Arch Physioter 2025; 15: 206-213
ISSN 2057-0082 | DOI: 10.33393/aop.2025.3482
ORIGINAL RESEARCH ARTICLE

Biomechanical of bilateral heel rise, and its association with balance, functional mobility, and walking speed in older adults

Cristian Caparrós-Manosalva[1,5,6], Rodrigo Guzmán-Venegas[2], Francisca Gajardo-Garrido[3], Marion González-Fuentes[3], Víctor Pino-Domínguez[3], Jessica Espinoza-Araneda[1,5,6], Ivan Palomo[4,5,6], Nacim Molina[4,5,6]

[1]Department of Human Movement Sciences, Faculty of Health Sciences, Universidad de Talca, Talca - Chile
[2]School of Kinesiology, Faculty of Medicine, Universidad de los Andes, Santiago - Chile
[3]School of Kinesiology, Faculty of Health Sciences, Universidad de Talca, Talca - Chile
[4]Thrombosis Research Center, Medical Technology School, Department of Clinical Biochemistry and Immunohematology, Faculty of Health Sciences, Universidad de Talca, Talca - Chile
[5]Interuniversity Center for Healthy Aging - Chile
[6]VITALIS Longevity Center, Faculty of Health Sciences, Universidad de Talca, Talca - Chile

ABSTRACT

Introduction: Aging advancing decreases ankle-foot strength and mobility, affecting gait and balance control. The heel-rise (HR) task requires the ankle-foot to control different biomechanical demands. It is still unclear whether these demands during HR are associated with functional performance in older adults. The aim was to describe the association between HR biomechanical parameters and single-leg stability, functional mobility, and walking speed in community-dwelling older adults.

Methods: Sixty-nine older adults (73.0, SD 6.8 years) were tested on a force platform performing bilateral rapid HR in the rise and drop phases. The biomechanical parameters measured were peak force and time, impulse, root mean square and displacement of the center of pressure (CoP), as well as displacement and velocity of the center of mass (CoM), and vertical stiffness. Functional performance was assessed through balance using the single-leg stance test (SLS), functional mobility with the Timed Up & Go test (TUG), and walking speed (WS). Associations between functional tests and biomechanical parameters were determined using correlation tests.

Results: HR peak strength and time showed a medium to large association with TUG and WS but not SLS. CoP anteroposterior displacement showed a large association in the drop phase with all functional tests but not in the rise phase. CoM velocity and vertical stiffness were associated with all tests in both phases.

Conclusion: Older adults HR biomechanical parameters are more closely associated with functional mobility and walking speed tests (TUG and WS) than with static balance tests such as SLS.

Keywords: Older Adults, Physical Functional Performance, Heel Rise, Ankle, Biomechanics

What is already known about this topic?

- *Older adults often experience decreased ankle and foot strength and mobility, which can significantly impact their gait and balance.*
- *Achieving tasks such as heel rise are key to maintaining functional performance in older adults.*

What does the study add?

- *Ankle and foot biomechanical parameters during heel rise are associated with performance on standard functional tests for older adults.*
- *The biomechanical demands of a bilateral rapid heel rise offer interesting insight into functional capabilities important for daily mobility in older age.*

Received: January 31, 2025
Accepted: July 15, 2025
Published online: July 30, 2025

This article includes supplementary materials

Corresponding author:
Nacim Molina
email: nacim.molina@gmail.com

Introduction

The strength, power, and mobility of the ankle-foot complex play a significant role in controlling postural balance, functional capacity, and the risk of falls in older adults (1,2). The strength and the muscular power of the ankle plantarflexors may serve as significant predictors of physical functional performance in older adults, particularly in assessments such as the Timed Up & Go Test (TUG) and maximum walking speed (3-5). A common task in these functional tests is the heel rise (HR), a key milestone in the capacity of weight transfer during tasks such as walking. It is also used to identify ankle-foot dysfunctions, determine the strength of ankle plantarflexors, or prescribe exercises to recover ankle-foot functions (6-8). For proper function of the ankle plantarflexors during HR, the ankle and foot are required to be able to control different biomechanical demands, such as force, position, or speed, both during HR (concentric work) and when controlling body weight (Bw) when lowering the heel on the ground (eccentric work) (9). The behavior of these biomechanical parameters during impulse tasks, such as rising and dropping the heel of the foot, may influence functional performance; however, little has been discussed about these aspects in older adults.

The advancing age leads to a decrease in the strength and mobility of the ankle-foot, as shown, for example, by an annual rate of loss of ankle plantarflexor strength of approximately 2.3% in older adults (10), which impacts the phases of walking and balance control (11). During the push-off in walking, the foot must increase its rigidity allowing greater activity of the foot's intrinsic muscles so that the ankle plantarflexors can adequately transmit their force and thus achieve adequate elevation (7,12). In this sense, older adults have shown a 24%-37% decrease in strength of the extrinsic and intrinsic muscles of the ankle and foot compared to young subjects (13), which would limit adequate mobility and stability of the foot to achieve sufficient HR (14). On the other hand, the HR implies a decrease in the base of support of the foot and shifts the CoM anteriorly, increasing the demand for postural control to avoid losing balance (15). Older adults employ a more proximal posture control strategy than younger subjects (16), implying a greater biomechanical demand on the ankle-foot complex through the CoP to rise and control the heel drop without losing balance. HR has been reported to present numerous health benefits, as it enables the development or maintenance of lower extremity muscle strength and stability (17), thereby improving balance and muscle strength and consequently reducing the incidence of falls (2).

