BJMB
Brazilian Journal of Motor Behavior

Research Article

The presence of a second obstacle in the obstacle avoidance task changes the locomotor pattern of older adults at lower and higher risk of falling

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https://doi.org/10.20338/bjmb.v19i1.446

HIGHLIGHTS
- Older adults change their locomotor pattern when avoiding a double obstacle.
- The changes in locomotor pattern are more evident in group at higher risk of falling.
- The characteristic of the obstacles did not influence the locomotor pattern.

ABBREVIATIONS

Dvideow	Digital Video for Biomechanics
FES-I	Falls Efficacy Scale-International
LL	Leading limb
MANOVA	Multivariate Analysis of Variance
ME	Maximum foot elevation
MMSE	Mini Mental State Examination
OHHD	Obstacle-heel horizontal distance
TC	Toe clearance
TL	Trailing limb
TOHC	Toe-Obstacle Horizontal Distance

PUBLICATION DATA
Received 01 12 2024
Accepted 09 05 2025
Published 14 05 2025

BACKGROUND: The literature does not fully explain how the sequenced addition of a second obstacle during walking influences the avoidance task in older adults at lower and higher risk of falling.
AIM: The objective was investigating the locomotor performance of older adults at higher and lower risk of falling during sequenced obstacles avoidance with different physical characteristics.
METHODS: 10 older adults at higher risk of falling and 11 older adults at lower risk of falling participated in this study and performed the following tasks: 1) single obstacle avoidance and 2) double obstacle avoidance. For both conditions, the physical characteristics of the obstacles were manipulated: solid (a single piece of foam) and fragile (foam blocks stacked) obstacles were used.
RESULTS: Older adults at higher risk of falling, when compared to older adults at lower risk of falling, showed longer right stride duration (1.261s | 1.030s, respectively; p≤0.001), longer left stride duration (1.409s | 1.073s, p≤0.001), and lower left stride velocity (0.866 cm/s | 1.130 cm/s, p=0.013). They also showed a longer avoidance time (0.772s | 0.635s, p=0.009), and lower toe clearance (0.327 cm | 0.380 cm, p=0.037) and obstacle-heel horizontal distance (0.651 cm | 0.798 cm, p=0.025).
INTERPRETATION: Older adults at higher risk of falling showed changes in locomotor pattern when avoidance obstacles when they were subjected to a more challenging task. These results enable the development of targeted approaches for the rehabilitation of older adults at higher risk of falling and for the prevention of falls.

KEYWORDS: Older adult | Risk of falling | Obstacle avoidance | Double obstacle

INTRODUCTION

Falling is the unintentional displacement of the body to a lower level than the initial position [1]. It is therefore considered a public health problem and occurs, most of the time, in older adults [2], especially when avoiding an obstacle [3]. Falls in the older population lead to increased morbidity and mortality, being the main cause of death in elderly people over 85 years old [4]. In addition, they cause an increase in costs and in the use of specialized health services [5]. Consequently, it affects the performance of daily activities due to bone fractures, as well as the fear of falling, which directly influences quality of life [6], functionality [4] and causes changes in locomotor patterns [2].

This means that older adults adopt conservative strategies during single obstacle avoidance [7], such as lower velocity and stride length and longer stride duration [7], as well as longer contact time with the ground [8]. Older adults also get closer to obstacles during (less toe clearance) [9] and after (less horizontal distance) [10] obstacle avoidance, which increases the risk of tripping [9] and the chances of falling [11]. These gait adjustments occur due to the deterioration of sensory systems (visual, proprioceptive and vestibular) [12,13] and the reduction in muscle strength [14] due to the aging process. The deterioration of vision, proprioceptive and visuospatial cognition leads to the adoption of conservative strategies in older adults to allow greater control of the upper trunk [12,13]. In addition, muscle weakness has a negative impact on mobility, significantly decreasing propulsion power [14]. These findings demonstrate that, before avoiding the obstacle, the older adults perform anticipatory postural adjustments in an attempt to make the task safer [7].

At the same time, sequential obstacle avoidance makes tasks more complex, as the demands for planning and task control during obstacle avoidance are greater, as well as a planned task being more challenging for stability control [15]. A second obstacle can influence the locomotor pattern [15], especially in older adults who are at risk of falling, such as shorter step length before avoidance obstacles, greater toe clearance and shorter horizontal distance from the obstacle after avoiding obstacles [16]. This is because this sequenced task requires greater cognitive demand and attention from older adults, whose available attentional resources are compromised due to the aging process [17]. Cognitive decline related to executive function influences the planning and regulation of gait to avoid obstacles [18]. Older adults with lower executive function need more time to plan and execute adjustments during obstacle negotiation, contributing to increased fall rates [19]. In addition, the strategy and gaze direction on adaptations in environments with multiple obstacles to perform adjustments of sequential steps in an integrative manner [20]. However, the presence of the second obstacle reduces the accuracy of gaze and locomotor performance, which leads to changes in the planning and execution of multiple obstacles avoidance, which makes the task even more difficult and increases the risk of falls [21,22].

Furthermore, these changes are even more evident in older adults with a fear of falling [7]. Fear of falling is a psychological factor related to poorer locomotor pattern [23], as it promotes lower velocity and step length before obstacle avoidance, lower toe clearance of the supporting limb during avoidance, and shorter horizontal distance of the foot in relation to the obstacle of the approaching limb after obstacle avoidance [7]. Consequently, they have a worse locomotor pattern, which contributes to a decline in functionality [23], as it restricts daily activities and reduces the level of physical activity of older adults, leading to a lower quality of life [24] and a higher risk of tripping and falling [7].

