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Fear of falling is associated with gait parameters during obstacle avoidance with different physical characteristics in older adults

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HIGHLIGHTS

- Physical characteristic of the obstacle is not associated with FOF in older adults.
- FOF is associated to walking through and to obstacle avoidance.
- The obstacle avoidance phase is more associated with FOF than the approach phase.

ABBREVIATIONS

CoM	Center of mass
FES-I	Fall Efficacy Scale-International
FO	Walking with a Fragile obstacle
FOF	Fear of falling
FOHD	Horizontal distance foot-obstacle
FOHD_LL	Horizontal distance foot-obstacle for the leading limb
FOHD_TL	Horizontal distance foot-obstacle for the trailing limb
FOVD_LL	Vertical distance foot-obstacle for the leading limb
FOVD _TL	Vertical distance foot-obstacle for the trailing limb
Mini-BESTest	Mini-Balance Evaluation Systems Test
MMSE	Mini-Mental State Examination
OFHD	Horizontal distance obstacle-foot
OFHD_LL	Horizontal distance obstacle-foot for the leading limb
OFHD_TL	Horizontal distance obstacle-foot for the trailing limb
RSTRIDE	Right stride
LSTRIDE	Left stride
SO	Walking with a Solid obstacle
STEP_DST	Double support time
STEP_DUR	Step duration
STEP_LEN	Step length
STEP_VEL	Step velocity
STEP_WID	Step width
STEPO	Step during the obstacle avoidance
STEPO_DUR	Step duration during avoidance
STEPO_LEN	Step length during avoidance
STEPO_VEL	Step velocity during avoidance
STEPO_WID	Step width during avoidance
WT	Walking Through

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BACKGROUND: Fear of falling (FOF) is related to worse locomotor performance, is a predictor of decline in functionality, and predisposes falls in older adults. It is necessary to investigate how FOF influences locomotor parameters during walking and in obstacle avoidance in older adults.
AIM: To investigate the relationship between FOF and the locomotor variables during walking through and obstacle avoidance with different physical characteristics.
METHOD: 22 older adults participated in this study and were invited to perform three tasks: 1) Walking Through; 2) Walking with a solid obstacle and 3) Walking with a fragile obstacle.
RESULTS: Correlations were found between FOF and following variables: 1) Walking Through: step velocity (r=-0.640, p=0.003), width (r=0.641, p=0.003), double support time (r=0.523, p=0.022); 2) Solid obstacle: step velocity (r=-0.666, p=0.002), length (r=-0.758, p<0.001), foot-obstacle horizontal distance (r=-0.479, p=0.038), right stride velocity (r=-0.534, p=0.019), length (r=-0.522, p=0.022), left stride velocity (r=-0.551, p=0.014), left stride duration (r=0.561, p=0.012); 3) Fragilid obstacle: step velocity (r=-0.629, p=0.004), length (r=-0.556, p=0.014), foot-obstacle distance (r=-0.540, p=0.017), obstacle-foot distance (r=-0.492, p=0.032), right stride velocity (r=-0.583, p=0.009), length (r=-0.498, p=0.030), left stride velocity (r=-0.574, p=0.010), length (r=-0.462, p=0.047), width (r=-0.514, p=0.024), right stride duration (r=0.479, p=0.038), left stride duration (r=0.646, p=0.003).
INTERPRETATION: The characteristics of the obstacle did not influence the older adults FOF during walking through and obstacle avoidance. Although they adopt predictive and reactive compensatory adaptations in an attempt to make the task safer, these adaptations actually make the task more dangerous and increase the risk of stumbling and falling.

KEYWORDS: Aging | Locomotion | Dual task

INTRODUCTION

Aging is a continuous and irreversible physiological process sometimes associated with reduced functional capacity of the older adults [1], decline of the sensory system [2], and postural control mechanisms [3]. Thus, slower or diminished anticipatory and compensatory responses occur during gait, especially in complex tasks, such as, obstacle avoidance [4] and locomotion on unstable surfaces [5].

Thus, older adults have lower velocity and step width and longer duration [6] associated with gait variability [7]. These changes become more evident as the task complexity increases, which lead to more obstacles to avoid [8], leading to reductions in velocity and length and an increase in step width [9]. These changes are attempts to make gait safe and are caused by the fear of falling (FOF) [10]; however, it restricts the control and adjustment of movement [11], thus increasing the risk of falling.

FOF is a psychological factor related to worse gait performance [12] and a predictor of decline in functionality [13], as it restricts daily activities and reduces the level of physical activity of the older adults, leading to a lower quality of life [14]. These factors increase the fear of falling [13] in individuals after the first fall [15], making them more susceptible to new episodes [14], as well as in individuals who have never fallen [15]. Studies [12,16] have identified that FOF may be present in older adults regardless of the actual occurrence of a fall. Yet, these older adults present insecurity in avoiding falls [17] and restrict their activities [17,18], which further reduces functional capacity, increases fear, and generates a vicious cycle [18].