During HR, like walking, sufficient ankle and foot mobility, as well as increased midfoot stability, are required for adequate action of the ankle plantarflexors (14). Biomechanical parameters during HR, such as ground reaction force (GRF), CoP, and CoM, and their association with performance on functional tests frequently assessed in older adults, would allow for a better understanding of the prescription of plantar flexor strengthening exercises as a measure to mitigate fall risk. However, the association between these biomechanical parameters and performance on functional and stability tasks in older adults has been little discussed. The study aimed to describe the association between the biomechanical parameters of HR and single-leg stability, functional mobility, and walking speed in community-dwelling older adults. We hypothesize that the biomechanical parameters of heel rise would be associated with locomotion and, therefore, deteriorate, just as functional tests and balance are affected in older adults.

Methods

A cross-sectional study was conducted, inviting all community-dwelling, self-sufficient adults aged 60 and above who participated in a multimodal program offered at various primary care centers across the city. A total of 86 individuals were assessed between December and January 2024, of whom sixty-nine completed all evaluations (Fig. 1). Participants with evident balance disorders or who used walk-assistive devices were excluded (excluded = 3). During the initial interview, information was also collected regarding the presence of stroke sequelae, neurodegenerative diseases, diabetic foot, tendon injuries or fractures of the ankle or foot, or relevant medical history (excluded = 2). Additionally, individuals who failed to complete one or more functional tests (excluded = 10) or who did not understand the instructions and performed the tests poorly were excluded (excluded = 2). All participants received information about the study's purpose before providing their written informed consent, which was approved by the Scientific Ethics Committee of the University Institution in accordance with the guidelines of the Declaration of Helsinki.

The sample size was calculated based on an estimated medium correlation size of 0.3, which is the ratio reported for associations between ankle and foot strength and functional tests in older adults (18). Considering a significance level of 0.05 and a power of 80%, the calculation obtained indicated that 64 participants were needed.

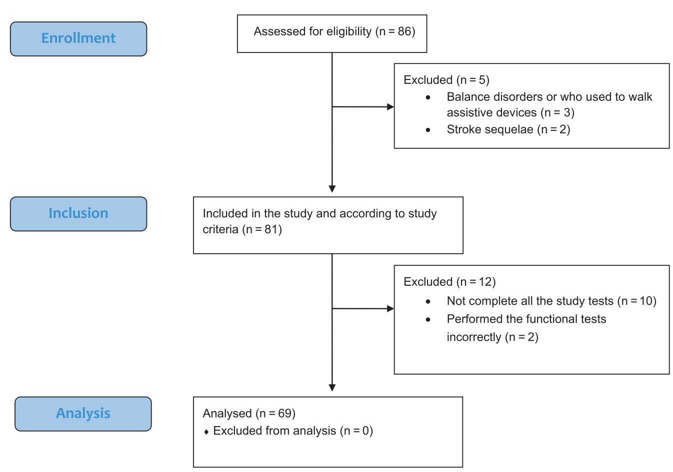

FIGURE 1 - Study participant flow chart.

Procedure

The anthropometric assessment was carried out according to the standardized protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (19). Height was measured using a portable stadiometer (Seca 213, Seca Corporation, Germany), and Bw was assessed with an eight-electrode bioelectrical impedance scale (Huawei Scale 3 Pro, China). Waist and calf circumferences were measured using a flexible tape measure, following the methodological recommendations described by Lera et al. (2014) (20).

Then, the functional tests of the TUG, single leg stance (SLS), and walking speed (WS) were assessed. An obstacle-free corridor was used for the TUG test, with a cone placed 3 meters from a chair with a backrest and a height of 40 cm. Each participant was instructed to start from a seated position, stand up without assistance, walk three meters, turn 180°, return to the starting point, and sit down again. The test was performed twice, asking the participant to complete it in the shortest possible time. The time was recorded with a stopwatch, and the shortest time obtained from the two attempts was used for analysis (21). The SLS was used to assess static balance. Before lifting the leg, the subject was instructed to cross their arms over the chest. A stopwatch was used to measure the time the subject could maintain balance on one leg. Timing began when the foot was lifted off the ground and ended if: (a) the arms were uncrossed, (b) the raised foot moved or touched the ground, (c) the supporting foot shifted to maintain balance, or (d) the maximum of 30 seconds was reached. The procedure was repeated three times, and the longest time obtained on the dominant leg was recorded for analysis (22). The WS test was conducted along a 4-meter corridor, measuring the time it took participants to comfortably walk a central 3-meter distance, with 1 meter allocated before and after for the acceleration and deceleration phases (23). The procedure was applied once, and the recording was used for analysis.