Thus, real-life situations and environments for older adults are complex, and obstacles and surfaces are not always shaped regularly [22]. Chapman and Hollands (2007) [23] investigated locomotor behavior and adaptive mechanisms during the avoidance of double obstacles with different heights in older adults, without taking into account different physical characteristics and the risk of falls among the older adults. Furthermore, Magalhães and collaborators (2023) [7] investigated the association between fear of falling and the locomotor pattern during the avoidance of a single obstacle with different physical characteristics, namely solid and fragile. Silva et al. (2024) [10] investigated the influence of physical characteristics during the avoidance of a single obstacle with different characteristics (solid and fragile) in older adults at lower and higher risk of falling. It was found that older adults at higher risk, when compared to older adults at lower risk of falling, had lower velocity and step length before avoidance, as well as greater width and duration of the same. Furthermore, they had lower toe clearance during avoidance and shorter horizontal foot-obstacle distances after the task. Furthermore, during daily activities, older adults are often exposed to different obstacles during walking, mainly in a sequential manner. However, the literature does not fully explain how the addition of a second obstacle sequentially during walking modulates the avoidance task in older adults at lower and higher risk of falling.

For this study, the level of difficulty of tasks was manipulated by changing the characteristic of the obstacle (solid or fragile) [4,14] and the number of obstacles (single obstacle or double obstacle). A single obstacle condition was considered when the participant only avoided one obstacle, and a double obstacle condition was considered when the participant avoided two obstacles in sequence (Figure 1A and 1B). The locomotor pattern, that is, the way they behave during walking, was investigated by comparing how the older adults avoid the first obstacle in the double condition with how they avoid the single obstacle, for the obstacles with the two different physical characteristics.

This study aimed to investigate the locomotor pattern of older adults at lower and higher risk of falling as they avoided obstacles with different physical characteristics. It is expected that 1) the locomotor performance of the older adults will change in the avoidance task when a second obstacle is added, such as lower velocity and length and longer duration of the strides and step over, lower toe clearance and horizontal distances; 2) older adults at higher risk of falling will show worse locomotor performance than older adults at lower risk of falling, especially when avoidance a second obstacle, such as lower velocity and length and longer duration of the strides and step over and greater proximity to obstacles and 3) the locomotor performance of the older adults will be influenced by the fragile characteristic of the obstacles.

METHODS

Participants

This is a quasi-experimental study. The study was approved by the local Research Ethics Committee (CAEE: 88258218.8.0000.5542) and participants signed an informed consent form to participate in the study.

In total, 21 older adults aged from 60 to 85 years took part. They were divided into two groups: 1) Older adults at lower risk of falling (n=11) and 2) Older adults at higher risk of falling (n=10), considered, according to the same classification used by Silva et al (2024) [10], to be those with fear of falling, worse balance control [25] and reporting a fall at least once in the last year [26]. The participants of this study were the same volunteers recruited in the study by Magalhães et al. (2023) [7], Silva et al. (2024) [10] and Silva et al. (2023) [24].

The inclusion criteria were: preserved cognitive function and independent walking without using assistive devices. The exclusion criteria were: any neurological, vestibular and musculoskeletal conditions that prevented older adults from performing the tasks.

Based on the sample calculation, a minimum sample size of 10 participants in each group was required to achieve 90% power and an error of 0.05 in Multivariate Analysis of Variance (MANOVA). The sample size was calculated using G*Power 3.1.9.2. (Heinrich-Heine-UniversitatDusseldorf). We included step velocity as a dependent variable for power analysis, which indicated a strong relationship. This calculation was based on the previous studies of Magalhães et al. (2023) [7] and Silva et al. (2024) [10].

Procedure

Initially, an anamnesis was taken to check the participants' general health status and the inclusion criteria. The Mini-Mental State Examination (MMSE) [27] was used to assess the cognitive function of the participants. The Falls Questionnaire was used to investigate the number and characteristics of falls in the past year, and the Falls Efficacy Scale-International (FES-I) was used to assess the fear of falling during daily activities [28]. On this scale, older people classify 16 daily activities as "not worried" (1 point), "somewhat worried" (2 points), "moderately worried" (3 points) or "very worried" (4 points) regarding their fear of falling. The higher the score, the greater the fear of falling. Scores greater than or equal to 23 points suggest fear of falling and sporadic occurrence of falls. A score greater than or equal to 31 points suggests recurrent falls [28]. The MiniBestest [29] was used to assess static and dynamic balance. This test analyses, using 14 tasks, balance in static and dynamic conditions with a maximum score of 32 points. Thus, the higher the participant's score, the better their balance [29]. Lastly, the Baecke questionnaire modified for older adults [30] was applied to assess the participants' level of physical activity.

Participants were asked to walk on a 9-meter walkway at their usual and self-selected velocity throughout the task and perform the following tasks: 1) single obstacle avoidance and 2) double obstacle avoidance. Participants were positioned four steps away from the starting point of the task, and the obstacle had to be comfortably avoided with the participant's dominant limb. Taking into account that anticipatory postural and locomotor adjustments occur two steps before the avoidance obstacle [7,31,32], for the double obstacle avoidance task, participants were positioned at a distance equivalent to two steps (adjusted for their individual conditions) (Figures 1A and 1B).

