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Association Between the History of Fall and the Fear of Falling on Stair Descent and Gait Transition Spatiotemporal Parameters and Lower-Limb Kinematics in Older Adults

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Abstract: Background: Among older adults, there is a high incidence of history of fall (HoF), fear of falling (FoF), and falls on stair descent during gait transitions. Purpose: We aim to evaluate the association between HoF and FoF on spatiotemporal and lower-limb kinematic parameters in older adults during stair descents and gait transitions. Methods: Sixty older adults (>60 years) were evaluated through an optoelectrical motion capture system during stair descents and gait transitions, using the mean value of the task velocity and time; single- and double-support time; peak downward center of mass (CoM) velocity; hip, knee, and ankle positions of ipsi and the contralateral limb; and foot clearance and foot placement, assessed through multivariate analysis of variance. Results: FOF exhibited longer time to complete (p = 0.009) and double-support (p = 0.047) and single-support (p = 0.009) times and a reduced peak downward CoM velocity (p = 0.043). In the gait transition cycle, HOF exhibited reduced ipsi ankle angles at toe-off (p = 0.015), and FOF presented reduced ipsi ankle angles at heel-strike (p = 0.041) and toe-off (p = 0.026) and reduced contralateral ankle angles at toe-off (p = 0.022). Conclusion: Older adults with HoF and FoF exhibit biomechanical changes during stair descents and gait transitions, in line with the use of more conservative strategies to avoid falling.

Keywords: history of fall; fear of falling; geriatrics; stair descent; biomechanics

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1. Introduction

The 21st century runs its course towards an aged society, with more than 1 billion people aged over 60 years [1].

The aging process causes systemic changes at functional and structural levels related to a higher prevalence of comorbidities, such as cardiovascular, cognitive, and neurodegenerative diseases [2,3]. Therefore, older adults often experience multimorbidity associated with polypharmacy [2,4], which can exacerbate their declines in physiological and biomechanical parameters, such as slowness, reduced flexibility and mobility, decreased proprioception and body stability, sarcopenia, and fatigue [4,5]. These alterations can be an early sign of their functional worsening and risk of falling [6,7], being particularly important given that falls are the main cause of injuries in this population [8]. It has been estimated that one third of the community-dwelling population aged over 60 years experiences at least one fall per year [9]. In this context, not only the history of fall (HoF) but also the fear of falling (FoF) has been shown to have a high association with the risk of falling [7,10]. In older

adults, it has been estimated that 20% of falls occur on stairs [8], and from these, 75% occur while descending stairs [11].

Stair descent imposes a higher neuromuscular and sensorimotor demand [12,13], and older adults have more difficulty controlling the fast vertical displacements of the center of mass (CoM) [14,15]. Additionally, they adopt alternative strategies, such as decreased descent velocity and single-support time [16], increased double-support time [17] and foot placement (FP) [16], and reduced foot clearance (FC) [18]. Falls usually happen during the transition to gait [18], when the nervous system must quickly respond to a change in the motor task, with this ability becoming less efficient with aging [19]. Notably, stair descent is related to a higher incidence of falls and worse consequences in older adults [20,21], and it is an essential task for the independence and quality of life of this population [12,22]. Therefore, the study of solutions capable of predicting incapacity in older adults is demanded to prevent the occurrence of falls [21].

Research has shown the influence of age on stair descent in older adults; however, few studies have integrated spatiotemporal parameters and lower-limb kinematics [8,15,16,18,19,21]. Few authors have focused on both stair descent and gait transition [8,11,14,19], and the literature lacks analyses of the association between HoF and FoF with respect to these parameters during stair descent and gait transition. Thus, beyond the range of kinematic parameters, during stair descent, the assessment of key events such as the transition to gait could bring relevant data, since, at these transitional moments, older adults exhibited strategies prioritizing stability over the range of motion [23].

Therefore, the aim of this study is to evaluate the association between HoF and FoF on spatiotemporal parameters and lower-limb kinematic parameters in older adults during stair descent and gait transition. Specifically, spatiotemporal parameters will be assessed through task velocity and time, single- and double-support time, and peak downward CoM velocity, and kinematic data will be assessed through hip, knee, and ankle positions, FC, and FP.

2. Materials and Methods

2.1. Study Design

According to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [24], a cross-sectional study was designed and implemented. Between 1 June 2022 and 31 March 2023, a sample selection questionnaire was distributed to the Center for Rehabilitation Research of the School of Health Polytechnic of Porto partners, where the study took place. Participants were also recruited through advertisements, and additional participants were enrolled via snowball sampling, whereby enrolled individuals referred others from their networks. Data collection continued until 30 April 2023.

2.2. Participants

Participants were considered eligible if they were community-dwelling healthy co-operative subjects aged 60 years or older and able to independently perform activities of daily living (ADLs) and descend stairs. The exclusion criteria included having an established diagnosis of malignancy or terminal diseases with an anticipated survival prognosis of less than a year and suffering from diabetic foot, lower-limb fracture in the previous 6 weeks, or other related conditions. Older adults were also excluded if they were recovering from an acute illness or injury; neurological, musculoskeletal, cognitive, cerebrovascular, and respiratory conditions and/or sensorimotor, visual, vestibular, and hearing deficits that prevent the subject from understanding the task; centrally acting medication that may affect movement and/or postural control; and the presence of pain that might impair the task. Participants responded to the sample selection questionnaire, and if the eligibility

criteria were met and the subjects accepted enrollment in the study, they were contacted to schedule the assessment (see Figure 1). During the assessment, the participants responded to the "Assessment and Characterization Questionnaire (ACQ)", which included several characterization questions and structured questionnaires that allowed us to allocate them according to their HoF and FoF.