Considering that most falls occur during gait associated with activities with support on one limb, such as obstacle avoidance, it is not totally clear how the fear of falling influences the avoidance movement and the reactive mechanisms that aim to prepare for the task and reduce postural changes [19]. Studies [4,20,21] investigated gait parameters during obstacle avoidance with a single obstacle, as well as manipulation of the height of obstacles [22,23,24]. However, there are few studies [25,26] on obstacle avoidance with different physical characteristics. Yet, there is also a gap about how FOF affects the spatiotemporal parameters of gait during obstacle avoidance with different physical characteristics. Therefore, this study aimed to investigate the relationship between FOF and the spatiotemporal variables during walking through and obstacle avoidance with different physical characteristics. It is expected that: a) during the fragile obstacle avoidance, FOF presents more correlations with locomotor parameters of older adults when compared with the solid obstacle avoidance without the perception of fragility; b) FOF presents correlations with variables of walking through, in which the greater the FOF, the slower, longer and unstable the walk; c) for both obstacle avoidance conditions, the avoidance phase presents more correlations with FOF compared to the approach phase, and d) for the approach and obstacle avoidance phases of both obstacles, there are important correlations between Fall Efficacy Scale-International (FES-I) and variables that identify changes and adaptations of gait that are influenced by FOF. It is expected that the higher the FOF, the closer the foot approaches the obstacle and the slower and longer the walk becomes, leading to more risk of stumbling.

METHODS

Participants

The study included 22 right-handed older adults with independent gait without the use of walking aids and able to perform the experimental protocol. Participants were excluded if they had cognitive (< 24 points in the Mini-Mental State Examination - MMSE) or neurological impairment, vestibular dysfunction, and/or if they were unable to walk without assistance. After agreeing to participate in the study, individuals signed an informed consent form.

Procedures

The study was conducted at the Laboratory of Biomechanical Analysis of Movement (Bio.Mov) of the Center for Physical Education and Sports at the Federal University of Espírito Santo (CEFD/UFES) and was approved by the Ethics Committee on Research of the Federal University of Espírito Santo (CAAE: 88258218.8.0000.5542). Initially, anamnesis was performed to verify the general health status of the participants and anthropometric measurements (height and body mass) were taken to calculate the Body Mass Index. The MMSE was applied for cognitive screening. Then, the Falls Questionnaire was administered to investigate the presence of a history of falls in the last 12 months and their characteristics. To determine and to evaluate the participants' FOF was used the FES-I. In this scale, the older adults quantify the fear of falling in “I am not worried” (1 point), “a little worried” (2 points), “moderately worried” (3 points) and “very worried” (4 points) 16 activities presented regarding the fear of falling while performing them. Thus, a score greater than or equal to 23 points suggests an association with the sporadic occurrence of falls, and a score greater than or equal to 31 points suggests a recurrent occurrence of falls [27]. For a better characterization of the sample the Mini-Balance Evaluation Systems Test (Mini-BESTest) [28] and the Modified Baecke Questionnaire for older adults were used [29]. The Mini-BESTest was used to assess balance. This has a maximum score of 28 points, and the higher the score, the better the balance of the older adults28. The Modified Baecke Questionnaire for older adults was used to verify the level of physical activity. This evaluates occupational, sports and leisure activities. A score equal to or less than 9.11 points indicates a low level of physical activity, between 9.12 and 16.17 points indicates a moderate level of physical activity, and an evaluation equal to or greater than 16.18 points indicates a high level of physical activity for the older adults [29]. For the gait conditions, the participants wore non-slip socks, and four passive reflective markers made of polystyrene spheres were placed on the fifth metatarsal and lateral aspect of the calcaneus in the right lower limb, and the first metatarsal and medial aspect of the calcaneus in the left lower limb. Passive markers were also placed at the top and bottom of the obstacle, allowing for the computation of variables related to obstacle avoidance (Figure 1).

Participants were asked to walk at a self-selected velocity along a 9 meter long walkway under walking through and obstacle avoidance conditions, with the obstacle located four steps from the beginning of the task. The starting point was adjusted to ensure that obstacle avoidance was performed with the dominant lower limb, in this case the right lower limb, considering that the participants were right-handed. Two foam obstacles in gray with a height of 15 centimeters were used: a solid obstacle (SO) made of a single piece, providing stability, and a fragile obstacle (FO) with two rows and four columns of stacked blocks, providing a perception of instability (Figure 1A and 1B). Thus, three experimental conditions were performed: 1) *Walking Through* (WT); 2) Walking with a solid obstacle (SO); and 3) Walking with a fragile obstacle (FO). Participants performed three trials in each walking condition (9 trials in total). The trials were totally randomized. When errors (obstacle avoidance with the left foot, tripped over the obstacle) occurred, trials were repeated at the end of each block without participants' awareness.