For the bilateral HR test, a clinician-guided warm-up was previously performed for 5 minutes, which included general mobility and flexibility exercises for the ankle and foot, followed by 30 seated HR tests and familiarization with the standing HR test through three repetitions to ensure adequate test performance. Then, each participant stood barefoot, with feet parallel, on a force platform (Bertec, USA) in front of a wall. They were instructed to rise both heels "as high and as fast as possible". The lowering of the heels was self-determined without receiving instructions for its control. During the execution of the test, each participant was instructed according to the procedure previously used for the bilateral heel rise (3,6). The participant could lightly support themselves against the wall with their fingers without assisting or pushing their body against it during the test. This was only used to avoid losing balance and ensure vertical displacement. Three valid repetitions were performed, eliminating those that presented visually noticeable asymmetry when lifting both heels, low elevation of both heels and loss of balance.

The force platform was configured to obtain the vertical ground reaction force (vGRF) and CoP signal at 200 Hz. The signals were smoothed post hoc with a 2nd-order filter and a 10 Hz low-pass filter, and the vGRF was adjusted to each participant's Bw. The signal onset was determined when the curve exceeded 3 SD of the pre-task resting signal average (24).

Figure 2 presents the variables obtained according to the phases defined for the HR. The rise phase was determined from the onset to the lowest point of the curve, and the drop phase was determined from the lowest point of the curve to the second peak of force.

The biomechanical parameter of peak force was determined from the top of the vGRF signal, and peak time was the difference between the onset and peak force time (24). Impulse was obtained from the area under the curve of the rise phase between the onset and when the signal equaled the Bw (25). Vertical stiffness (Kv) was obtained using a one-dimensional mass-spring model (26), which comprises a single mass (e.g., body mass) supported by a single spring-like system, represented, for example, by the legs. Therefore, this model enabled the calculation of vertical stiffness (Kv) by analyzing the relationship between the HR and the length change during the linear movement, as determined by the vertical displacement of the CoM and the vGRF. The CoM displacement was obtained by applying a double integration of the vertical acceleration with respect to time obtained from the vGRF ($a = F/m$), as reported (27). Kv (Bw/m), velocity (m/s), and CoM displacement (m) were obtained in both phases of the HR. The CoP in the anteroposterior (CoP y) and lateral (CoP x) axes were obtained during the HR. The Root Mean Square (RMS) value, which determines the average absolute displacement of the CoP around its mean position and CoP displacement in each axis, was analyzed for both the rise and drop phases.

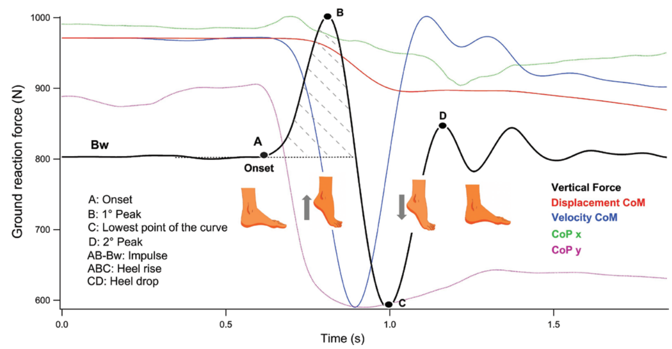

FIGURE 2 - Graphical summary of an example of the variables obtained during the Heel rise (HR) test. In the graph, the GRF is plotted on the vertical axis, and time in seconds is plotted on the horizontal axis. At the beginning of the recording, we observe the GRF line (in black) when the participant stands on the platform and registers their Bw. They then initiate the HR (point A: onset) by raising the heel (points ABC: rise phase) to the toe position (point C). They then lower the heel (points CD: drop phase) until the entire foot is in contact with the ground. The red line represents the displacement of the CoM, the blue line represents the CoM velocity, and the green and purple lines represent the displacements of the center of pressure in x and y, respectively. In addition, the impulse (shaded area under the curve at points AB and the projection of Bw) is shown in the GRF record.

Statistical analysis

Data were tabulated and presented as means and standard deviations for each HR phase and functional test. Normality assumptions were checked using the Kolmogorov-Smirnov test ($p > 0.05$). Associations between functional tests and biomechanical parameters were examined using bivariate correlations with Spearman rank correlation coefficients (*rho*). For the interpretation of the associations, the magnitude of rho in the range 0.1-0.29 was considered a small association, 0.3-0.49 a medium association, and >0.5 a large association (28). All analyses and graphs were performed using GraphPad Prism (GraphPad Software Inc., USA), with a significance level of 0.05.

Results

Table 1 describes the characteristics of the participants in the study sample. The older adults had an average age of 74 (62-88) years, a height of 1.54 (1.4-1.7) m, a weight of 70.3 (43.6-106.8) kg, a BMI of 29.4 (20.2-44.7) kg/m2, and 61 (88%) women and 8 (12%) men. In addition, they had a waist circumference of 94.9 (71-126) cm and a calf circumference of 36.1 (27-45) cm.