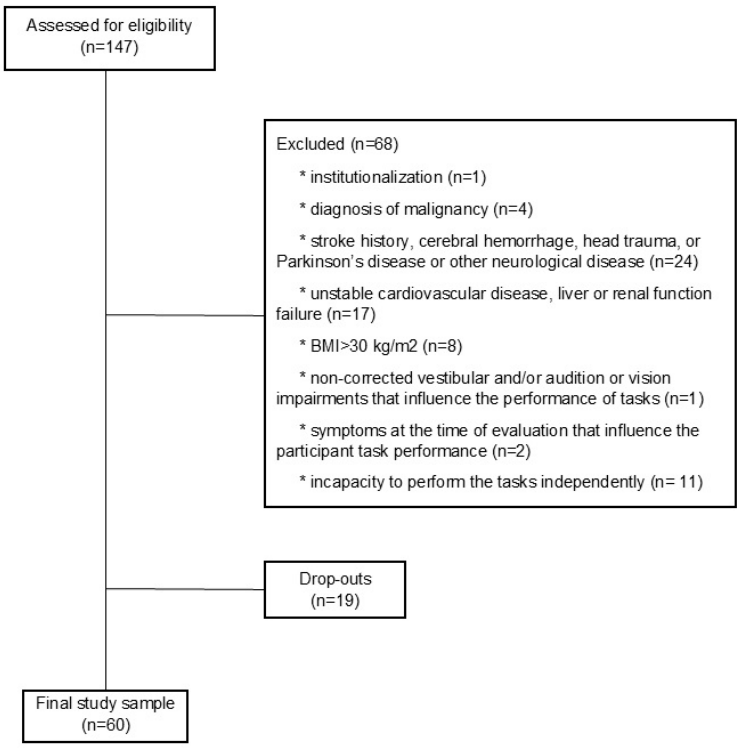


Figure 1. Flowchart of the sample selection.

2.3. Ethical Considerations

All participants were informed about the purpose of the study and its protocol, and they signed an informed consent form. This study was submitted to the Institutional Ethics Committee and received approval on 25 May 2022. Confidentiality was ensured by the investigator assigning a code to each participant's data, which was stored on a computer protected by a password known only to the investigator. The Ethics Committee Registration Number is CE0064C.

2.4. Testing Protocol

The experiment was conducted at the Center for Rehabilitation Research of the School of Health, Polytechnic of Porto. The session began with demographic and anthropometric data collection. Participants answered assessment and characterization questionnaires: the "International Physical Activity Questionnaire (IPAQ)" [25], the "Portuguese Version of Mini-Mental State Examination (MMSE)" [26], and the Barthel Index (BI) [27]. Afterwards, body composition data were collected through bioelectrical impedance, followed by the "hand grip strength (HGS)" test [28]. Prior to data collection, a total of 82 reflective markers were attached to anatomical landmarks according to the guidelines [29]. Participants were monitored with an optoelectronic system while performing the stair descent and gait transition.

Accordingly, kinematic data were collected synchronously using the Qualisys Track Manager (Qualisys AB®, Göteborg, Sweden) with thirteen optoelectronic cameras (eight

Oquos500 and four MiqusM3) and one Miqus video camera, using a marker setup previously used in research [29].

A three-step staircase (step height: 16 cm; tread depth: 29 cm; step width: 69 cm) was used to perform the stair descent (see Figure 2) [15]. In accordance with the previous literature, such as Francksen et al., all participants were instructed to start at the top of the staircase from an upright position, with their feet side by side, and to descend the staircase at their own self-selected velocity using their ipsi limb [16]. They were also instructed to continue walking for at least two steps once they reached level ground [14]. A trial was completed once the participants came to a stationary standing position on level ground [15]. Handrails were present throughout the trials as a safety precaution; however, participants were instructed not to use them unless necessary [16]. For safety reasons, there was also an investigator next to the staircase accompanying the descent [12]. All participants performed a stair descent practice trial before the experimental trial to enhance their familiarity with the protocol [15]. The protocol consisted of three completed trials per participant [16].