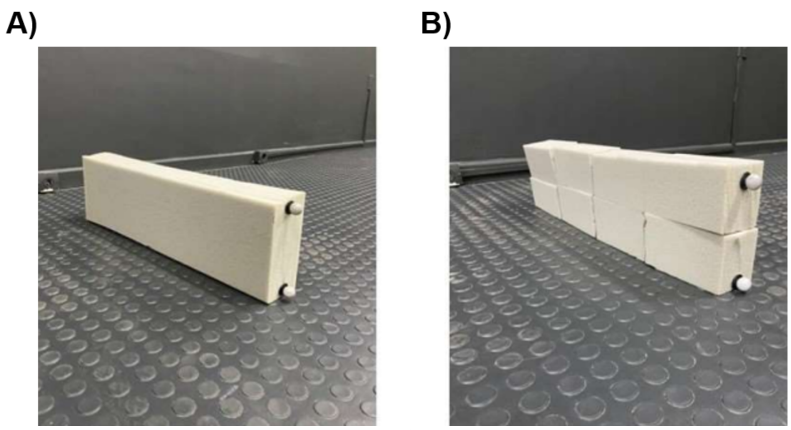


Figure 1. Two foam obstacles in gray with a height of 15 centimeters. Solid obstacle (SO) made of a single piece (A) and Fragile obstacle (FO) with two rows and four columns of stacked blocks (B). Passive markers were placed at the top and bottom of both obstacles.

Equipment

Two synchronized digital cameras were used and positioned to capture all participant markers. To enhance marker visibility, three white LED reflectors were placed on the ground near the walkway.

Recordings were made at 60 Hz with acquisition time corresponding to at least two contacts before and after obstacle avoidance. Camera calibration, record synchronization, frame marking, and coordinate reconstruction were performed using Dvideow software (Digital Video for Biomechanics for Windows 32). Space calibration was performed using ten points marked on the ground (x and y axes) and seven points marked on a topographic pole (z axis). Heel contact with the ground was used to determine the analyzed cycle. Data were analyzed using routines written in Matlab (Version 7.0 - Math Works, Inc.).

Data analysis

Walking Through

For the walking through condition, the study variables were: velocity (STEP_VEL) was calculated by dividing the length by the step duration, expressed in centimeters per second; length (STEP_LEN) was calculated by the absolute difference between the x-axis coordinates of the heel markers of the right and left foot, expressed in centimeters; width (STEP_WID) was calculated by the absolute difference between the y-axis coordinates of the heel markers of the right and left foot, expressed in centimeters; duration (STEP_DUR) was calculated by the frame difference between heel contact divided by the sampling frequency, expressed in seconds and double support time (STEP_DST) was calculated by the difference in frames between right heel strike left foot strike divided by the sample rate, expressed in seconds.

Obstacle avoidance in different physical characteristics conditions

Approach phase

The dependent variables analyzed in the step prior to the obstacle (STEP) were: velocity (STEP_VEL), length (STEP_LEN), width (STEP_WID), and duration (STEP_DUR) of the step and horizontal distance foot-obstacle (FOHD) was calculated by the linear distance in the x coordinate between the metatarsal marker when it left the ground to avoidance, and the obstacle marker for the leading limb (FOHD_LL) and for the trailing limb (FOHD_TL) for the solid and fragile obstacle conditions, expressed in centimeters.

Avoidance phase

The dependent variables of the step during the obstacle avoidance (STEPO) were: velocity (STEPO_VEL) was calculated by dividing the length by the duration of the step during avoidance, expressed in centimeters per second; length (STEPO_LEN) was calculated by subtracting the values of the points on the x-axis of the marker on the lateral face of the right calcaneus and the medial face of the left calcaneus, at the moment of avoidance, expressed in seconds; width (STEPO_WID) was calculated by the distance between the markers of the right and left calcaneus in the mediolateral direction, added to the width of the left foot, when it was before the obstacle and the right foot after the obstacle, expressed in centimeters; and duration (STEPO_DUR) was calculated by the frame difference between heel contact divided by the sampling frequency during avoidance, expressed in seconds. As well as horizontal distance obstacle-foot (OFHD) was calculated by the distance, in the x coordinate, between the calcaneal marker and the obstacle marker after obstacle avoidance, expressed in centimeters for the leading limb (OFHD_LL) and for the trailing limb (OFHD_TL). The vertical distance foot-obstacle was calculated by the vertical distance between the metatarsal marker and the upper edge of the obstacle when the foot was on the obstacle, expressed in centimeters for the leading limb (FOVD_LL) and for the trailing limb (FOVD_TL) for the solid and fragile obstacle conditions.

The stride was determined by two successive contacts of the same calcaneus on the surface. For the right stride (RSTRIDE), the variables were: velocity (RSTRIDE_VEL) was calculated by dividing the length by the duration of the left stride, expressed in centimeters per second; length (RSTRIDE_LEN) was calculated by subtracting the values of the points on the x-axis of the marker on the lateral face of the right calcaneus and the medial face of the right calcaneus, expressed in seconds; width (RSTRIDE_WID) was calculated by the distance between the markers of the position right calcaneus in the mediolateral direction, added to the width of the right foot, expressed in centimeters and duration (RSTRIDE_DUR) was calculated by the frame difference between heel contact divided by the sampling frequency, expressed in seconds. For the left stride (LSTRIDE), the same variables were analyzed: velocity (LSTRIDE_VEL), length (LSTRIDE_LEN), width (LSTRIDE_WID), and duration (LSTRIDE_DUR). Both were analyzed for the solid and fragile obstacle conditions.

Statistical analysis

The SPSS software (version 21) was used for all analyses. To check for normality and homogeneity of the data, the Shapiro-Wilk and Levene tests were respectively employed. In case of deviation from a normal distribution, z-score standardization was used for later parametric analysis.