TABLE 1 - Characteristics of the study sample participants. Mean, standard deviation (SD), and minimum-maximum values are presented

Characteristics	n total = 69		
Sex (%women / %men)	**88% / 12%**		
	Mean	**SD**	**Min-Max**
Age, y	74.1	6.8	62.2-88.7
HR. Bpm	74.9	9.7	54.0-108.0
SBP, mmhg	134.1	19.6	104.0-190.0
DBP, mmhg	76.2	10.0	52.0-104.0
Weight, kg	70.3	15.2	43.6-106.8
Height, m	1.54	0.7	1.39-1.72
BMI, kg/m²	29.4	4.8	20.2-44.7
WC, cm	94.9	10.8	71.0-126.0
HC, cm	104.6	9.7	89.0-132.0
MCC, cm	36.1	3.6	27.0-45.0

Abbreviations: Y = years, HR = Heart rate, SBP = Sistolic blood pressure, DBP = Diastolic blood pressure, bpm = beat per minute, mmHg = millimeter of mercury, kg = Kilograms, cm = centimeters, kg/m^2 = kilograms per square meter, WC = Waist circumference, HC = Hip circumference, MCC = Max Calf circumference.

Heel rise during the rise and drop phases, and functional tests

Table 2 summarizes the results of the functional test performance and biomechanical parameters during the rise and drop phases. It was observed that the older subjects showed a CoPy (anteroposterior axis) displacement of 0.093, SD 0.02 m, a CoM velocity of 0.40, SD 0.09 m/s, a CoM vertical displacement of 0.05, SD 0.03 m and a vertical stiffness of 10.0, SD 6.2 Bw/m during the rise phase. On the other hand, during the drop phase, a CoPy displacement of 0.006, SD 0.00 m, CoM velocity of 0.21, SD 0.05 m/s, CoM displacement of 0.08, SD 0.05 m, and a vertical stiffness of 13.7, SD 13.7 Bw/m were obtained.

Correlations between the biomechanical parameters and the functional tests

The HR correlations with the functional tests (Table 3) showed a large correlation between the functional tests with the peak force (TUG: *rho* = -0.566 (-0.711, -0.374), *p*<0.001; WS: *rho* = 0.567 (0.376, 0.712), *p*<0.001), a medium correlation of the TUG and WS with the peak time (TUG: *rho* = 0.385 (0.157, 0.575), *p* = 0.001; WS: *rho* = -0.384 (-0.574, -0.155), *p* = 0.001), and no correlation of the impulse with the functional tests (*p*>0.05). In the rise phase, in general, the functional tests did not present a correlation with the displacement and RMS of the CoP (*p*>0.05), but this was not the case in the drop phase, where a significant correlation was observed with the anteroposterior displacement with the functional tests (TUG: *rho* = -0.562 (-0.708, -0.369), *p*<0.001; WS: *rho* = 0.558 (0.364, 0.705), *p*<0.001).

On the other hand, vertical stiffness showed a small to medium correlation in the rise phase (TUG: *rho* = -0.434 (-0.613, -0.214), *p*<0.001; WS: *rho* = 0.474 (0.261, 0.643), *p*<0.001), and also in the drop phase (TUG: *rho* = -0.387 (-0.576, -0.159), *p* = 0.001; WS: *rho* = 0.445 (0.226, 0.621), *p*<0.001). Similar behavior was shown by the CoM velocity in the rise phase (TUG: *rho*= -0.576 (-0.719, -0.387), *p*<0.001; WS: *rho* = 0.546 (0.349, 0.697), *p*<0.001) and in the drop phase (TUG: *rho* = -0.592 (-0.730, -0.408), *p*<0.001; WS: *rho* = 0.571 (0.380, 0.715), *p*<0.001). The CoM displacement did not present correlations with the functional tests in either of the two phases of the HR (*p*>0.05). All correlations were also illustrated in figures, see supplementary material.

Correlations between biomechanical parameters and the balance test

Correlations of HR biomechanical parameters with balance tests (see also Table 3) showed a medium correlation between SLS performance and peak force (*rho* = 0.387 (0.159, 0.576), *p* = 0.001), but no correlation with peak time and impulse (*p*>0.05). CoP displacement and RMS showed a significant large correlation between anteroposterior displacement and SLS (*p* = 0.511 (0.306, 0.671), *p*<0.001) only in the drop phase.

Vertical stiffness showed a small correlation in the rise phase (SLS: *rho* = 0.262 (0.020, 0.475), *p* = 0.029) and in the drop phase (SLS: *rho* = 0.278 (0.037, 0.488), *p* = 0.020). CoM velocity showed a medium and large correlation with SLS in the rise and drop phases (*rho* = 0.383 (0.154, 0.573), *p* = 0.001; *rho* = 0.543 (0.346, 0.695), *p*<0.001, respectively). As with the functional tests, the correlations with the balance test were illustrated in the figures (see also supplementary material).

Discussion

The present study aimed to describe the association between the biomechanical parameters of HR and single-leg stability, functional mobility, and walking speed in community-dwelling older adults. The main results show that greater peak force and shorter peak time in the rise phase during HR are more associated with better performance in walking and speed tests, such as the TUG and WS, than with balance (SLS). Additionally, a greater anteroposterior displacement of the CoP was associated with better performance in the drop phase of the three functional tests but not in the rise phase. Finally, greater vertical stiffness and velocity of the CoM were associated with better functional performance in the tests in both phases.