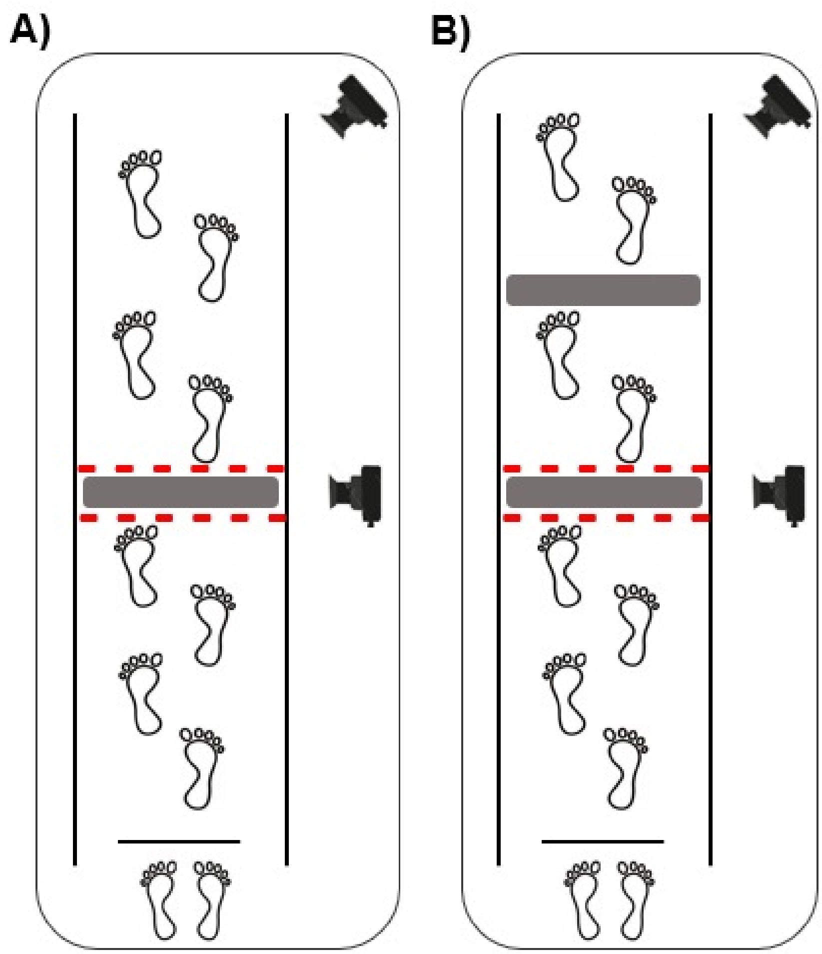

Figure 1. Top view of the setup for the single(A) and the double obstacle avoidance task (B). Legend: To analyze the movement, two cameras were positioned parallel and diagonally across the walkway, capturing the entire route, markers and obstacles. Red indicates the first obstacle of the double condition and single condition that were used to analyze the locomotor pattern.

Solid and fragile obstacles were used for both tasks, both made of foam, as a safety measure in case the participants fell over.

The solid obstacles were made of a single piece of foam (60 cm length x 7 cm wide x 15 cm high) and the fragile obstacles were stacked in foam blocks (15 cm length x 7 cm wide x 7.5 cm high) in two rows and four columns, like blocks. These blocks were freely positioned to provide a visual stimulus of instability and fragility of the task, in an attempt to make the task more complex, as in the work carried out by Magalhães et al. (2023) [7] and Silva et al. (2024) [10]. If the participants tripped over them, the blocks were repositioned in the same position. Two passive markers were placed at the bottom and top of the obstacles, which allowed the calculation of the variables related to avoidance (Figures 2A and 2B).

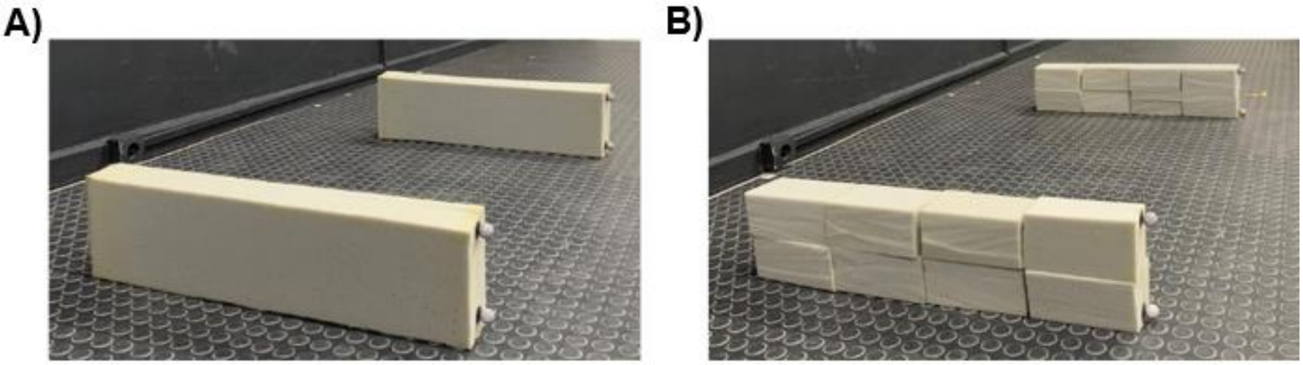

Figure 2. Solid obstacle (A) and fragile obstacle (B).

To perform the tasks, the participants wore black non-slip socks. Over these socks, 1.5 cm diameter reflective passive markers were placed on the fifth metatarsal and lateral surface of the calcaneus of the right lower limb and the first metatarsal and medial surface of the calcaneus of the left lower limb (Figure 2). For each task, three trials were made, totaling 12 trials. For each participant, randomization was performed individually between the tasks using the electronic randomizer available at https://sorteador.com.br/. This program allows random programming, through previously created codes related to the conditions.

Equipment

Two digital cameras (GoPro model Hero 7 Black) positioned to the side of the walkway and diagonally across it were used in order to view all the markers on the participants' feet. The cameras were triggered synchronously with recordings made at 60 Hz. For greater reflection and visualization of the markers, three LED spotlights were positioned on the ground close to the walkway.

The videogrammetric analysis of the images was carried out using the Dvideow (Digital Video for Biomechanics for Windows 32) system for the procedures of camera calibration, synchronization of recordings, frame marking and coordinate reconstruction. The image acquisition time included two contacts, before and after the obstacle was avoided. The space was calibrated using ten points marked on the ground (x and y axes) and seven points marked on a topographic stick (z axis), forming a large cube that provided Dvideow with accurate measurements of the space through which the participant performed the task. This made it possible to reconstruct the trajectories of the markers in three dimensions. The data were analyzed using routines written in MATLAB (Version 7.0 - Mathworks, Inc.).

Data analysis

The variables used to analyze the locomotor pattern were those related to the first obstacle of the double obstacle task and to the only obstacle of the single obstacle task. The variables related to the avoidance movement for the trailing limb (TL) and leading limb (LL) were: toe clearance (Figure 3A), toe-obstacle horizontal distance and obstacle-heel horizontal distance (Figure 3B), maximum elevation (Figure 3C). The following were also calculated: step velocity; length, width and duration of the step during obstacle avoidance (step over); and length, velocity, width and duration of the left and right stride.