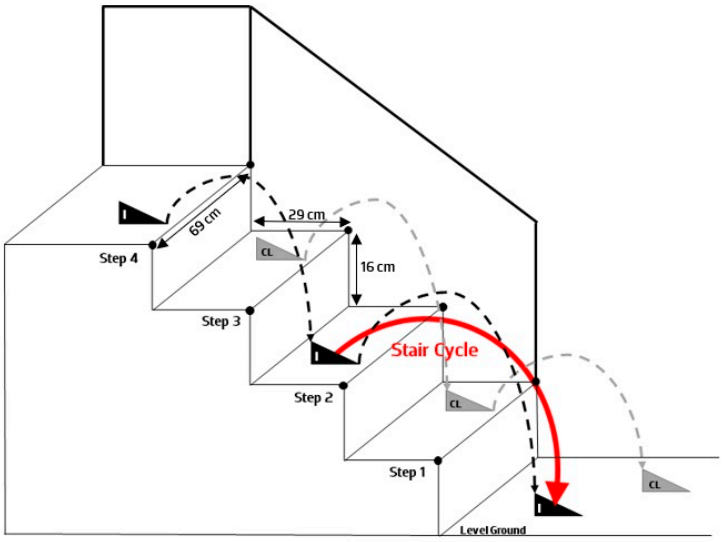


Figure 2. Schematic demonstrating the ipsi limb (I—in black) and contralateral limb (CL—in gray) trajectories during the stair descent. The red arrow represents the stair cycle, starting with the ipsi limb on step 2 and terminating with the ipsi limb on level ground. The triangle on the step represents the stance phase, and the dashed line represents the swing phase. Stair descent data selected for further analysis were extracted from the stair-cycle and the gait-transition data from the gait cycle on level ground.

2.5. Data Processing

Data processing was applied in both previous software and in Visual3D ProfessionalTM (v.6.01.36, C-Motion, Inc., Germantown, MD, USA). Anthropometric measurements from each participant were entered into the model [Buckley, King]. In line with previous studies such as Alcock et al., a static calibration trial was conducted prior to the movement trials to define segment lengths and identify lower-limb joint centers [11].

Data from the three stair descent and gait transition trials per participant were collected for the purpose of this study. Therefore, for data collection facilitation, the topmost step of the staircase was labeled "Step 4", and the subsequent steps were labeled "Step 3", "Step 2", and "Step 1" (see Figure 1) [11]. The stair descent data selected for further analysis was extracted from the stair cycle, and the gait transition data was extracted from the gait cycle on level ground [11]. The stair cycle was initiated at the moment of the ipsi limb heel-strike (HS) on "Step 2" and finished with the ipsi limb HS on level ground (see Figure 1) [30]. The gait cycle was initiated when the ipsi limb HS occurred on level ground and finished with

the subsequent ipsi limb HS [31]. According to Foster et al., the moment of toe-off (TO) was defined by the maximum heel marker's vertical velocity, and the moment of HS was defined by the minimum downwards CoM velocity [32].

The extracted spatiotemporal parameters included task velocity (m/s) and time (s), single- and double-support time (s) [11], and peak downward CoM velocity (m/s) [33]. In the stair cycle, lower-limb kinematics were characterized by FC and FP; and hip, knee, and ankle angles at the moment of FC and FP [14]. In the gait cycle, the lower-limb kinematics were characterized by the ipsi and contralateral hip, knee, and ankle angles at HS and TO [34]. A low-pass filter from the Butterworth class with a cut-off frequency of 6.0 Hz was used on the joint angles' variables.

The reference frame was set as a positive *z*-axis directed vertically upward, a positive *y*-axis directed in the direction of motion, and a positive *x*-axis directed from the left to the right (x: flexion/extension; y: abduction/adduction; z: longitudinal rotation) [11]. The segmental CoM location was obtained from the body-segment-parameter data, and the position of the whole-body CoM was estimated as the weighted sum of various body segments [35]. According to Francksen et al., FC was established as the minimum resultant horizontal distance between the step-edge and the heel at the instant the heel passed the vertical height of the step-edge [16]. For the ipsi limb, FC data were extracted from the instant the heel passed the vertical height of Step 1. For the contralateral limb, FC data were extracted from the instant the heel passed the vertical height of Step 2. FP was measured as the horizontal distance between the step-edge and the calcaneus at the instant of the initial foot contact [16]. For the ipsi limb, FP data were extracted from the instant of the initial foot contact on Step 2. For the contralateral limb, FP data were extracted from the initial foot contact on Step 1.

2.6. Statistical Analysis

The sample size calculation was conducted through the "G*Power 3.1.9.7" statistical software. By having an estimation of the statistical power, significance level, and expected effect size through the difference between two independent-mean *T* tests, it was possible to establish an "a priori sample size calculation" that determined the minimum value required to minimize the publication bias of the current study [36]. Using the purpose of detecting differences on the "hip angle at TO" of older adults during the stair descent trial of Marques et al., it was possible to estimate an "effect size of d" of 0.8631101 for an "α err prob" of 0.05 and a "power" of 0.8 [34]. The result of the sample size calculation was 23 participants in each group, with a total sample size of 46. In studies examining falls among older adults, it is possible not to have groups with the same N, as long as around 30% of the participants present HoF, since it has been consistently estimated in the previous literature that the prevalence of falls in this population stands at 30% [17,34,37].