For analysis of gait tasks, the mean value of three trials for each condition was used in the statistical analysis. Pearson correlation test was performed between FES-I and the condition of walking through for the variables: [STEP_VEL, STEP_LEN, STEP_WID, STEP_DUR, and STEP_DST]. Between FES-I and the conditions ([SO, FO]) for the variables: [STEP_VEL, STEP_LEN, STEP_WID, STEP_DUR, FOHD_TL, FOHD_LL]; [STEPO_VEL, STEPO_LEN, STEPO_WID, STEPO_DUR, FOVD_TL, FOVD_LL]; [RSTRIDE_VEL, RSTRIDE_LEN, RSTRIDE_WID, RSTRIDE_DUR]; and [LSTRIDE_VEL, LSTRIDE_LEN, LSTRIDE_WID, LSTRIDE_DUR]. The Pearson correlation coefficient should be between -1 and +1. A coefficient of +1 indicates that the two variables are perfectly positively correlated, so when one variable increases, the other increases proportionally. However, a coefficient of -1 indicates a perfect negative relationship: if one variable increases, the other decreases by a proportional value. Moreover, a correlation coefficient of ± 0.1 represents a small effect, ± 0.3 a medium effect, and ± 0.5 a large effect. The significance level adopted in all analyses was $p \leq 0.05$ [30].

RESULTS

Sample characterization

Table 1 presents the age, anthropometric characteristics, cognitive state, level of physical activity, balance, fear of falling and number of falls of the sample. The study included 22 older adults, three male (13.64%) and 19 female (86.36%), with a mean age of 69.47 (±5.30) years, preserved cognitive function, preserved dynamic balance (21.89 ± 5.22 points on the Mini-BESTest), and low level of physical activity (5.29 ± 5.30 points on the Modified Baecke Questionnaire).

Table 1. Mean and standard deviation (in parenthesis) for the age, anthropometric characteristics and cognitive state, level of physical activity, balance, fear of falling and number of falls of the sample.

	Group
Variables	**OA (n=22)**
Age (year)	69.47 (±5.30)
Height (m)	161.16 (±6.47)
Body Mass (kg)	68.56 (±10.47)
Body Mass Index (kg/m2)	26.35 (±3.35)
Mini-Mental State Exam (points)	26.68 (±2.11)
Modified Baecke Questionnaire (points)	5.29 (±5.30)
MiniBESTest (points)	21.89 (±5.22)
Falls Efficacy Scale (points)	25.47 (±7.83)
Number of falls	0.37 (±0.68)

Legend: OA (older adults); n (number of sample participants); kg (kilogram); m (meters); kg/m2 (kilogram per square meter).

Walking Through

There was a negative correlation between FES-I and the STEP_VEL (r= -0.640, p=0.003) and positive correlation for the STEP_WID (r=0.641, p=0.003) and STEP_DST (r=0.523, p=0.022) (Figure 2). These findings indicate that older adults with higher levels of FOF exhibit lower walking velocity, wider step widths, and longer durations of double support during walking through.

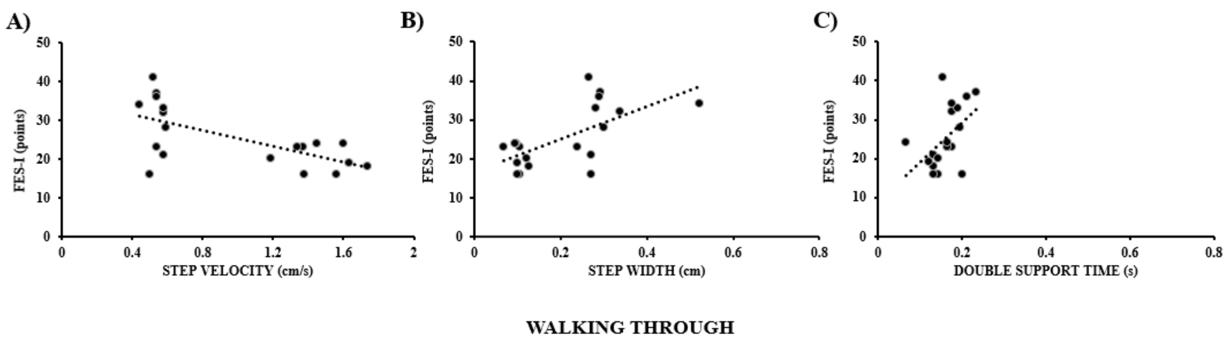


Figure 2. Correlation between FES-I and step velocity (A), step width (B) and double support time (C) during walking through.

Obstacle avoidance in different physical characteristics conditions

Obstacle Avoidance – Solid Obstacle

During the approach phase, for the pre-crossing step of solid obstacle, the STEP_VEL (r= -0.666, p=0.002); STEP_LEN (r= -0.758, p<0.001); and FOHD_LL (r= -0.479, p=0.038) showed a negative correlation with FES-I (Figure 3). Thus, older adults with FOF adjust their gait before obstacle avoidance. They decrease walk velocity and step length and approached closer to the obstacle with trailing limb.