Statistical Analysis

To verify the normality and homogeneity of the data, the Shapiro-Wilk test and the Levene test were carried out, respectively. T-tests were carried out to compare the age, anthropometric measurements (height and body mass) and clinical characteristics (Mini-Mental, MiniBESTest, Baecke and FES-I) of the older adults.

To analyze the gait tasks, the average value of the three trials to overtake single and double solid and fragile obstacles was used. Seven two-way MANOVAs (obstacles [first obstacle, simple], conditions ([solid obstacle, fragile obstacle]) with repeated measures for the last factor were performed for the following sets of dependent variables: (1) toe-obstacle horizontal distance and obstacle-heel horizontal distance for the leading limb; (2) toe-obstacle horizontal distance and obstacle-heel horizontal distance for the trailing limb; (3) toe clearance and maximum toe elevation of the lead limb; (4) toe clearance and maximum toe elevation for the trailing limb; (5) velocity, length, width and duration of the left stride; (6) velocity, length, width and duration of the right stride; and (7) velocity, length, width and duration of the step over. When the MANOVAs showed a main effect and an interaction, only the interaction effect was described. Post-hoc tests with the Bonferroni correction were carried out for the significant interactions. The significance level adopted in all analyses was p≤0.05.

Figure 3. Identification of the avoidance variables. Legend: Toe clearance (TC) (A), Toe-Obstacle Horizontal Distance (TOHD) and Obstacle-heel horizontal distance (OHHD) (B) and Maximum foot elevation (ME) (C) for the trailing limb (TL) and leading limb (LL).

RESULTS

Sample characterization

Of the 21 older adults who participated in the study, 18 were female and three were male. Of these, ten were classified as older adults at higher risk of falling and 11 were classified as older adults at lower risk of falling. The T-test revealed an effect for the MiniBESTest and the number of falls. The older adults at higher risk of falling showed worse balance performance (lower score on the MINI-BESTest) than the older adults at lower risk of falling, as well as a higher number of reported falls and a greater fear of falling (Table 1). This study was a secondary analysis of data collected in previous studies [7,10,24].

Table 1. Mean and standard deviation for the clinical characteristics of higher risk and lower risk falling.

	Group		
Variables	**Higher risk (n=10)**	**Lower risk (n=11)**	**t Test**
Age (year)	69.4 (±6.06)	69.5 (±4.84)	t_{1-17} = -0.02, p=0.98
Height (m)	161.4 (±5.17)	160.9 (±7.72)	t_{1-17} = 0.18, p=0.86
Body Mass (kg)	71.12 (±11.32)	66.25 (±9.63)	t_{1-17} = 1.0, p=0.32
Mini-Mental (points)	27.33 (±1.80)	26.1 (±2.28)	t_{1-17} = 1.3, p=0.21
Baecke Questionnaire (points)	6.09 (±6.66)	4.582 (±3.95)	t_{1-17} = 0.6, p=0.55
MiniBESTest (points)	17.67 (±3.50)	25.7 (±3.09)	t_{1-17} = -5.3, p≤0.01*
Falls Efficacy Scale (points)	31.67 (±6.56	19.9 (±3.38)	t_{1-17} = 4.5, p≤0.001*
Number of falls (n)	0.78 (±0.83)	0 (0)	t_{1-17} = 2.9, p≤0.01*

Legend: n (number); m (meters); kg (kilogram). *Difference between older adults at higher risk and lower risk of falling (p≤0.05).

Avoidance phase

Table 2 shows the MANOVA values for the avoidance phase variables.

Right stride

The post hoc tests revealed that the older adults at higher risk of falling had a longer right stride duration when compared to the older adults at lower risk of falling (1.261s | 1.030s, respectively; p=0.001) (Figure 4A). The same result was found for the double obstacle task (1.295s | 0.947s, respectively; p≤0.001) (Figure 4B).

Table 2. F and p values for the main effect and interaction between the factors (group, condition, obstacle and group*obstacle) of the MANOVAS for variables related to the toe-heel horizontal distance, toe clearance and maximum toe elevation to trail limb (TL) and lead limb (LL), velocity, length, width and duration for the left and rigth stride and step over.