For the statistical analysis, data consisting of the mean values of the three trials of each participant [Bosse] were exported into "IBM SPSS STATISTICS" v28.0.0.0 (190) (SPSS Inc., Chicago, IL, USA) [30]. The data were assessed for normality of the distribution. Given that the NHOF and NFOF groups had an N > 30, it was assumed that their data followed a normal distribution [38]. On the contrary, the normality of the distribution of the HOF and FOF groups was assessed through the Shapiro–Wilk test [38]. A mixed-design multivariate analysis of variance (MANOVA), with HOF and FOF as fixed factors and the characteristics, spatiotemporal, and kinematic parameters as dependent variables, was used to determine the main and interaction effects for each of the parameters, in compliance with the MANOVA assumptions verified through multivariate normality, probability sampling methods, equal variance, and the absence of multivariate outliers [39]. The categorical

variables were analyzed through the Pearson's chi-square test [40] and Fisher's exact test [41]. The level of significance was set at $p \leq 0.05$ [42].

3. Results

A total of 60 participants were enrolled in this study (see Figure 2), and the descriptive statistics of their characteristics are summarized in Table 1. Older adults with HoF presented a significantly higher number of prescribed medications when compared to older adults without HoF ($p = 0.018$). On the contrary, regarding MMSE, the HOF group scored significantly lower than the NHOF group ($p = 0.014$). Older adults with FoF presented a significantly higher "Body Mass Index (BMI)" compared to older adults without FoF ($p = 0.037$). On the contrary, regarding BI, the FOF group scored significantly lower than the NFOF ($p \leq 0.001$). There was no interaction between HoF and FoF for any dependent variable.

Table 1. Baseline participant characteristics and mean (±SD) differences in older adults with (HOF) and without history of fall (NHOF) and with (FOF) and without fear of falling (NFOF). Statistical significant differences are identified with bold.

Characteristics	NHOF (n = 38)	HOF (n = 22)	NFOF (n = 41)	FOF (n = 19)	Between-Subject Comparison p Value (Observed Power)		
					HOF	FOF	HOF × FOF
Age (y)	66.34 ± 5.11	68.91 ± 7.51	66.68 ± 6.47	68.58 ± 5.37	0.228 (0.224)	0.421 (0.125)	0.691 (0.068)
Gender							
Men	17 (44.7%)	5 (22.7%)	18 (43.9%)	4 (21.1%)	0.104 [b]	0.149 [b]	-
Women	21 (55.3%)	17 (77.3%)	23 (56.1%)	15 (78.9%)			
Height (m)	1.63 ± 0.08	1.57 ± 0.07	1.62 ± 0.08	1.58 ± 0.07	0.061 (0.468)	0.151 (0.299)	0.347 (0.154)
Weight (kg)	67.92 ± 10.20	63.01 ± 9.45	65.92 ± 10.56	66.54 ± 9.40	0.114 (0.352)	0.557 (0.089)	0.557 (0.089)
Body Mass Index (kg/m^2)	25.68 ± 3.11	25.34 ± 2.59	25.03 ± 2.84	26.67 ± 2.83	0.496 (0.103)	**0.037 (0.558)**	0.899 (0.052)
Health Condition							
Yes	29 (76.3%)	17 (77.3%)	31 (75.6%)	15 (78.9%)	0.597 [a]	0.526 [a]	-
No	9 (23.7%)	5 (22.7%)	10 (24.4%)	4 (21.1%)			
Number of Health Conditions	1.61 ± 1.26	1.45 ± 1.10	1.39 ± 1.13	1.89 ± 1.29	0.268 (0.196)	0.173 (0.273)	0.158 (0.290)
Medication							
Yes	32 (84.2%)	21 (95.5%)	35 (85.4%)	18 (94.7%)	0.246 [a]	0.414 [a]	-
No	6 (15.8%)	1 (4.5%)	6 (14.6%)	1 (5.3%)			
Number of Medications	2.42 ± 2.06	4.14 ± 2.59	2.88 ± 2.42	3.42 ± 2.36	**0.018 (0.666)**	0.720 (0.065)	0.672 (0.070)
History of Fall							
Yes	0	100%	13 (31.7%)	9 (47.4%)	-	0.264 [a]	-
No	100%	0	28 (68.3%)	10 (52.6%)			
Number of Falls	0	1.50 ± 0.86	0.44 ± 0.74	0.79 ± 1.13			
Fear of Fall							
Yes	10 (26.3%)	12 (54.5%)	0	100%	0.104 [b]	-	-
No	28 (73.7%)	10 (45.5%)	100%	0			
Mini-Mental State Examination	29.16 ± 1.27	28.27 ± 1.42	28.95 ± 1.43	28.58 ± 1.26	**0.014 (0.701)**	0.437 (0.120)	0.355 (0.151)
IPAQ (MET min/week)	3279.78 ± 2857.65	3403.91 ± 3002.25	3426.68 ± 3047.40	3106.50 ± 2569.57	0.653 (0.073)	0.776 (0.059)	0.429 (0.123)
Barthel Index	19.92 ± 0.27	19.82 ± 0.40	20 ± 0.00	19.63 ± 0.50	0.365 (0.146)	**0.000 (0.996)**	0.365 (0.146)
Hand Grip Strength	29.57 ± 8.00	25.00 ± 9.00	29.09 ± 9.28	25.30 ± 6.35	0.067 (0.451)	0.167 (0.280)	0.634 (0.076)

[a] Pearson's chi-squared Test [b] Fisher's Exact Test.