Postural balance impairment in older adults has been frequently associated with greater oscillation of the CoP due

TABLE 2 - Summary of biomechanical parameters of the heel rise and functional tests in older adults. Values obtained during the rise and drop phases and functional tests in older adults are presented. Values are presented as mean (standard deviation)

Heel rise	Mean (SD)	Heel drop	Mean (SD)	Functional test	Mean (SD)
Fpeak (Bw)	1.34 (0.1)	n.a.	n.a.	TUG (s)	8.7 (1.9)
Impulse (Ns)	179.0 (40.9)	n.a.	n.a.		
Time Peak (ms)	149.0 (31.3)	n.a.	n.a.		
RMS CoP x (m)	0.015 (0.01)	RMS CoP x (m)	0.016 (0.01)	SLS (s)	10.2 (10.4)
RMS CoP y (m)	0.060 (0.02)	RMS CoP y (m)	0.067 (0.03)		
Displacement Cop x (m)	0.022 (0.01)	Displacement CoP x (m)	0.013 (0.01)		
Displacement CoP y (m)	0.093 (0.02)	Displacement Cop y (m)	0.006 (0.00)		
Vertical Stiffness (Bw/m)	10.0 (6.2)	Vertical Stiffness (Bw/m)	13.7 (13.7)	WS (m/s)	1.19 (0.2)
Displacement CoM (m)	0.05 (0.03)	Displacement CoM (m)	0.08 (0.05)		
Velocity CoM (m/s)	0.40 (0.09)	Velocity CoM (m/s)	0.21 (0.05)		

Abbreviations: Fpeak: Force peak (maximum vertical ground reaction force during hell rise); Bw: body weight; ms: milliseconds; RMS: Root Mean Square; CoPx: center of pressure mediolateral direction; CoPx: center of pressure anteroposterior direction; m: meter; CoM: center of mass; m/s: meter/second; n.a.: not applicable; TUG: timed Up & Go test; SLS: single leg stance; WS: walking speed.

TABLE 3 - Correlations between biomechanical parameters of the heel rise and the performance of functional tests. Spearman rank correlation coefficient values and confidence Interval 95% are presented, and significant values are shown in bold

Outcomes	TUG			SLS			WS		
	rho	CI 95%	p	rho	CI 95%	p	rho	CI 95%	p
Heel rise									
Fpeak (Bw)	-0.566	-0.711, -0.374	**<0.001**	0.387	0.159, 0.576	**0.001**	0.567	0.376, 0.712	**<0.001**
Impulse (Ns)	0.013	-0.230, 0.256	0.910	-0.102	-0.337, 0.144	0.401	0.045	-0.199, 0.286	0.707
Time Peak (ms)	0.385	0.157, 0.575	**0.001**	-0.133	-0.365, 0.113	0.273	-0.384	-0.574, -0.155	**0.001**
RMS CoP x (m)	0.246	0.00339, 0.462	**0.041**	-0.073	-0.311, 0.173	0.549	-0.151	-0.380, 0.0958	0.215
RMS CoP y (m)	-0.224	-0.443, 0.0197	0.063	0.202	-0.042, 0.425	0.094	0.206	-0.038, 0.428	0.088
Displacement CoP x (m)	-0.087	-0.323, 0.159	0.476	-0.012	-0.255, 0.231	0.919	0.149	-0.097, 0.378	0.221
Displacement CoP y (m)	-0.117	-0.350, 0.129	0.337	0.095	-0.151, 0.331	0.436	0.110	-0.136, 0.344	0.366
Vertical Stiffness (Bw/m)	-0.434	-0.613, -0.214	**<0.001**	0.262	0.020, 0.475	**0.029**	0.474	0.261, 0.643	**<0.001**
Displacement CoM (m)	0.196	-0.049, 0.419	0.105	-0.095	-0.331, 0.151	0.435	-0.247	-0.463, -0.004	**0.040**
Velocity CoM (m/s)	-0.576	-0.719, -0.387	**<0.001**	0.383	0.154, 0.573	**0.001**	0.546	0.349, 0.697	**<0.001**
Heel drop									
RMS CoP x (m)	0.073	-0.172, 0.311	0.546	-0.012	-0.255, 0.231	0.915	0.012	-0.231, 0.255	0.919
RMS CoP y (m)	-0.161	-0.389, 0.085	0.184	0.146	-0.100, 0.376	0.229	0.120	-0.126, 0.353	0.323
Displacement CoP x (m)	-0.270	-0.482, -0.029	**0.024**	0.102	-0.144, 0.337	0.400	0.226	-0.017, 0.445	0.061
Displacement CoP y (m)	-0.562	-0.708, -0.369	**<0.001**	0.511	0.306, 0.671	**<0.001**	0.558	0.364, 0.705	**<0.001**
Vertical Stiffness (Bw/m)	-0.387	-0.576, -0.159	**0.001**	0.278	0.037, 0.488	**0.020**	0.445	0.226, 0.621	**<0.001**
Displacement CoM (m)	0.018	-0.225, 0.260	0.879	0.049	-0.196, 0.289	0.686	-0.109	-0.344, 0.137	0.368
Velocity CoM (m/s)	-0.592	-0.730, -0.408	**<0.001**	0.543	0.346, 0.695	**<0.001**	0.571	0.380, 0.715	**<0.001**

Abbreviations: Fpeak: Force peak (maximum vertical ground reaction force during hell rise); Bw: body weight; ms: milliseconds; RMS: Root Mean Square; CoPx: center of pressure mediolateral direction; CoPx: center of pressure anteroposterior direction; m: meter; CoM: center of mass; m/s: meter/second; TUG: timed Up & Go test; SLS: single leg stance; WS: walking speed.

