48448.14	108782.85

Notes: SD: Standard deviation; MC: Motor capacity; MP: Mobility performance; 30-s CST: 30-s chair stand test; TOLS-EC: Timed one-leg stance with eyes closed; FMA-LE: Fugl-Meyer assessment of lower extremity; MVPA: moderate to vigorous physical activity; METs: metabolic equivalents.

10 were considered valid, indicating no significant multicollinearity issues [63].

Statistical significance was determined at a threshold of $p < 0.05$, with a confidence interval (CI) of 95%.

3. Results

3.1. Descriptive statistics

A total of 58 older female participants were included, with an average age of 68.66 years and an average body fat percentage of 39.13%. Descriptive characteristics are summarized in Table 1.

3.2. Correlations

Concerning the MC of the lower extremity, a moderate negative correlation was observed between the peak force and the 30-s CST ($r = -0.515$, $p = 0.000 < 0.01$). This indicates that an increase in the number of 30-s CST is correlated with a decrease in peak force. A similar correlation was noted between peak pressure and 30-s CST ($r = -0.363$, $p = 0.005 < 0.01$). Additionally, a weak negative correlation existed between the FMA-LE score and peak force ($r = -0.288$, $p = 0.028 < 0.05$), and a moderate negative correlation between the FMA-LE score and peak pressure ($r = -0.365$, $p = 0.005 < 0.01$). These findings suggest that a higher FMA-LE score is associated with slightly lower levels of both peak force and pressure of the dominant foot.

Regarding MP in physical activities, a moderate positive correlation was found between METs and peak force ($r = 0.340$, $p = 0.009 < 0.01$). This implies that an increase in Average MVPA is correlated with higher levels of peak force in the dominant foot. The correlation results are presented in Table 2.

3.3. Regressions

3.3.1. MC of the lower extremity and MP in daily physical activities with peak force

In Table 3, Model A and Model B illustrate the associations between the MC of the lower extremity, MP in daily physical activities, and peak force. Table 4, Model C integrates variables from both Model A and B, providing a comprehensive result.

In Model A, a significant regression equation was observed ($F = 16.709$, $p < 0.001$), with the 30-s CST identified as the most effective independent variable. The 30-s CST ($\beta = -0.237$, $p = 0.017$) and the FMA-LE score ($\beta = -0.229$, $p = 0.012$) showed significant negative associations with peak force. Conversely, the TOLS-EC ($\beta = 0.208$, $p = 0.028$) exhibited a notable positive association. In Model B, a significant regression equation was found ($F = 17.050$, $p < 0.001$) with METs identified as the most effective independent variable. METs had a positive association with peak force ($\beta = 0.402$, $p = 0.003$), while Average MVPA had a significant negative association with peak force ($\beta = -0.309$, $p = 0.018$). Collectively, the MC of the lower extremity explained 57.9% of the variance in peak force, which exceeded the explanatory power of MP in daily physical activities ($R^2 = 0.\ 530$).

In Model C, providing a more comprehensive understanding compared to Models A and B ($R^2 = 0.612$, $F = 13.831$, $p < 0.001$), a robust model fit and predictive power was indicated (Table 4). The 30-s CST ($\beta = -0.239$, $p = 0.024$) and the FMA-LE score ($\beta = -0.197$, $p < 0.019$), both demonstrating significant negative associations with peak force in Model A, retained their relevance in Model C. Furthermore, METs ($\beta = 0.364$, $p = 0.016$) revealed a positive association in Model C, aligning with Model B. Body fat percentage showed positive associations in all models ($\beta_{model\ A} = 0.632$, $\beta_{model\ B} = 0.555$, $\beta_{model\ C} = 0.528$; $p < 0.001$).

3.3.2. MC of the lower extremity and MP in daily physical activities with peak pressure

In Table 5, Model D and Model E illustrate the associations between the MC of the lower extremity, MP in daily physical activities, and peak pressure. Table 6, Model F integrates variables from both Model D and E, providing a comprehensive result.