3.1. Spatiotemporal Parameters

The task's spatiotemporal descriptive statistics are summarized in Table 2 and plotted in Figure 3. Older adults with FoF exhibited significantly longer task ($p = 0.009$), double-support ($p = 0.047$), and single-support ($p = 0.009$) times when compared to older adults without FoF. On the contrary, the FOF group showed a significantly reduced peak downward CoM velocity than the NFOF group ($p = 0.043$). There was no interaction between HoF and FoF for any dependent variable.

Table 2. Task's spatiotemporal parameters' group mean (±SD) differences in older adults with (HOF) and without history of fall (NHOF) and with (FOF) and without fear of falling (NFOF) when descending Steps 2 and 1, reaching level ground, and walking. Statistical significant differences are identified with bold.

Spatiotemporal Parameters	NHOF (n = 38)	HOF (n = 22)	NFOF (n = 41)	FOF (n = 19)	Between-Subject Comparison p Value (Observed Power)		
					HOF	FOF	HOF × FOF
Task Velocity (m/s)	0.87 ±0.15	0.81 ±0.28	0.88 ±0.22	0.79 ±0.16	0.488 (0.106)	0.257 (0.203)	0.417 (0.127)
Task Time (s)	1.13 ±0.18	1.18 ±0.25	1.09 ±0.18	1.26 ±0.22	0.689 (0.068)	**0.009** **(0.764)**	0.586 (0.084)
Double-Support Time (s)	0.28 ±0.06	0.28 ±0.09	0.26 ±0.06	0.30 ±0.09	0.705 (0.066)	**0.047** **(0.513)**	0.873 (0.053)
Single-Support Time (s)	0.70 ±0.11	0.71 ±0.16	0.68 ±0.11	0.77 ±0.14	0.710 (0.066)	**0.009** **(0.755)**	0.476 (0.109)
Peak downward CoM Velocity (m/s)	−0.54 ±0.09	−0.49 ±0.14	−0.54 ±0.11	−0.47 ±0.11	0.287 (0.185)	**0.043** **(0.530)**	0.668 (0.071)

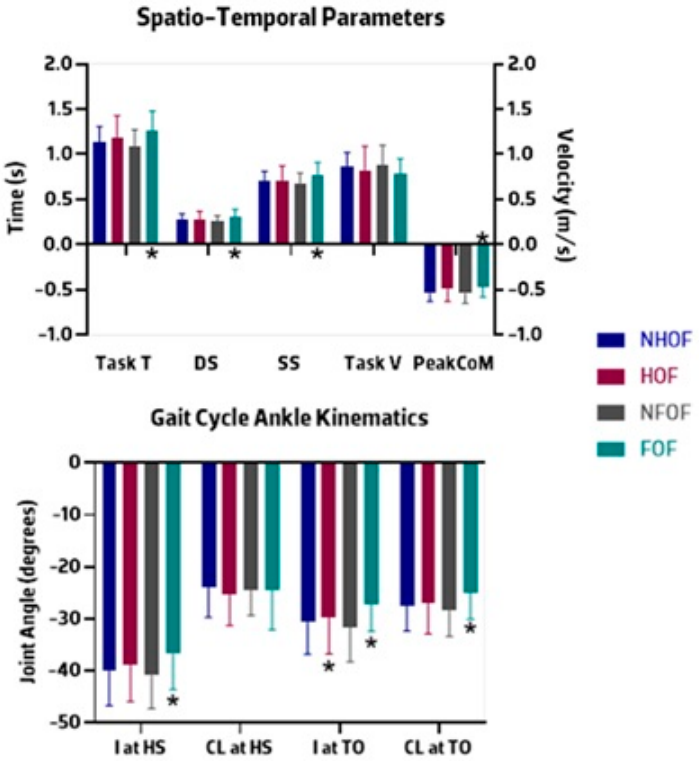


Figure 3. Graphic of mean and standard deviation of time to complete (T), velocity (V), double-support (DS) and single-support (SS) time, peak downward CoM velocity (PeakCoM), and joint angle of the ankle at heel-strike (HS) and toe-off (TO) in the ipsi (I) and contralateral (CL) limb. * Statistically significant difference.

3.2. Stair- and Gait-Cycle Kinematic Parameters

The kinematic descriptive statistics of the stair and gait cycles are summarized in Table 3.

Regarding lower-limb kinematics, in the stair cycle, there is a tendency towards existing statistically significant differences between older adults with and without FoF in the ipsi FC and the contralateral hip angle at the moment of FP. Both were reduced in the FOF group when compared to the NFOF group.

Table 3. Kinematic parameters and group mean (±SD) differences in older adults with (HOF) and without history of fall (NHOF) and with (FOF) and without fear of falling (NFOF) when descending Steps 2 and 1, reaching level ground, and walking. Statistical significant differences are identified with bold.