For the avoidance phase, there was a positive correlation between FES-I and the STEPO_DUR (r=0.549, p=0.015). For the right stride, there was a negative correlation between FES-I and RSTRIDE_VEL (r= -0.534, p=0.019) and RSTRIDE_LEN (r= -0.522, p=0.022), as well as for the variable of the left stride LSTRIDE_VEL (r= -0.551, p=0.014). Additionally, there was a positive correlation between FES-I and LSTRIDE_DUR (r=0.561, p=0.012) (Figure 4). The higher the FOF, the greater the duration of the solid obstacle avoidance step. These older adults tend to perform slower and shorter obstacle avoidance strides with the leading limb and slower and longer strides with the trailing limb.

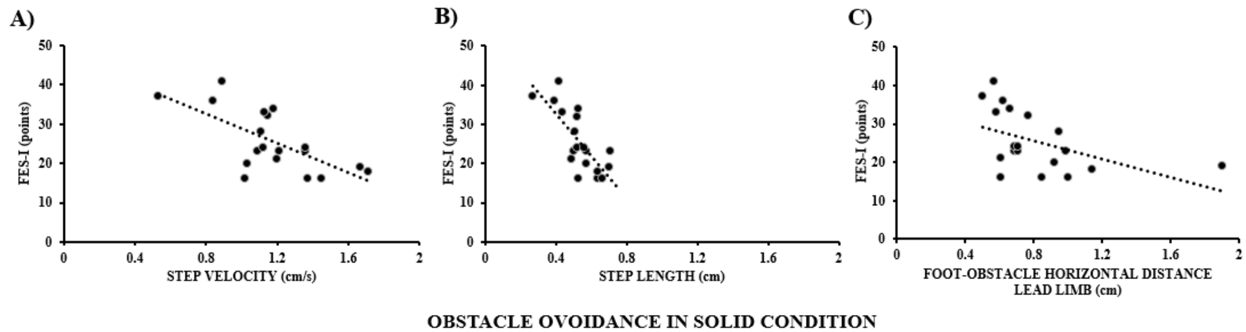


Figure 3. Correlation between FES-I and the approximation phase variables step velocity (A), step length (B) and foot-obstacle horizontal distance lead limb (C) during obstacle avoidance in solid condition.

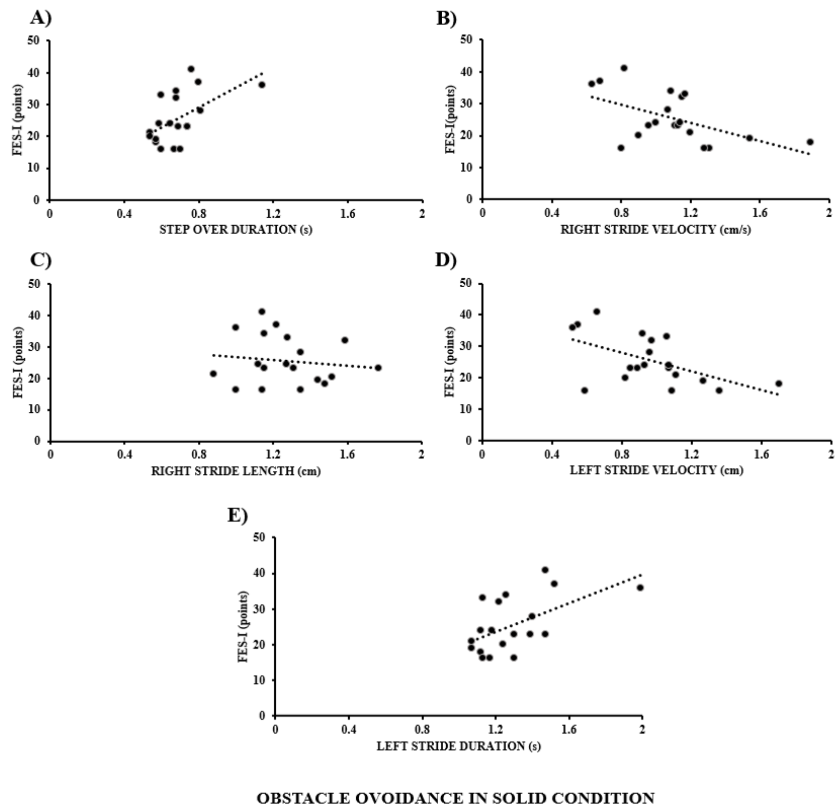
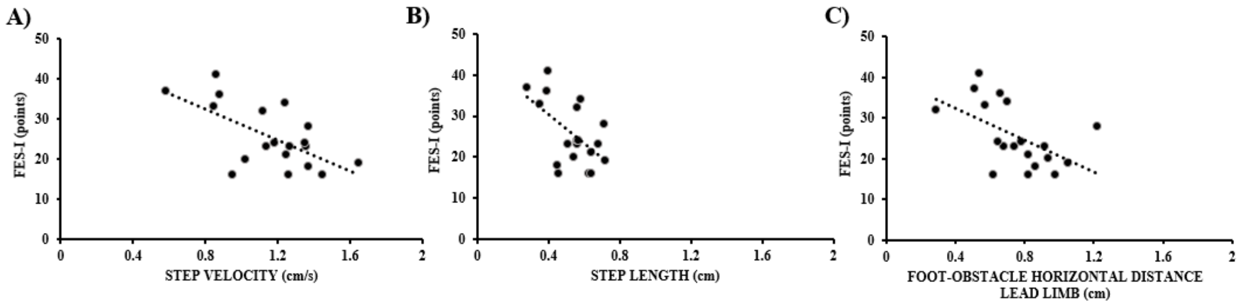


Figure 4. Correlation between FES-I and the avoidance phase variables step over duration (A), right stride velocity (B), right stride length (C), left stride velocity (D) and left stride duration (E) during obstacle avoidance in solid condition.