In Model D, the results indicated a significant regression equation ($F = 17.050$, $p < 0.001$), with METs identified as the most effective independent variable. METs exhibited a positive association with peak force ($\beta = 0.402$, $p = 0.003$) while Average MVPA demonstrated a significant negative association with peak force ($\beta = -0.309$, $p = 0.018$). However, in Model E, the MP variables did not display significant associations with peak pressure. Collectively, the MC of the lower extremity explained 40.8% of the variance in

Table 2
Correlations between MC of the lower extremity, MP in daily physical activities, and foot plantar pressure (n = 58).

	Peak force (N)	P	Peak pressure (Pa)	P
MC of the lower extremity				
30-s CST (n)	−0.515***	0.000	−0.363**	0.005
TOLS-EC (s)	−0.050	0.710	−0.088	0.512
FMA-LE score	−0.288*	0.028	−0.365**	0.005
MP in daily physical activities				
Average MVPA (min/d)	−0.131	0.325	−0.175	0.189
METs	0.340**	0.009	0.113	0.398

Notes: a) MC: Motor capacity; MP: Mobility performance; 30-s CST: 30-s chair stand test; TOLS-EC: Timed one-leg stance with eyes closed; FMA-LE: Fugl-Meyer assessment of lower extremity; MVPA: moderate to vigorous physical activity; METs: metabolic equivalents. b) Inference: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

Table 3
Model A and B multiple linear regression results.

	B	β	t	p	VIF	F	Adjusted R^2
Model A: MC of the lower extremity and peak force							
Age (years)	−0.468	−0.077	−0.887	0.379	1.023	16.709***	0.579
Body fat percentage (%)	2.823	0.632	6.292	<0.001	1.369		
30-s CST (n)	−0.259	−0.237	−2.457	0.017	1.259		
TOLS-EC (s)	0.285	0.208	2.266	0.028	1.142		
FMA-LE score	−0.217	−0.229	−2.606	0.012	1.050		
Model B: MP in daily physical activities and peak force							
Age (years)	−0.117	−0.019	−0.211	0.833	1.005	17.050***	0.530
Body fat percentage (%)	2.480	0.555	5.475	<0.001	1.247		
Average MVPA (min/d)	−0.359	−0.309	−2.434	0.018	1.959		
METs	0.481	0.402	3.104	0.003	2.035		

Notes: a) VIF: variance inflation factor; 30-s CST: 30-s chair stand test; TOLS-EC: Timed one-leg stance with eyes closed; FMA-LE: Fugl-Meyer assessment of lower extremity; MVPA: moderate to vigorous physical activity; METs: metabolic equivalents. b) Inference: ***$p < 0.001$.

Table 4
Model C multiple linear regression results.

Model C	B	β	t	p	VIF	F	Adjusted R^2
Age (years)	−0.399	−0.066	−0.785	0.436	1.027	13.831***	0.612
Body fat percentage (%)	2.357	0.528	5.002	<0.001	1.635		
30-s CST (n)	−0.239	−0.218	−2.332	0.024	1.287		
TOLS-EC (s)	0.219	0.160	1.774	0.082	1.196		
FMA-LE score	−0.197	−0.208	−2.423	0.019	1.079		
Average MVPA (min/d)	−0.224	−0.193	−1.615	0.113	2.100		
METs	0.364	0.305	2.506	0.016	2.169		

Notes: a) VIF: variance inflation factor; 30-s CST: 30-s chair stand test; TOLS-EC: Timed one-leg stance with eyes closed; FMA-LE: Fugl-Meyer assessment of lower extremity; MVPA: moderate to vigorous physical activity; METs: metabolic equivalents. b) Inference: ***$p < 0.001$.

Table 5
Model D and E multiple linear regression results.

	B	β	t	p	VIF	F	Adjusted R^2
Model D: MC of the lower extremity and peak pressure							
Age (years)	−0.045	−0.009	−0.087	0.931	1.023	8.854***	0.408
Body fat percentage (%)	2.037	0.552	4.630	<0.001	1.369		
30-s CST (n)	−0.089	−0.098	−0.855	0.396	1.259		
TOLS-EC (s)	0.164	0.145	1.328	0.190	1.142		
FMA-LE score	−0.246	−0.315	−3.013	0.004	1.050		
Model E: MP in daily physical activities and peak pressure							
Age (years)	0.166	0.033	0.300	0.765	1.005	7.284***	0.306
Body fat percentage (%)	2.012	0.545	4.427	<0.001	1.247		
Average MVPA (min/d)	−0.139	−0.145	−0.936	0.353	1.959		
METs	0.075	0.076	0.483	0.631	2.035		

Notes: a) VIF: variance inflation factor; 30-s CST: 30-s chair stand test; TOLS-EC: Timed one-leg stance with eyes closed; FMA-LE: Fugl-Meyer assessment of lower extremity; MVPA: moderate to vigorous physical activity; METs: metabolic equivalents. b) Inference: ***$p < 0.001$.