Stair-Cycle Kinematics	Limb	NHO (n = 38)	HOF (n = 22)	NFOF (n = 41)	FOF (n = 19)	Between-Subject Comparison p Value (Observed Power)		
						HOF	FOF	HOF × FOF
Foot Placement (m)	Ipsi	0.20 ± 0.01	0.20 ± 0.02	0.20 ± 0.01	0.20 ± 0.01	0.855 (0.054)	0.882 (0.052)	0.622 (0.078)
	Contra	0.19 ± 0.01	0.19 ± 0.02	0.19 ± 0.01	0.20 ± 0.02	0.594 (0.082)	0.349 (0.153)	0.644 (0.074)
Foot Clearance (m)	Ipsi	0.19 ± 0.04	0.20 ± 0.03	0.20 ± 0.04	0.19 ± 0.04	0.747 (0.062)	0.066 (0.453)	0.074 (0.432)
	Contra	0.06 ± 0.01	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.01	0.282 (0.187)	0.884 (0.052)	0.385 (0.138)
Hip Angle (degrees)								
At Foot Placement	Ipsi	29.38 ± 10.99	29.41 ± 10.73	29.28 ± 11.49	29.60 ± 9.44	0.877 (0.053)	0.984 (0.050)	0.623 (0.077)
	Contra	28.47 ± 10.56	31.66 ± 10.60	31.07 ± 10.18	26.56 ± 11.10	0.272 (0.194)	0.071 (0.441)	0.485 (0.106)
At Foot Clearance	Ipsi	32.67 ± 10.84	32.20 ± 10.83	31.72 ± 10.92	34.17 ± 10.46	0.687 (0.068)	0.451 (0.116)	0.665 (0.071)
	Contra	30.30 ± 10.98	32.80 ± 9.99	32.24 ± 10.22	29.01 ± 11.37	0.362 (0.147)	0.211 (0.237)	0.785 (0.058)
Knee Angle (degrees)								
At Foot Placement	Ipsi	19.14 ± 7.01	19.71 ± 6.99	19.76 ± 7.44	18.46 ± 5.83	0.901 (0.052)	0.398 (0.133)	0.393 (0.135)
	Contra	19.73 ± 6.48	20.40 ± 7.00	20.37 ± 7.11	19.11 ± 5.54	0.970 (0.050)	0.337 (0.158)	0.167 (0.280)
At Foot Clearance	Ipsi	15.30 ± 7.24	14.41 ± 6.87	14.81 ± 6.90	15.33 ± 7.58	0.483 (0.107)	0.836 (0.055)	0.466 (0.111)
	Contra	20.14 ± 7.06	19.82 ± 5.99	20.19 ± 6.94	19.67 ± 6.09	0.658 (0.072)	0.675 (0.070)	0.299 (0.178)
Ankle Angle (degrees)								
At Foot Placement	Ipsi	−40.44 ± 8.02	−39.42 ± 6.58	−39.97 ± 8.10	−40.27 ± 6.12	0.625 (0.077)	0.829 (0.055)	0.983 (0.050)
	Contra	−38.50 ± 6.54	−38.72 ± 4.69	−38.44 ± 5.86	−38.89 ± 6.09	0.974 (0.050)	0.826 (0.055)	0.850 (0.054)
At Foot Clearance	Ipsi	−46.55 ± 5.62	−44.23 ± 6.30	−45.88 ± 6.13	−45.31 ± 5.60	0.235 (0.218)	0.960 (0.050)	0.629 (0.076)
	Contra	−41.26 ± 5.22	−42.35 ± 4.17	−41.18 ± 4.93	−42.71 ± 4.64	0.463 (0.112)	0.299 (0.178)	0.750 (0.061)
Gait-Cycle Kinematics								
Hip Angle (degrees)								
At Heel-Strike	Ipsi	27.68 ± 10.43	26.36 ± 10.40	26.84 ± 10.57	27.97 ± 10.09	0.522 (0.007)	0.705 (0.003)	0.652 (0.004)
	Contra	43.02 ± 10.96	42.66 ± 10.51	42.56 ± 10.78	43.58 ± 10.81	0.845 (0.001)	0.739 (0.002)	0.924 (0.000)
At Toe-Off	Ipsi	8.55 ± 10.22	9.18 ± 11.62	9.11 ± 9.90	8.06 ± 12.41	0.732 (0.002)	0.738 (0.002)	0.782 (0.001)
	Contra	8.95 ± 9.33	9.10 ± 10.36	9.25 ± 9.83	8.47 ± 9.45	0.837 (0.001)	0.818 (0.001)	0.715 (0.002)
Knee Angle (degrees)								
At Heel-Strike	Ipsi	16.45 ± 4.62	15.67 ± 5.97	15.81 ± 5.21	16.92 ± 4.98	0.563 (0.006)	0.379 (0.014)	0.815 (0.001)
	Contra	14.28 ± 6.38	16.27 ± 7.47	14.21 ± 6.98	16.72 ± 6.27	0.483 (0.009)	0.285 (0.020)	0.621 (0.004)
At Toe-Off	Ipsi	47.24 ± 6.08	46.81 ± 10.47	46.76 ± 7.71	47.78 ± 8.43	0.991 (0.000)	0.529 (0.007)	0.380 (0.014)
	Contra	48.82 ± 7.33	47.88 ± 8.80	48.64 ± 8.09	48.12 ± 7.46	0.794 (0.001)	0.921 (0.000)	0.768 (0.003)
Ankle Angle (degrees)								
At Heel-Strike	Ipsi	−39.98 ± 6.66	−38.80 ± 7.09	−40.87 ± 6.37	−36.68 ± 6.91	0.870 (0.000)	**0.041 (0.072)**	0.604 (0.005)
	Contra	−23.84 ± 5.85	−25.32 ± 5.97	−24.35 ± 4.97	−24.46 ± 7.66	0.224 (0.026)	0.910 (0.000)	0.260 (0.023)
At Toe-Off	Ipsi	−30.61 ± 6.17	−29.68 ± 7.04	−31.66 ± 6.59	−27.26 ± 5.11	**0.015 (0.000)**	**0.026 (0.085)**	0.280 (0.021)
	Contra	−27.50 ± 4.83	−26.89 ± 5.96	−28.38 ± 4.96	−24.90 ± 5.13	0.980 (0.000)	**0.022 (0.091)**	0.868 (0.000)