Obstacle Avoidance – Fragile Obstacle

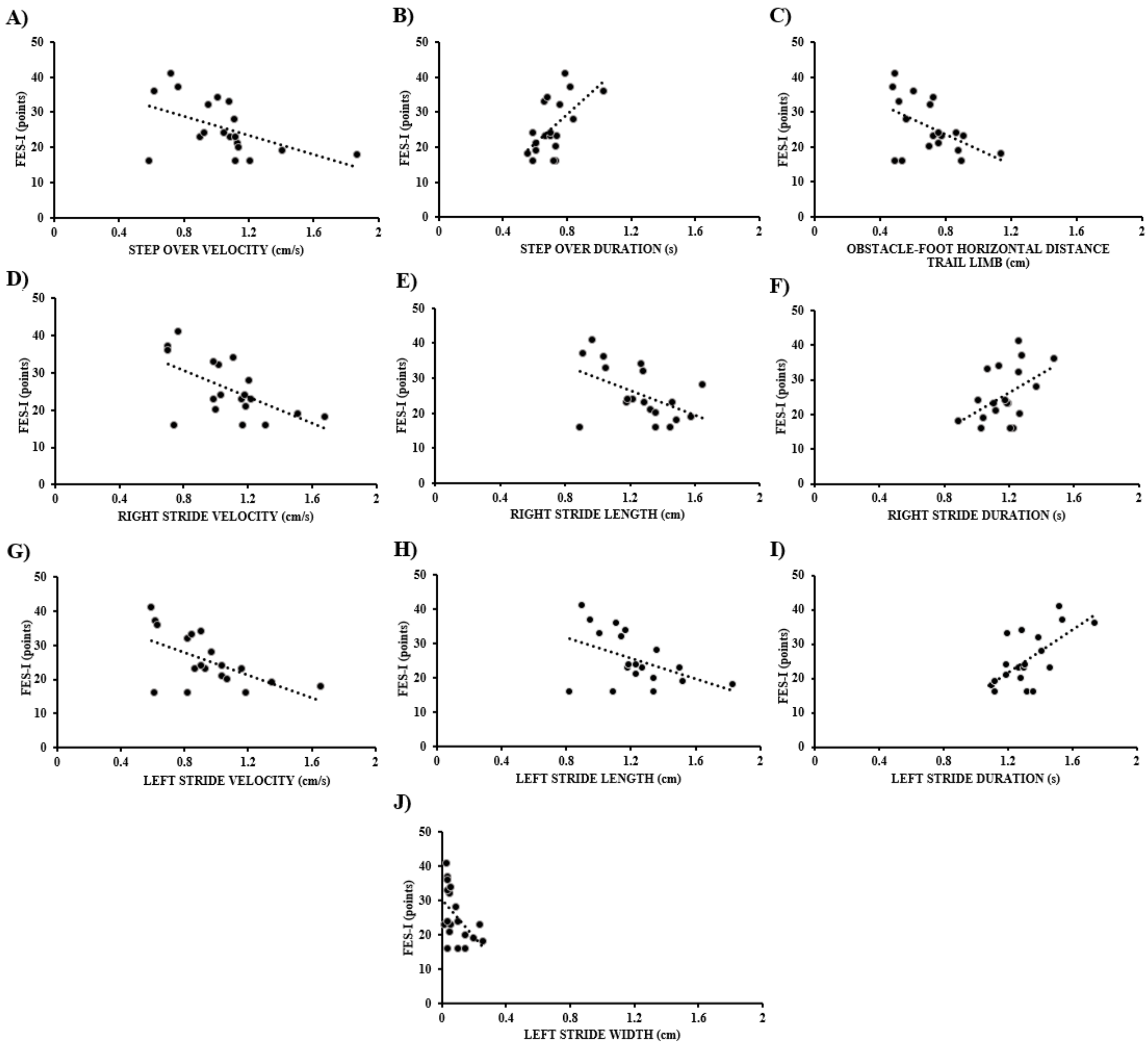
For the approach phase, STEP_VEL (r= -0.629, p=0.004), STEP_LEN (r= -0.556, p=0.014), and FOHD_LL (r= -0.540, p= 0.017) showed a negative correlation with FES-I (Figure 5). Older adults with higher levels of FOF tend to decrease their walking velocity and step length when approaching a fragile obstacle. Additionally, they tend to come closer to the obstacle with their trailing limb.