to impaired postural control, which increases the risk of falls (29). In dynamic tasks such as HR, a greater anterior displacement of the CoP and CoM, as well as increased work of the ankle plantarflexor muscles, has been observed (30). Our results showed that a greater anteroposterior displacement of the CoP during the drop phase was associated with better performance in the three functional tests studied, but not during the rise phase. Few studies have analyzed the drop phase during HR in older adults; however, physiotherapists are known to prescribe eccentric ankle plantarflexor training when controlling heel drop (31,32). Therefore, the ability to better control balance in different tasks would depend not only on the concentric capacity of the ankle plantar flexors but also on the eccentric control capacity required to control movement (29). Furthermore, foot and ankle biomechanics are affected by advancing age, with increased stiffness, decreased range of motion, and postural changes in the foot, resulting in decreased propulsion capacity, for example, during walking (33). Along these lines, plantarflexor training has shown benefits in heel rise strength, dynamic balance (34), and in reducing the risk of falls, through a reduced fear of falling and increased fall self-efficacy in older adults (8).

In functional transfer tasks, such as gait, the ankle-foot complex needs to be able to transition between flexible and stiff conditions in order to adequately act during the push-off and absorption of foot impact in the stance phase (35). Our results showed that in both phases of HR, rise and drop, greater vertical stiffness and vertical CoP velocity were associated with better performance in functional tests in older adults. Although it has been described that both muscle strength and joint flexibility decrease in advanced ages, which would cause a lower functional capacity in balance and walking (36), older adults have shown that ankle mechanical stiffness is maintained in activities such as walking due to neural and musculoskeletal changes to maintain ankle stability (37). This could explain the association found between the biomechanical parameters and the functional tests analyzed. However, neither the plantarflexor muscle strength nor ankle range of motion was part of this study, making it necessary to incorporate these control parameters when evaluating HR.

Regarding the clinical implications of this study, the fast bilateral heel rise provides a compact window into several capacities—strength, power and balance control—that are important for everyday mobility in late life. Decades of work with the unilateral version already show that the number of pain-free rises an older person can complete mirrors their static and dynamic balance scores (38), and the test itself is both easy to teach and highly reliable across sessions and examiners (39). When heel rise metrics are normalized to body mass, they track plantar-flexor torque almost as well as an isokinetic dynamometer, yet need only a stopwatch or force plate.

More recently, researchers have begun to connect those same metrics with downstream outcomes that physiotherapists care about. Slower gait speed, shorter strides, and longer double-support phases—kinematic fingerprints of fall-prone elders—co-vary with weaker or slower heel-rise performance, suggesting a shared physiological bottleneck in ankle power generation (40). Sadeh et al. (2023) study on sit-to-stand mechanics shows a similar result. Compared to younger adults, seniors take longer to stand, flex their trunks more, and sway more afterward, all hallmarks of reduced ankle stiffness and delayed plantar-flexor activation (41). Interestingly, even brief interventions can make a significant impact. An eight-week balance block that blended progressive calf-raise drills with sensory-challenge exercises cut TUG times and trimmed fall-risk scores in community-dwelling participants over 70 (8).

Technological tools have also taken on importance in these areas. Pressure mats in footwear, inertial units, and small force sensors attached to the heel can record elevation height, velocity, and even fatigue-induced asymmetries, turning a two-minute field test into a clinical-quality data stream without the need to strap the patient into bulky laboratory equipment (42). Together, these developments position the heel rise not merely as a snapshot of calf strength but as a versatile, intervention-responsive marker that physiotherapists can use to screen, stratify, and track older adults who are slipping toward mobility loss or recurrent falls.

This study is not without limitations. An important aspect was that ankle plantarflexor muscle strength and ankle joint range of motion were not measured, which would limit the interpretation of some functional performance results in older adults, which have been shown to be related to strength and mobility capacity. Studies analyzing biomechanical factors in this type of dynamic testing should consider strength and mobility capacities in older adults, as well as attempt to compare these parameters with younger or middle-aged individuals. Another limitation was that the sample of participants presented a significant difference in the number of women compared to older men. Although it has been reported that sex does not influence both the concentric and eccentric phases of the HR (9), maximum strength values were normalized concerning Bw to control for differences obtained when using absolute strength values. Another factor that could limit the analysis of the results was the methodological configuration used, which allowed finger support during the HR execution. Although other studies have proposed this configuration (3,6), no form of control was applied to this strategy, nor was the number of participants who used or required this support considered, which should be taken into account in future applications of this test in older adults.

Conclusion

Older adults present biomechanical parameters of HR that are more closely associated with functional tests, such as the TUG and WS, than with balance tests (SLS). The fast HR showed associations with vGRF, anteroposterior displacement control, vertical stiffness, and vertical speed with tasks of greater dynamic demand, such as TUG and WS. Bilateral rapid heel rise and its biomechanical demands offer interesting insight into functional capabilities important for daily mobility in old age.

Acknowledgments

The authors thank all the community-dwelling older people who gave their time to participate in this study.