In the gait cycle, older adults with HoF exhibited significantly reduced ipsi ankle angles at TO than older adults without HoF (p = 0.015). The FOF group presented a significantly reduced ipsi ankle angle at HS (p = 0.041) and TO (p = 0.026) when compared to the NFOF group. Older adults with FoF exhibited significantly reduced contralateral ankle angles at TO when compared to older adults without FoF (p = 0.022). There was no interaction between HoF and FoF for any dependent variable.

4. Discussion

This study aimed to evaluate the influence of HoF and FoF on spatiotemporal parameters, including task velocity and time; single- and double-support times; peak downward CoM velocity; and kinematic parameters, such as, hip, knee, and ankle angles, as well as FC and FP with respect to older adults during stair descents and gait transitions.

At baseline, the participants exhibited similar characteristics regarding age, gender, health conditions, and prescribed medication, as well as physical activity conditions and functional mobility. However, regarding BMI, cognitive conditions, and ADL performance, the participants exhibited different characteristics. The probability of falling increases with age [2,5], and the previous literature has reported that one third of the community-dwelling

population aged 60 and over experiences at least one fall per year [6,9]. The participants who exhibited HoF in our study corroborate these findings. Gender differences in stair negotiation were previously reported, showing that women present a higher risk of falling and a higher prevalence of falls on stairs [10]. The female ratio in the participants with HoF in our study supports these findings. Excessive body weight has been reported to contribute to a reduction in the ability to perform ADLs, such as stair negotiation, and therefore, it has been associated with falls in older adults [43]. Accordingly, the current study shows that older adults with FoF are more likely to fall due to the significantly higher BMI when compared to older adults without FoF. Polypharmacy has been reported to be one of the major factors in the risk of falling [2,7] to the extent that there is a specific category of medications denominated as "Fall-Risk-Increasing Drugs" (FRIDs). FRIDs can influence the risk of falling by adversely affecting the cardiovascular or central nervous systems [44]. The participants with HoF in our study corroborate these findings, presenting a combination of prescribed medications that can be considered FRIDs.

To the best of our knowledge, an HGS cut-off that predicts the risk of falling has not been determined; however, the loss of muscle mass and strength has been established as an important risk factor for falls [45]. Comparing our results to the data provided by Mendes et al., who established that the average HGS for older Portuguese adults was 30.3 Kg among men and 18 Kg among women [46], it is possible to assume that our participants presented reasonable HGS.

Regarding spatiotemporal parameters, in line with previous reports, our results showed that older adults with HoF and FoF adopt conservative strategies, descending stairs slower and more cautiously to avoid falling [8]. It has been stated that the gait velocity is the most consistent change associated with age, diminishing 1% per year from the age of 60 onwards, being responsible for a 7% increase in falls [17]. Accordingly, Jacobs et al. also reported that older adults descend stairs more slowly [20]. Our results support these findings, with both HoF and FoF groups presenting reduced task velocity and time. This may indicate that older adults use a more conservative and cautious strategy to maintain dynamic balance to prevent falls [37]. The previous literature has found that at level gait and during stair descent, older adults show increased double-support time [2,20], which may be the result of a weaker swing limb advancement because of muscle power loss, as well as decreased trunk and lower-limb stability [17]. This also indicates that older adults may require more time after the limb advancement to maintain weight-bearing stability [37]. Accordingly, Kwon et al. found that at level gait, older adults with HoF exhibit increased double-support time [37]; however, in our study, only older adults with FoF presented longer double-support time when compared to older adults without FoF.

The results of the current study also demonstrate that participants with HoF and FoF present decreased peak downward CoM velocity. This finding is in accordance with Bosse et al., who examined dynamic stability control during stair descents and found that, when compared to younger adults, older adults are at greater risk of falling due to their body's lowered safety control ability with respect to the CoM while stepping down [14]. Our results are also in accordance with Buckley et al., who investigated CoM vertical velocity profiles, reporting that the peak downward CoM velocity was significantly reduced by age [15]. The previous literature has also found that older adults may adopt a stair descent strategy where the downward CoM velocity is limited to decrease fall risks [16], with the reduced peak occurring approximately at the instant of contact with the step below [15].