During the avoidance phase, STEPO_VEL (r= -0.502, p=0.028) and OFHD_TL (r= -0.492, p=0.032) showed negative correlations with FES-I, and STEPO_DUR (r= 0.586, p=0.008) showed a positive correlation with FES-I. For the right stride variables, there was a negative correlation for RSTRIDE_VEL (r= -0.583, p=0.009) and RSTRIDE_LEN (r= -0.498, p=0.030), and a positive correlation for RSTRIDE_DUR (r= 0.479, p=0.038). Regarding the left stride, there was a negative correlation for the LSTRIDE_VEL (r= -0.574, p=0.010), LSTRIDE_LEN (r= -0.462, p=0.047), and LSTRIDE_WID (r= -0.514, p=0.024), and a positive correlation for LSTRIDE_DUR (r =0.646, p=0.003) (Figure 6). These results demonstrate that older adults with the highest levels of FOF adopt a slower crossing step and position themselves closer to the obstacle with the leading limb when passing a fragile obstacle, as well as perform slower, shorter, and more prolonged strides.



OBSTACLE AVOIDANCE IN FRAGILE CONDITION

Figure 5. Correlation between FES-I and the approximation phase variables step velocity (A), step length (B) and foot-obstacle horizontal distance lead limb (C) during obstacle avoidance in fragile condition.



OBSTACLE AVOIDANCE IN FRAGILE CONDITION

Figure 6. Correlation between FES-I and avoidance phase variables step over velocity (A), step over duration (B), obstacle-foot horizontal distance trail limb (C), right stride velocity (D), right stride length (E), right stride duration (F), left stride velocity (G), left stride length (H), left stride duration (I) and left stride width (J) during obstacle avoidance in fragile condition.

DISCUSSION

This study aimed to investigate the relationship between FOF and variables related to the locomotor parameters of older adults individuals during walking through and obstacle avoidance with different physical characteristics.

The first hypothesis was not confirmed, as obstacle fragility and task complexity did not influence gait performance. The second hypothesis was confirmed: an adaptive locomotor pattern influenced by FOF was identified, even under walking through conditions. The third and fourth hypotheses were confirmed too: correlations with FES-I were more evident during the obstacle avoidance phase for both obstacles; correlations were found for the variables of pre-crossing step and horizontal distance to obstacle for the approach phase; for the crossing step variables; and both strides for obstacle avoidance.

Correlation between FES-I and obstacle avoidance with different physical characteristics in older adults

Although it was expected, the physical characteristics of the obstacle did not influence the older adult's FOF during obstacle avoidance. Thus, it is believed that FOF is related to the complexity of the task of obstacle avoidance and not to the physical characteristics of the obstacle. A similar result was found by Worden, Jong and Vallis (2016) [31], where no difference was found in spatial-temporal parameters of gait when obstacle avoidance with different characteristics (ground obstacle x floating obstacle). Therefore, visual perception of the obstacle alone is capable of causing the gait changes observed during obstacle avoidance, as well as reactive responses to perform the task. It was identified that continuous visual disturbances during gait, such as an obstacle, caused effects of variability in the width and length of stpe and stride [32]. In addition, previous experience and knowledge about the complexity and risk of the task, influence reactive postural control strategies. For example, viewing obstacles or unstable surfaces with different conformations can change the gait pattern to avoid a fall [24], both in the approach phase and in the phase of obstacle avoidance, as will be discussed later.

Correlation between FES-I and kinematic variables during walking through

Older adults with FOF showed lower velocity and wider step width, as well as longer double-support time during walking through. These results demonstrate that fear influences locomotor parameters in older adults, even under conditions of low risk of falls, causing them to have slower and more cautious gait. Other studies [12,16] also identified that older adults who reported FOF had significantly slower gait velocity and longer double-support time than those without fear, as well as wider step width in those prone to falls [33].

These results suggest that these spatiotemporal gait changes are compensatory adaptations caused by fear itself in an attempt to reduce the risk of falls [12] and maintain stability while walking [16]. Moreover, these adaptations occur in an associated manner, as the increase in step time variable in older adults with FOF is partly due to their reduced gait velocity [10], whereas the increased step width occurs to increase the support base during the double-support phase [10], thus improving balance [34] and making the task safer.

Although they occur in an attempt to adopt a cautious gait pattern, these adjustments do not have the expected protective effect [35,36]. Slow step velocity contributes to poorer gait quality, as reductions in spatiotemporal parameters, particularly gait velocity [37], as well as increased double-support time [35], and step width in an attempt to compensate for reduced stability during gait [33], lead to a pattern that increases risk and predisposes to falls [35]. Thus, FOF potentially affects gait parameters and is identified as one of the factors involved in the occurrence of new falls and by individuals who have not yet fallen [15].

Correlation between FES-I and kinematic variables of gait on obstacle avoidance

Approach phase

When approaching the obstacle, regardless of its physical characteristics, the older adults with FOF reduced the velocity and length of the pre-crossing step and approached it with the trailing limb. These findings demonstrate that, before obstacle avoidance, older adults perform anticipatory postural adjustments to make the task safer. Adaptations of gait spatiotemporal parameters, such as faster and shorter steps, during a challenging task [31], consequently lead to increased stability margins, which allows greater stability and postural control during a task, such as obstacle avoidance [32,38]. These adjustments occur up to two steps before the obstacle to provide enough time for changing the movement direction, if the foot landing is unstable, and for correction of limb trajectory. Similar results [39] identified that older adults initiate corrections in length and velocity one or two steps before an obstacle; they also approach the obstacle with the trailing limb [39,40]. These changes in spatiotemporal parameters occur in an attempt to promote temporal adjustment and better dynamic segmental coordination to perform the complex task [41] and to reduce the risk of falling [10].