Variables	Group	Condition	Obstacle	Group*Obstacle
MANOVA	Wilk's Lambda=0.818	Wilk's Lambda=0.919	Wilk's Lambda=0.975	Wilk's Lambda=0.830
Follow-up univariate	$F_{2,18}$=2.000, p=0.164, η^2p=0.182	$F_{2,18}$=0.792, p=0.468, η^2p =0.081	$F_{2,18}$=0.227, p=0.799, η^2p=0.025	$F_{2,18}$=1.846, p=0.187, η^2p=0.170
Toe-obstacle horizontal distance – LL	$F_{1,19}$=1.182, p=0.291, η^2p=0.059	$F_{1,19}$=1.645, p=0.215, η^2p=0.080	$F_{1,19}$=0.306, p=0.586, η^2p=0.016	$F_{1,19}$=1.885, p=0.186, η^2p=0.090
Obstacle- heel horizontal distance - LL	$F_{1,19}$=3.898, p=0.063, η^2p=0.170	$F_{1,19}$=0.416, p=0.526, η^2p=0.021	$F_{1,19}$=0.000, p=0.987, η^2p=0.000	$F_{1,19}$=0.129, p=0.724, η^2p=0.129
MANOVA	Wilks' Lambda=0.782	Wilks' Lambda=0.787	Wilk's Lambda=0.780	Wilks' Lambda=0.397
Follow-up univariate	$F_{2,18}$=2.503, p=0.110, η^2p=0.218	$F_{2,18}$=2.430, p=0.116, η^2p=0.213	$F_{2,18}$=2.533, p=0.107, η^2p=0.220	$F_{2,18}$=13.690, p=0.000*, η^2p=0.603
Toe-obstacle horizontal distance – TL	$F_{1,19}$=3.116, p=0.094, η^2p=0.141	$F_{1,19}$=5.127, p=0.035*, η^2p=0.213	$F_{1,19}$=4.065, p=0.058, η^2p=0.176	$F_{1,19}$=3.598, p=0.073, η^2p=0.159
Obstacle- heel horizontal distance - TL	$F_{1,19}$= 3.494, p=0.077, η^2p=0.155	$F_{1,19}$=0.535, p=0.473, η^2p=0.027	$F_{1,19}$=0.405, p=0.532, η^2p=0.021	$F_{1,19}$=4.796, p=0.041*, η^2p=0.202
MANOVA	Wilks' Lambda=0.803	Wilks' Lambda=0.923	Wilks' Lambda=0.896	Wilks' Lambda=0.920
Follow-up univariate	$F_{2,18}$=2.215, p=0.138, η^2p=0.197	$F_{2,18}$=0.747, p=0.488, η^2p=0.077	$F_{2,18}$=1.041, p=0.373, η^2p=0.104	$F_{2,18}$=0.779, p=0.474, η^2p=0.080
Toe clearance – LL	$F_{1,19}$=3.764, p=0.067, η^2p=0.165	$F_{1,19}$=1.073, p=0.313, η^2p=0.053	$F_{1,19}$=1.056, p=0.317, η^2p=0.053	$F_{1,19}$=1.352, p=0.259, η^2p=0.066
Maximum toe elevation – LL	$F_{1,19}$=0.891, p=0.357, η^2p=0.045	$F_{1,19}$=0.064, p=0.804, η^2p=0.003	$F_{1,19}$=2.049, p=0.169, η^2p=0.097	$F_{1,19}$=0.008, p=0.259, η^2p=0.066
MANOVA	Wilks' Lambda=0.685	Wilks' Lambda=0.838	Wilks' Lambda=0.929	Wilks' Lambda=0.908
Follow-up univariate	$F_{2,18}$=4.147, p=0.033*, η^2p=0.315	$F_{2,18}$=1.738, p=0.204, η^2p=0.162	$F_{2,18}$=0.686, p=0.516, η^2p=0.071	$F_{2,18}$=0.916, p=0.420, η^2p=0.092
Toe clearance – TL	$F_{1,19}$=5.045, p=0.037*, η^2p=0.210	$F_{1,19}$=1.189, p=0.289, η^2p=0.059	$F_{1,19}$=1.035, p=0.322, η^2p=0.052	$F_{1,19}$=1.773, p=0.199, η^2p=0.085
Maximum toe elevation – TL	$F_{1,19}$=3.883, p=0.064, η^2p=0.170	$F_{1,19}$=3.665, p=0.071, η^2p=0.162	$F_{1,19}$=1.386, p=0.254, η^2p=0.068	$F_{1,19}$=1.497, p=0.236, η^2p=0.073
MANOVA	Wilks' Lambda=0.228	Wilks' Lambda=0.835	Wilks' Lambda=0.277	Wilks' Lambda=0.169
Follow-up univariate	$F_{4,16}$=13.574, p=0.000*, η^2p=0.721	$F_{4,16}$=0.788, p=0.550, η^2p=0.195	$F_{4,16}$=10.425, p=0.000*, η^2p=0.807	$F_{4,16}$=19.617, p=0.000*, η^2p=0.832
Left stride				
Velocity	$F_{1,19}$=1.460, p=0.013*, η^2p=0.281	$F_{1,19}$=1.884, p=0.186, η^2p=0.090	$F_{1,19}$=2.421, p=0.136, η^2p=0.113	$F_{1,19}$=0.990, p=0.332, η^2p=0.050
Length	$F_{1,19}$=0.007, p=0.934, η^2p=0.000	$F_{1,19}$=0.646, p=0.431, η^2p=0.033	$F_{1,19}$=3.981, p=0.061, η^2p=0.173	$F_{1,19}$=14.521, p=0.001*, η^2p=0.433
Width	$F_{1,19}$=3.436, p=0.079, η^2p=0.153	$F_{1,19}$=3.346, p=0.083, η^2p=0.150	$F_{1,19}$=0.001, p=0.972, η^2p=0.000	$F_{1,19}$=0.455, p=0.508, η^2p=0.023
Duration	$F_{1,19}$=21.504, p=0.000*, η^2p=0.531	$F_{1,19}$=1.085, p=0.311, η^2p=0.054	$F_{1,19}$=32.597, p=0.000*, η^2p=0.632	$F_{1,19}$=58.600, p=0.000*, η^2p=0.755
MANOVA	Wilks' Lambda=0.363	Wilks' Lambda=0.760	Wilk's Lambda=0.705	Wilks' Lambda=0.324
Follow-up univariate	$F_{4,16}$=7.010, p=0.002*, η^2p=0.637	$F_{4,16}$=1.264, p=0.325, η^2p=0.240	$F_{4,16}$=1.675, p=0.205, η^2p=0.295	$F_{4,16}$=0.167, p=0.001*, η^2p=0.676
Right stride				
Velocity	$F_{1,19}$=3.564, p=0.074, η^2p=0.158	$F_{1,19}$=0.324, p=0.576, η^2p=0.017	$F_{1,19}$=0.062, p=0.806, η^2p=0.003	$F_{1,19}$=0.085, p=0.773, η^2p=0.004
Length	$F_{1,19}$=0.206, p=0.655, η^2p=0.011	$F_{1,19}$=0.492, p=0.491, η^2p=0.025	$F_{1,19}$=2.183, p=0.156, η^2p=0.103	$F_{1,19}$=8.604, p=0.009*, η^2p=0.547
Width	$F_{1,19}$=1.583, p=0.230, η^2p=0.075	$F_{1,19}$=2.006, p=0.173, η^2p=0.095	$F_{1,19}$=0.027, p=0.871, η^2p=0.001	$F_{1,19}$=0.103, p=0.751, η^2p=0.005
Duration	$F_{1,19}$=18.928, p=0.000*, η^2p=0.499	$F_{1,19}$=0.999, p=0.330, η^2p=0.050	$F_{1,19}$=4.080, p=0.058, η^2p=0.177	$F_{1,19}$=22.416, p=0.000*, η^2p=0.541
MANOVA	Wilks' Lambda=0.502	Wilks' Lambda=0.926	Wilks' Lambda=0.445	Wilks' Lambda=0.762
Follow-up univariate	$F_{4,16}$=3.964, p=0.020*, η^2p=0.498	$F_{4,16}$=0.318, p=0.861, η^2p=0.074	$F_{4,16}$=4.988, p=0.008*, η^2p=0.555	$F_{4,16}$=1.249, p=0.330, η^2p=0.238
Step Over				
Velocity	$F_{1,19}$=1.250, p=0.277, η^2p=0.062	$F_{1,19}$=0.364, p=0.553, η^2p=0.019	$F_{1,19}$=7.845, p=0.011*, η^2p=0.292	$F_{1,19}$=0.377, p=0.546, η^2p=0.019
Length	$F_{1,19}$=0.384, p=0.543, η^2p=0.020	$F_{1,19}$=0.120, p=0.732, η^2p=0.006	$F_{1,19}$=5.919, p=0.025*, η^2p=0.328	$F_{1,19}$=3.422, p=0.0.080, η^2p=0.153
Width	$F_{1,19}$=0.087, p=0.771, η^2p=0.005	$F_{1,19}$=0.025, p=0.877, η^2p=0.001	$F_{1,19}$=0.120, p=0.732, η^2p=0.006	$F_{1,19}$=0.990, p=0.332, η^2p=0.050
Duration	$F_{1,19}$=8.338, p=0.009*, η^2p=0.305	$F_{1,19}$=0.443, p=0.514, η^2p=0.023	$F_{1,19}$=0.084, p=0.775, η^2p=0.004	$F_{1,19}$=3.361, p=0.082, η^2p=0.150