Greater FP [16] and reduced FC have been associated with a higher risk of falling during stair negotiation [18]. Kunzler et al. reported that falls during stair descent are more likely to occur near the bottom of the staircase, when older adults tread on the last step [18], so it was important to analyze FC and FP during this transition. Our results showed that

older adults with and without HoF and FoF present similar strategies when negotiating FP and FC, leaving and reaching the steps within a reasonable distance in a safe manner. Francksen et al. analyzed the influence of age and step height inconsistency on FP and FC, reporting significantly greater FP in older adults when comparing the same steps [16]. Their study states that this finding is related to the more cautious stepping strategies adopted by older adults, which increase the chances of overstepping and the foot slipping forwards over an edge, causing a backward loss of balance and possibly a fall [16]. However, their study could not establish an association between age and changes in FP and FC on the last step, similarly to our results, which were not able to associate HoF and FoF with lower FC and greater FP. This could be related to the chosen moment of FP and FC data extraction in both protocols, given that when the limb leaves the last step and initiates gait transition, the vertical and horizontal distance of the foot to the step is considerably higher because there is no step below to limit its trajectory [15].

Within the stair cycle, it was important to analyze the lower-limb joint angles at the instant of the aforementioned events because their reduction in older adults has been reported to result in a higher risk of falling [2]. Our results do not demonstrate the influence of HoF and FoF on lower-limb kinematics, given that the participants exhibit similar position angles. It is also not possible to compare our results to other studies, given that, to the best of our knowledge, no authors have focused on the lower-limb joint position at specific FC and FP events.

In the gait cycle, we analyzed lower-limb joint angles at HS and TO after stair descent. These events are the most significant given that the previous literature has found that older adults present altered lower-limb joint motion [20], resulting in limited capacities in limb advancement during gait [17]. Our results showed that participants exhibited similar angles in the hip and knee joints; however, regarding the ankle, older adults with HoF and FoF adopted different angle positions. This resulted in different ankle strategies, specifically diminished ankle dorsiflexion at HS and diminished plantarflexion at TO.

Reduced hip and ankle angles are the most consistent finding among older adults [38]; however, only significant differences were present at the ankle in participants with HoF and FoF. Our study found that older adults with FoF adopted significantly reduced ipsi ankle angles at HS, in accordance with Arnold et al., who compared older and younger adults, reporting reduced ankle dorsiflexion at HS in older adults [47]. We can also report that older adults with HoF and FoF adopted significantly reduced ipsi ankle angles at TO, with the latter also exhibiting reduced contralateral ankle angles at TO, in accordance with Arnold et al., who reported reduced plantarflexion at TO in older adults [47].

Several authors have focused on studying older adults during stair descent [8,11,12,14–16,18,19,21,30,32,48]; however, to the best of our knowledge, there is no previous literature that has evaluated the association between HoF and FoF. There are also a few authors who have analyzed both stair descent and gait transition [8,11,14,19]. Most of the existing literature only analyzes the influence of age in a sample of older and younger adults, ensuring different characteristics at baseline [12,14–16,19,32]. Some authors studied different moments and strategies in older adults during stair descent and their step negotiation with irregular staircase characteristics [16,30,32,35]. Thus, this study holds its pertinence in evaluating not only the association between HoF and FoF in older adults during stair descent but also during the gait transition. It also differentiates itself from the previous literature by including not only a spatiotemporal analysis but also a kinematic one.

One limitation of the current study was related to the simulation of external conditions in the laboratory, with the assumption that it would be representative of daily life conditions. Although participants wore usual fitting clothes and shoes to ensure the data collection resembled daily life conditions, controlled laboratory conditions do not include

environmental, individual, and/or other factors such as dual-tasking while descending stairs [48]. Also, the analysis of the medication type was not the object of this study; therefore, future studies should address this relationship, particularly given that older adults take more medication than their counterparts and are highly influenced by their medication intake [7].

Future research may also incorporate participants with a history of recurrent falls to analyze the association with higher incapacity levels, causing more changes in spatiotemporal and kinematic parameters during stair descent and gait transition. Future research should also consider differentiating the degrees of fear of falling to analyze if higher levels lead to more changes in the aforementioned parameters. It is also important to identify other changes in the spatiotemporal and kinematic parameters of older adults during stair descent and gait transition that are associated with a higher risk of fall to implement prevention strategies and, ultimately, reduce fall occurrence.

5. Conclusions

Older adults adopt more conservative strategies during stair descent and gait transition to maintain dynamic stability and, consequently, avoid falling. Particularly, older adults with HoF and FoF are at a higher risk of falling, displaying biomechanical changes during stair descents and gait transitions. The findings from this study provide valuable insights into the biomechanical contributors to stair descent and inform the development of targeted interventions to enhance functional independence and reduce the incidence of falls in older adults.

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Abbreviations

The following abbreviations are used in this manuscript:

HoF	History of fall;
FoF	Fear of falling;
CoM	Center of mass;
FP	Foot placement;
FC	Foot clearance;

STROBE	Strengthening the Reporting of Observational Studies in Epidemiology;
ADLs	Activities of daily living;
ACQ	Assessment and Characterization Questionnaire;
IPAQ	International Physical Activity Questionnaire;
MMSE	Portuguese Version of Mini-Mental State Examination;
BI	Barthel Index;
HGS	Hand grip strength;
HS	Heel-strike;
TO	Toe-off;
MANOVA	Multivariate analysis of variance;
BMI	Body mass index;
FRID's	Fall-risk-increasing drugs.

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