As a strategy to increase stability, these older adults reduce their velocity as they approach the obstacle [42]. As a result, they adopt shorter steps, which brings them closer to the obstacle [39]. However, closer proximity of the trailing limb to the obstacle increases the probability of contact during obstacle avoidance [39,43] and limits the recovery of balance if contact occurs [43]. Thus, this behavior during the approach phase may predispose individuals to lose balance when crossing an obstacle and hinders subsequent postural transitions [8]. This also occurs because, in complex situations, the gait adaptability in older adults at high risk of falling is weakened [42]. Additionally, these adjustments disturb the balance and control of step [8], especially in older adults with FOF who have impaired anticipatory adjustments. Thus, the high variability of spatiotemporal parameters of gait during the preparation for obstacle avoidance contributes to a more unstable walk and is a risk factor for falls, especially in older adults with FOF [41].

Avoidance phase

For the obstacle avoidance step of both obstacles, the older adults presented longer step duration. For the fragile obstacle, older adults presented lower step velocity and approached the obstacle after avoidance with the leading member. These results demonstrate that they adopt slower crossings and position themselves close to the obstacle in an attempt to make the task safer. Similar findings demonstrated that older adults, when crossing obstacles, exhibited a cautious behavior with reduced velocity and shorter obstacle-heel distance [44]. Moreover, longer duration and slower steps were present to increase the time available for visual information collection and movement planning during the approach phase [45].

Other studies [42,44,46] have shown that the velocity is reduced when an obstacle is crossed and that it is even lower when the task complexity increases [44], mainly in older adults with FOF. As a consequence, they present greater variability of stride regularity [10], which has also been related to the risk of falling [38]. These changes in step behavior during obstacle avoidance is an attempt to avoid a collision with obstacles, however, these step adjustments become exaggerated and affect gait stability during the obstacle approach [46].

For both strides, older adults reduced velocity and increased duration when avoiding obstacles. Additionally, for the right stride, they decreased the length for both obstacles. For the left stride, they decreased the length and width when passing the fragile obstacle. These results indicate that older adults with FOF adopt a reactive control strategy when avoiding obstacles in an attempt to control the disturbance generated by the task [19,47].

These older adults use different strategies to maintain stability when walking and avoiding obstacles, such as shorter stride length [38], and, therefore, slower velocity and longer duration. Moreover, shorter steps require the foot to be placed closer to the obstacle, increasing the risk of stumbling and falls [20]. Older adults with a higher risk of falls adopt a narrower step width [38], which contributes to a more unstable gait and an even greater risk of falls [36]. Consequently, the task becomes riskier due to greater step variability, which can lead to foot positioning errors and insufficient reactive adaptations to control the center of mass (CoM) on the support base [9].

Finally, the left stride seems to be more challenging, and the risk of stumbling may be higher with the trailing limb. Similar findings have identified that older adults were more prone to make contact with the trailing limb during obstacle avoidance, especially when task complexity increased [48]. This behavior occurs because during obstacle avoidance with the leading limb, visual information about the obstacle is used for controlling movement and creating an avoidance strategy, as well as reorganizing it. Older adults can visually confirm and trust the obstacle's height [23], distance [21], and characteristics [25] during the leading limb's stride [23]. However, during obstacle avoidance with the trailing limb, visual information is not available [36], and it is necessary to rely on the memory of previous experiences and knowledge of the obstacle's physical characteristics [35], such as position, depth, and perceived characteristics, such as fragility [35]. When this information is reduced, improper foot positioning movements may occur, increasing the risk of falls [21], as identified in this study for older adults.

Furthermore, during the obstacle avoidance with the leading limb, the CoM is behind the base of support, and in this case, simple movement corrections such as greater knee flexion improve the foot trajectory [21]. However, during the trailing limb crossing, the CoM is in front of the base of support [21], making postural control more difficult, with the need to change the direction and positioning of the foot to establish a new secure base [48] by reactive control of the CoM [21]. Nevertheless, when these changes are exaggerated, they increase the trajectory variability and decrease the stride precision [21], increasing the risk of contact with the obstacle, as discussed earlier.

Limitations

The lack of sample calculation is a limitation of this study. Another limitation found was the number of participants. The study was carried out during the pandemic period, which made it difficult to recruit more participants, as they were still fearful. Thus, 22 older adults participated in the study.

CONCLUSION

Based on the results, the characteristics of the obstacle did not influence the oldr adult's FOF. The FOF is related to the task of walking through and obstacle avoidance regardless of obstacle physical characteristics. Although they adopt predictive and reactive compensatory adaptations in an attempt to make the task safer, these adaptations actually make the task more dangerous and increase the risk of stumbling and falling. Therefore, these results contribute to clinical practice in the field of fall prevention and rehabilitation for older adults with fear of falling, providing better quality of life and functionality for older adults.

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