Disclosures

Conflict of interest: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Financial support: This research received no specific grant from public, commercial, or not-for-profit funding agencies

Authors' contributions: Conceptualization: CCM, NM; Formal analysis: CCM, FGG, MGF, VPD; Investigation: CCM, NM; Methodology: CCM, RGV; Project administration: NM, IP; Writing – original draft: CCM, NM, RGV; Writing – review & editing: CCM, RGV, JEA, IP, NM

Data Availability Statement: Data available on request: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy policy of the institution.

References

1. Menz HB, Morris ME, Lord SR. Foot and ankle characteristics associated with impaired balance and functional ability in older people. J Gerontol A Biol Sci Med Sci. 2005;60(12): 1546-1552. CrossRef PubMed
2. Menz HB, Morris ME, Lord SR. Foot and ankle risk factors for falls in older people: a prospective study. J Gerontol A Biol Sci Med Sci. 2006;61(8):866-870. CrossRef PubMed
3. Hester GM, Ha PL, Dalton BE, et al. Rate of Force Development as a Predictor of Mobility in Community-dwelling Older Adults. J Geriatr Phys Ther. 2021;44(2):74-81. CrossRef
4. Kanayama A, Minami M, Yamamoto S, et al. Examination of the Impact of Strength and Velocity of the Knee and Ankle on Gait Speed in Community-Dwelling Older Adults. Healthcare (Basel). 2022;10(10):2093. CrossRef PubMed
5. Stenroth L, Sillanpää E, McPhee JS, et al. Plantarflexor Muscle-Tendon Properties are Associated With Mobility in Healthy Older Adults. J Gerontol A Biol Sci Med Sci. 2015;70(8): 996-1002. CrossRef PubMed
6. André HI, Carnide F, Borja E, Ramalho F, Santos-Rocha R, Veloso AP. Calf-raise senior: a new test for assessment of plantar flexor muscle strength in older adults: protocol, validity, and reliability. Clin Interv Aging. 2016;11:1661-1674. CrossRef PubMed
7. Jeong HJ, Mueller MJ, Zellers JA, Hastings MK. Midfoot and ankle motion during heel rise and gait are related in people with diabetes and peripheral neuropathy. Gait Posture. 2021;84:38-44. CrossRef PubMed
8. Maritz CA, Silbernagel KG. A Prospective Cohort Study on the Effect of a Balance Training Program, Including Calf Muscle Strengthening, in Community-Dwelling Older Adults. J Geriatr Phys Ther. 2016;39(3):125-131. CrossRef PubMed
9. Ugbolue UC, Yates EL, Ferguson K, et al. Electromyographic Assessment of the Lower Leg Muscles during Concentric and Eccentric Phases of Standing Heel Raise. Healthcare (Basel). 2021;9(4):465. CrossRef PubMed
10. Winegard KJ, Hicks AL, Sale DG, Vandervoort AA. A 12-year follow-up study of ankle muscle function in older adults. J Gerontol A Biol Sci Med Sci. 1996;51(3):B202-B207. CrossRef PubMed
11. Ishikawa M, Komi PV, Grey MJ, Lepola V, Bruggemann GP. Muscle-tendon interaction and elastic energy usage in human walking. J Appl Physiol (1985). 2005;99(2):603-8. CrossRef
12. Hastings MK, Woodburn J, Mueller MJ, Strube MJ, Johnson JE, Sinacore DR. Kinematics and kinetics of single-limb heel rise in diabetes related medial column foot deformity. Clin Biomech (Bristol). 2014;29(9):1016-1022. CrossRef PubMed
13. Spink MJ, Fotoohabadi MR, Menz HB. Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. Gerontology. 2010;56(6):525-532. CrossRef PubMed
14. Houck JR, Neville C, Tome J, Flemister AS. Foot kinematics during a bilateral heel rise test in participants with stage II posterior tibial tendon dysfunction. J Orthop Sports Phys Ther. 2009;39(8):593-603. CrossRef PubMed
15. Wang J, Wang Y, Zhou B, Wang L, Lai Z. Age-Related Reduction of Foot Intrinsic Muscle Function and the Relationship with Postural Stability in Old Adults. Clin Interv Aging. 2024;19: 1005-1015. CrossRef PubMed
16. Boyas S, Medd ER, Beaulieu S, Boileau A, Lajoie Y, Bilodeau M. Older and young adults adopt different postural strategies during quiet bipedal stance after ankle plantarflexor fatigue. Neurosci Lett. 2019;701:208-212. CrossRef PubMed
17. Flanagan SP, Song JE, Wang MY, Greendale GA, Azen SP, Salem GJ. Biomechanics of the heel-raise exercise. J Aging Phys Act. 2005;13(2):160-171. CrossRef PubMed
18. Spink MJ, Fotoohabadi MR, Wee E, Hill KD, Lord SR, Menz HB. Foot and ankle strength, range of motion, posture, and deformity are associated with balance and functional ability in older adults. Arch Phys Med Rehabil. 2011;92(1):68-75. CrossRef PubMed
19. Esparza-Ros F, Vaquero-Cristóbal R, Marfell-Jones M. International standards for anthropometric assessment. International Society for the Advancement of Kinanthropometry (ISAK): Glasgow, UK, 2019; 154.
20. Lera L, Ángel B, Sánchez H, et al. [Validation of cut points of skeletal muscle mass index for identifying sarcopenia in Chilean older people]. Nutr Hosp. 2014;31(3):1187-97. CrossRef
21. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39(2):142-148. CrossRef PubMed
22. Springer BA, Marin R, Cyhan T, Roberts H, Gill NW. Normative values for the unipedal stance test with eyes open and closed. J Geriatr Phys Ther. 2007;30(1):8-15. CrossRef PubMed
23. Bohannon RW, Wang YC. Four-Meter Gait Speed: Normative Values and Reliability Determined for Adults Participating in the NIH Toolbox Study. Arch Phys Med Rehabil. 2019;100(3): 509-513. CrossRef PubMed
24. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations. Eur J Appl Physiol. 2016;116(6):1091-1116. CrossRef PubMed
25. Zellers JA, Baxter JR, Grävare Silbernagel K. Functional Ankle Range of Motion but Not Peak Achilles Tendon Force Diminished With Heel-Rise and Jumping Tasks After Achilles Tendon Repair. Am J Sports Med. 2021;49(9):2439-2446. CrossRef PubMed
26. McMahon JJ, Comfort P, Pearson S. Lower Limb Stiffness: Effect on Performance and Training Considerations. Strength Condit J. 2012;34(6):94-101. CrossRef
27. Donelan JM, Kram R, Kuo AD. Simultaneous positive and negative external mechanical work in human walking. J Biomech. 2002;35(1):117-124. CrossRef PubMed
28. Ellis PD, ed. PD E. Effect sizes and the interpretation of results. In: The Essential Guide to Effect Sizes: Statistical Power, Meta-Analysis, and the Interpretation of Research Results. Cambridge University Press; 2010:1-2. CrossRef
29. Brech GC, Bobbio TG, Cabral KN, et al. Changes in postural balance associated with a woman's aging process. Clinics (Sao Paulo). 2022;77:100041. CrossRef PubMed
30. Ridge ST, Rowley KM, Kurihara T, et al. Contributions of Intrinsic and Extrinsic Foot Muscles during Functional Standing Postures. BioMed Res Int. 2022;2022(1):7708077. CrossRef PubMed