Left stride

The post hoc tests revealed that the older adults at higher risk of falling had a lower left stride velocity than the older adults at lower risk of falling (0.866 m/s | 1.130 m/s, respectively; p=0.013) (Figure 4C). The older adults at higher risk of falling had a longer left stride duration than the older adults at lower risk of falling (1.409 s | 1.073 s, respectively; p≤0.001) (Figure 4D). For both groups, the duration of the left stride was shorter when avoiding the double obstacle than when avoiding the single one (1.175 s | 1.307 s, respectively; p≤0.001) (Figure 4E).

Older adults at higher risk of falling had a lower left stride velocity when avoiding a double obstacle than older adults at lower risk of falling (0.877 cm/s | 1.177 cm/s, respectively; p=0.009). The same occurred for single obstacle avoidance (0.856 cm/s | 1.084 cm/s, respectively; p=0.042) (Figure 4F). The older adults at higher risk of falling had a longer left stride duration when avoiding the double obstacle than when avoiding the single obstacle (1.295 s | 1.228 s, respectively; p≤0.001) (Figure 4G).

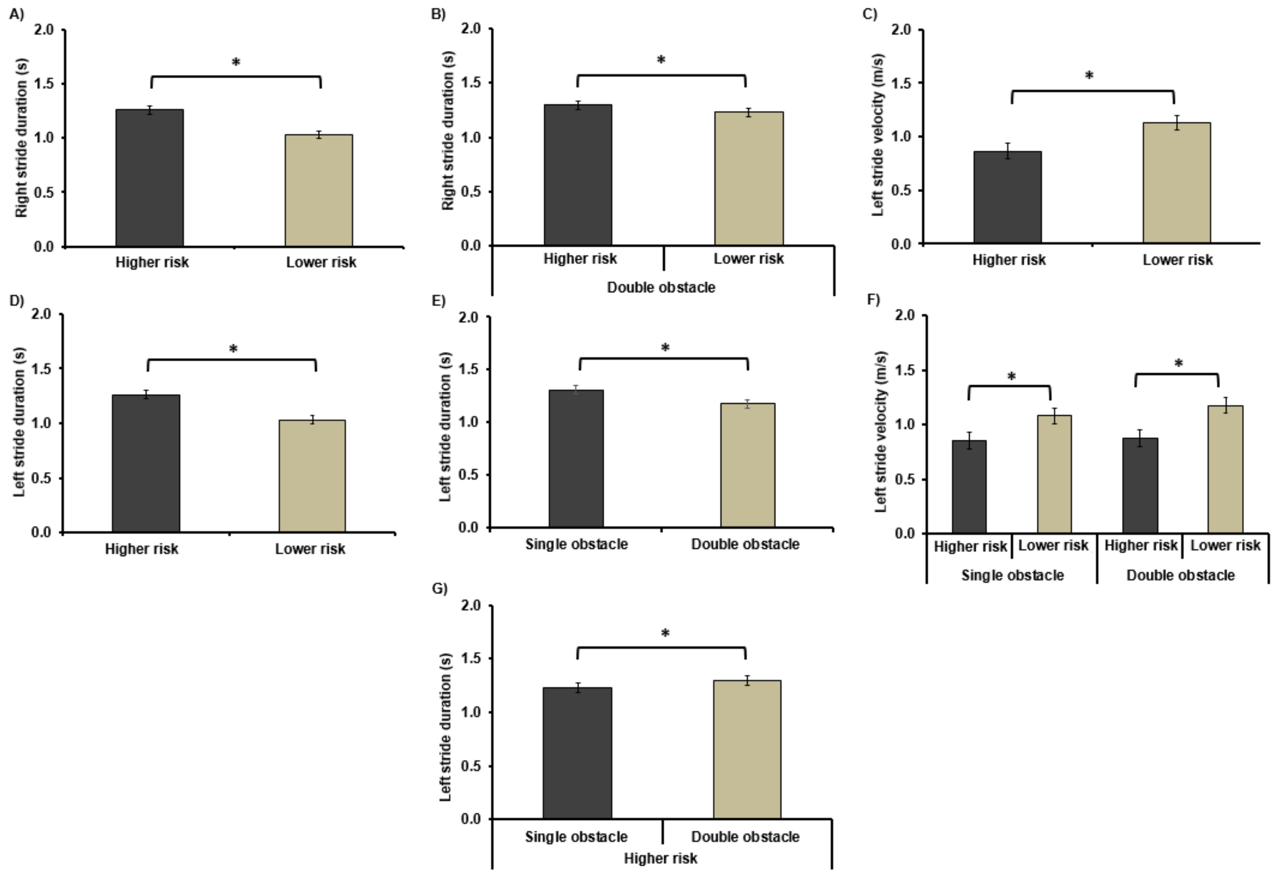

Figure 4. Mean and standard deviation of the spatiotemporal parameters. Legend: Duration right stride at higher and lower risk (A), duration right stride at higher and lower risk for double obstacle (B), velocity left stride at higher and lower risk (C), duration left stride at higher and lower risk (D), duration left stride for single and double obstacle (E), velocity left stride at higher and lower risk for single and double obstacles (F) and duration left stride of single and double obstacles at higher risk (G). s (seconds); m/s (meters per second).