Table 6
Model F multiple linear regression results.

Model F	B	β	t	p	VIF	F	Adjusted R^2
Age (years)	−0.055	−0.011	−0.105	0.917	1.027	6.128***	0.386
Body fat percentage (%)	2.043	0.554	4.174	<0.001	1.635		
30-s CST (n)	−0.084	−0.093	−0.79	0.433	1.287		
TOLS-EC (s)	0.166	0.147	1.295	0.201	1.196		
FMA-LE score	−0.243	−0.310	−2.879	0.006	1.079		
Average MVPA (min/d)	−0.033	−0.035	−0.231	0.818	2.100		
METs	−0.013	−0.013	−0.087	0.931	2.169		

Notes: a) VIF: variance inflation factor; 30-s CST: 30-s chair stand test; TOLS-EC: Timed one-leg stance with eyes closed; FMA-LE: Fugl-Meyer assessment of lower extremity; MVPA: moderate to vigorous physical activity; METs: metabolic equivalents. b) Inference: ***$p < 0.001$.

peak pressure, exceeding the explanatory power of MP in daily physical activities ($R^2 = 0.306$).

In Table 6, Model F contributed to a moderate proportion of variance in peak pressure ($R^2 = 0.386$), positioning it intermediate to Models D and E in terms of explanatory power. In Model F, FMA-LE score ($\beta = -0.310$, $p = 0.006$) demonstrated a positive association, aligning with Model B. Body fat percentage showed positive associations in all models ($\beta_{model\ D} = 0.552$, $\beta_{model\ E} = 0.545$, $\beta_{model\ F} = 0.554$; $p < 0.001$).

4. Discussions

In our study, the 6-time multiple regression models offered valuable insights, revealing significant associations between both MC of the lower extremity and MP in daily physical activities with peak foot plantar pressures. The explanatory powers in exploring predicting factors of peak force among older women exceeded 50%, with the MC of the lower extremity demonstrating higher explanatory power than MP in daily physical activities.

The association between body fat percentage and peak force and pressure in older women aligns with previous research [66,68,69]. Our regression analysis further validated this finding, highlighting the effect of excessive fat tissue on increased loading and stress on the foot's musculoskeletal structure [70]. Maintaining a normal weight and reducing body fat emerge as crucial to mitigating foot plantar pressure and decreasing the likelihood of foot-related issues. Previous studies have revealed that high peak pressure measurement can indicate discomfort or pain during walking or functional activities, especially when individuals cannot effectively communicate their problems, making objective measurements crucial [71–73].

The 30-s CST demonstrated a potential negative association with peak force, as evident in Models A and C, affirming its robustness as a significant predictor variable. Consistent with prior evidence in older women, the 30-s CST was a significant negative predictor for peak plantar pressures [31]. Previous research has demonstrated the effectiveness of both the sitting-rising test and sit-to-stand tests as assessments of functional shifting capacity [74]. Shifting between sitting and standing on a chair or rising from the floor requires adequate levels of muscle strength, flexibility, balance, and coordination [75]. In real-life scenarios for older adults, the sit-to-stand capacity proves more crucial than the sit-to-rise capacity, in real life for older adults since they are essential for various demanding activities, such as getting up, performing housework, and sitting and rising from the toilet bowl. Our findings align with a previous study [22], indicating a potential positive association between lower scores on balance and postural control tests and peak force. Despite differences in test methods, both studies imply the importance of proprioception and foot stability in predicting foot pressure. However, the most important finding in our study is the significantly negative associations between the FMA-LE score and both peak force and pressure among older women, as observed in Models A, C, D, and F. This underscores the robustness of the FMA-LE score as a significant predictor variable for foot plantar pressures. While the FMA is primarily designed for stroke patients [76], our study supports its relevance in assessing lower-limb abilities across various age groups [77–79] and even in fall prevention efforts [80]. Therefore, we speculate that older women who have good neuromuscular coordination are likely to have lower peak foot plantar pressure and even less risk of foot pains and discomforts.