31. Jeong S, Lee DY, Choi DS, Lee HD. Acute effect of heel-drop exercise with varying ranges of motion on the gastrocnemius aponeurosis-tendon's mechanical properties. J Electromyogr Kinesiol. 2014;24(3):375-379. CrossRef PubMed
32. Lee SM, Cynn HS, Yoon TL, Lee JH. Effects of different heel-raise-lower exercise interventions on the strength of plantarflexion, balance, and gait parameters in stroke survivors. Physiother Theory Pract. 2017;33(9):706-715. CrossRef PubMed
33. Menz HB. Biomechanics of the Ageing Foot and Ankle: A Mini-Review. Gerontology. 2015;61(4):381-388. CrossRef PubMed
34. Jeon MY, Jeong H, Petrofsky J, Lee H, Yim J. Effects of a randomized controlled recurrent fall prevention program on risk factors for falls in frail elderly living at home in rural communities. Med Sci Monit. 2014;20:2283-2291. CrossRef PubMed
35. Akuzawa H, Imai A, Iizuka S, Matsunaga N, Kaneoka K. The influence of foot position on lower leg muscle activity during a heel raise exercise measured with fine-wire and surface EMG. Phys Ther Sport. 2017;28:23-28. CrossRef PubMed
36. Boyer KA, Johnson RT, Banks JJ, Jewell C, Hafer JF. Systematic review and meta-analysis of gait mechanics in young and older adults. Exp Gerontol. 2017;95:63-70. CrossRef PubMed
37. Krupenevich RL, Clark WH, Sawicki GS, Franz JR. Older Adults Overcome Reduced Triceps Surae Structural Stiffness to Preserve Ankle Joint Quasi-Stiffness During Walking. J Appl Biomech. 2020;36(4):209-216. CrossRef PubMed
38. Hashish R, Samarawickrame SD, Wang MY, Yu SS, Salem GJ. The association between unilateral heel-rise performance with static and dynamic balance in community dwelling older adults. Geriatr Nurs. 2015;36(1):30-34. CrossRef PubMed
39. Hébert-Losier K, Wessman C, Alricsson M, Svantesson U. Updated reliability and normative values for the standing heel-rise test in healthy adults. Physiotherapy. 2017;103(4):446-452. CrossRef PubMed
40. Marques NR, Spinoso DH, Cardoso BC, Moreno VC, Kuroda MH, Navega MT. Is it possible to predict falls in older adults using gait kinematics? Clin Biomech (Bristol). 2018;59:15-18. CrossRef PubMed
41. Sadeh S, Gobert D, Shen KH, Foroughi F, Hsiao HY. Biomechanical and neuromuscular control characteristics of sit-to-stand transfer in young and older adults: A systematic review with implications for balance regulation mechanisms. Clin Biomech (Bristol). 2023;109:106068. CrossRef PubMed
42. Pires IM, Ponciano V, Garcia NM, Zdravevski E. Analysis of the Results of Heel-Rise Test with Sensors: A Systematic Review. Electronics (Basel). 2020;9(7):1154. CrossRef