Step over

The post hoc tests revealed that the older adults at higher risk of falling had a longer step over duration when avoiding obstacles when compared to the older adults at lower risk of falling (0.772 s | 0.635 s, respectively; p=0.009) (Figure 5A). In addition, both groups' velocity was lower when avoiding the double obstacle than when avoiding the single obstacle (0.979 cm/s | 1.050 cm/s, respectively; p=0.011) (Figure 5B). The same result was identified for step over length during the avoidance tasks (0.666 cm | 0.718 cm, respectively; p=0.025) (Figure 5C).

Toe clearance

For the trailing limb, the older adults at higher risk of falling had lower toe clearance while avoidance than the older adults at lower risk of falling did (0.327 cm | 0.380 cm, respectively; p=0.037) (Figure 5D).

Obstacle-heel horizontal distance

The post hoc tests revealed that, when performing the single obstacle task, the older adults at higher risk of falling showed a shorter horizontal obstacle-foot distance than the older adults at lower risk of falling (0.651 cm | 0.798 cm, respectively; p=0.025) for the trailing limb (Figure 5E).

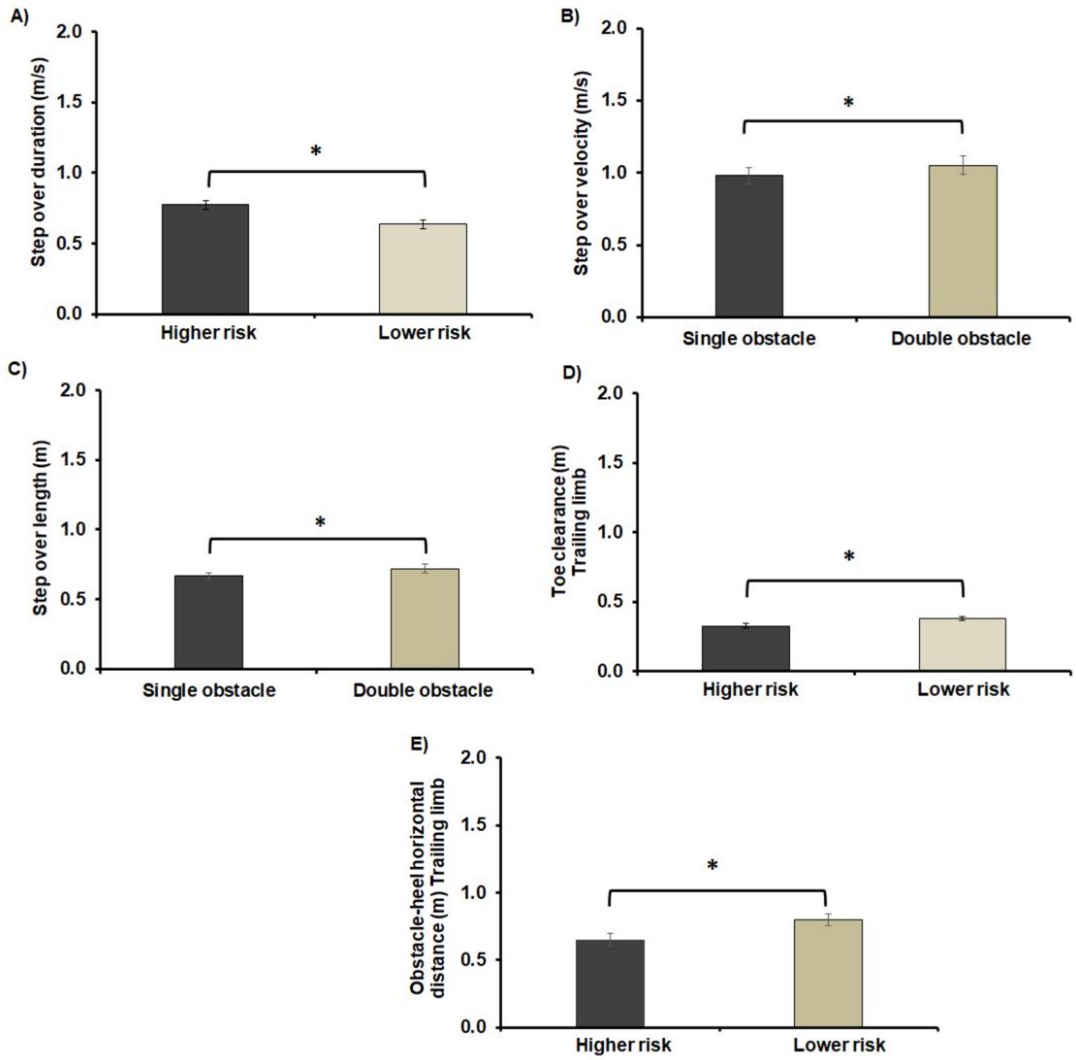

Figure 5. Mean and standard deviation of the spatiotemporal parameters. Legend: Duration step over at higher and lower risk (A), velocity step over for single and double obstacles (B), length step over for single and double obstacles (C), toe clearance for the trailing limb at higher and lower risk (D) and obstacle-heel horizontal distance for the trailing limb at higher and lower risk (E). m/s (meters for seconds); m (meters).