Our study further reveals that lower time spent in Average MVPA and higher METs are associated with higher peak force. Comparing Average MVPA with Models B and C, METs emerge as the more robust predictor variable for peak force. Similar findings have been reported in previous studies focused on children and adolescents [21,26], although not specifically on the elderly. Nonetheless, regular physical activity proves beneficial for older individuals, enhancing physical function and reducing the risk of age-related loss of physical capacity and falls [81,82]. Furthermore, a previous study established a significant correlation between less time spent in sedentary behaviors and lower peak plantar pressures among older women [12]. Combining our study's results with the aforementioned literature, we infer that older women engaging in higher levels of MVPA, spending less time in sedentary behaviors, and avoiding excessive energy expenditure to generate more METs are likely to experience lower peak force. Walking emerges as the most common form of daily physical activity among older adults [83], yet foot discomfort is frequently experienced during walking and associated with higher plantar pressures [84]. These findings not only suggest that the duration of physical activity should not be excessively long to prevent plantar discomfort but also underscore the importance of METs assessment as a predictor variable for peak force.

In conclusion, our study holds significant implications, particularly in the field of community-level healthcare where care conditions may vary, and foot plantar pressure assessment might face limitations due to constraints such as funds and facilities. Nevertheless, our research detected significant associations between MC of the lower extremity and peak force or the peak pressure, as well as MP in daily physical activities and both. Most notably, the FMA-LE score emerged as a predictor for peak foot and pressure, while the 30-s CST and METs were the predictor variables for peak force. These findings offer practical insights for grassroots-level elderly healthcare practices, particularly for older women, providing valuable references-especially when plantar pressure assessment is impractical, necessitating a risk analysis for foot discomfort.

However, our study has several limitations. Firstly, the cross-sectional design restricts our ability to establish causality between MC of the lower extremity, MP in daily physical activities, and foot plantar pressures. Secondly, although our sample size aligns with analytical methods [85,86], a larger sample could potentially strengthen the robustness of our findings. Thirdly, we focused only on the peak force and pressure of the dominant foot, excluding variables from the non-dominant foot. The dominance difference may contribute to varied results. Fourthly, while we prioritized body fat percentage and age as covariates, this is not comprehensive. The importance of other potential variables such as foot shape [87] and foot posture [88], etc. should be acknowledged. Therefore, we suggest that future research utilizes longitudinal datasets with larger samples, incorporates variables from both dominant and non-dominant feet, and considers additional covariates for a comprehensive investigation of causal associations with foot plantar pressures.

5. Conclusions

In conclusion, this study reveals four key findings. Firstly, the MC of the lower extremity demonstrates higher explanatory power for peak foot plantar pressures. Secondly, body fat percentage shows a positive association with both peak force and pressure. Thirdly, the FMA-LE score emerges as a significant negative predictor variable for both peak force and peak pressure. The 30-s CST is a significant negative predictor variable for peak force, while METs serve as a significant positive predictor variable.

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Ethics statement

This study was reviewed and approved by [the Institution Review Committee of Peking University], with the approval number: [20190804]. All participants provided informed consent to participate in the study.

Data availability statement

The raw data will be made available by the corresponding authors. Requests to access these datasets should be directed to GC, chengong@pku.edu.

CRediT authorship contribution statement

Min Liu: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Ning Kang:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Yalu Zhang:** Writing – review & editing, Project administration. **Erya Wen:** Resources. **Donghui Mei:** Resources. **Yizhe Hu:** Formal analysis, Data curation. **Gong Chen:** Supervision, Project administration, Conceptualization. **Dongmin Wang:** Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Chen Gong reports financial support was provided by The Major Program of National Fund of Philosophy and Social Science of China. Chen Gong reports financial support was provided by the National Key Research and Development Program of China. Chen Gong reports financial support was provided by the Strategic Research and Consulting Project of the Chinese Academy of Engineering. Wang Dongmin reports financial support was provided by the Beijing Municipal Social Science Foundation. Zhang Yalu reports financial support was provided by the National Social Science Fund of China. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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