DISCUSSION

This study aimed to investigate the locomotor pattern of older adults at lower and higher risk of falling during sequenced obstacle avoidance with different physical characteristics. The first and second hypotheses were confirmed: older adults change their locomotor pattern when avoiding an obstacle in the presence of another one in sequence, and these changes are more evident in older adults at higher risk of falling. However, the third hypothesis was not confirmed, as the physical characteristics of the obstacles did not influence the locomotor pattern of the older adults, as they avoided them.

The older adults at higher risk of falling had worse locomotor performance (lower velocity and longer stride duration, as well as longer step duration when obstacles were positioned in sequence) during obstacle avoidance. These results indicate that older adults at higher risk of falling change their locomotor pattern when avoiding the obstacle, further increasing their own risk of falling.

This behavior occurs in an attempt to make the task more stable and secure. Sudo et al. (2023) [26] also found that older adults at higher risk of falling slowed down and prolonged the time taken to avoid obstacles. This behavior is considered conservative and cautious [33], which negatively influences gait planning and regulation when avoiding obstacles [18]. Another explanation is that with aging, locomotor changes may occur due to the degradation of our sensory systems and the decrease in strength [12] and muscle power [34], which influences the reaction time of corrective responses and muscle responses to threats more slowly. Thus, these older adults need more time to plan and make adjustments when avoiding the obstacle [19]. However, reducing velocity [33] and increasing stride duration, especially during obstacle avoidance, are behaviors that increase the risk of falling [35], especially in older adults who have already fallen before.

In addition, the older adults at higher risk of falling showed lower toe clearance of the trailing limb. In other words, these older adults get closer to obstacles when they avoid them. This behavior leads to a greater risk of tripping [13], since when crossing an obstacle, one must be sufficiently far from it to ensure safer avoidance [36]. Thus, showing lower toe clearance means having a smaller safety margin for the foot in relation to the obstacle and, consequently, being at a greater risk of falling [22,36,37].

The older adults at higher risk of falling had a shorter obstacle-heel horizontal distance of the trailing limb after avoiding the single obstacle. In other words, they came closer to the obstacle after avoiding it. This behavior compromises locomotor performance and increases the chances of tripping over the obstacle [38]. This is because these individuals adopt different avoidance strategies from those of older adults at lower risk of falling due to reduced lower limb function and gait propulsion, which means that the position of the foot is adjusted during and, consequently, after avoidance of the obstacle [16], favoring the approach to the obstacle.

Lastly, as shown, the worst performance of the trailing limb (lower horizontal distance) was identified while and after avoiding the obstacle. This is because visuospatial memory is strongly related to obstacle crossing [36]. When avoidance with the leading limb, vision is available at all times, whereas this is not the case for the trailing limb [39]. This impairs the performance of the task, especially in older adults at higher risk of falling who have greater cognitive impairment [40].

The older adults showed a lower step over velocity and length and a shorter left stride duration when avoiding sequenced obstacles. The presence of a second obstacle can influence the locomotor pattern of older adults, making it differ from the one they show when avoiding a single obstacle. Galna et al. (2009) [13] found that older adults take slower and smaller steps when avoiding a single obstacle. Thus, when older adults are subjected to a sequenced obstacle avoidance task, as in this study, these changes become even more evident. This behavior indicates that there are changes in the avoidance strategy associated with age and the complexity of the task [15].

The age-related reduction in cognitive capacity alters the planning and execution of the avoidance task with multiple obstacles [23], as greater planning and motor organization are needed to integrate the steps when avoiding obstacles [15]. Furthermore, the increased complexity of tasks (in this case, the presence of a second obstacle) also places greater demands on the sensory-motor processing of older adults, influencing their behavior [16,23]. Thus, a task that requires a greater attentional load and divides the older adult's attention negatively impacts their ability to avoid obstacles and increases the risk of tripping and, consequently, of falling [9], especially when avoiding an obstacle with another one in sequence. These results contribute to the literature, as little has been discussed about how the presence of a second obstacle in the avoidance task influences the locomotor pattern of older adults and how it increases the risk of falls.

Lastly, the characteristics of obstacles did not influence the locomotor pattern of the older adults when they avoided them. This is because the complexity is related to the avoidance task and the number of obstacles. Furthermore, other factors may have influenced the task, such as a laboratory environment different from everyday life and the color and texture of the obstacles used, which may have been a limitation of this study. Future studies should investigate obstacle avoidance in different environmental contexts, as well as obstacles in different physical structures. Therefore, the visual perception of the obstacle alone can cause gait alterations and reactive responses [4], regardless of the physical characteristics of the obstacles.

Furthermore, the data for this study were collected at the end of the pandemic, when the older adults were still beginning their vaccination schedule and were unsure about external contact with their family environment. Therefore, we were unable to control and match the number of men and women for this study. Future studies should take into account the number of men and women to investigate locomotor performance, as well as test gender differences for gait and balance measures.

CONCLUSION

Older adults at higher risk of falling show an altered locomotor pattern when avoiding sequenced obstacles, regardless of their physical characteristics. These results are important and expand the literature on the influence of sequenced obstacles on locomotor patterns and fall risk in older adults, as well as how the physical characteristics of obstacles modulate this task. It is possible to draw up targeted conduct for the rehabilitation of older adults at higher risk of falling, prevention of falls for older adults and improvement of the performance of older adults when avoiding obstacles during daily activities.

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Citation: Magalhães GV, Correa MEM, Silva JA, Razuk M, Rinaldi NM. (2025). The presence of a second obstacle in obstacle avoidance task changes the locomotor pattern of older adults at lower and higher risk of falling. *Brazilian Journal of Motor Behavior*, 19(1):e446.

Funding: This study was funded by the State Foundation for Research Support of Espírito Santo (FAPES) and the National Coucil for Scientific and Technologic Development (CNPq). Process No.: 85192910, CNPq/FAPES call No. 22/2018.
Competing interests: The authors have declared that no competing interests exist.
DOI: https://doi.org/10.20338/bjmb.v19i1.446