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Step length appears to be a strong discriminant gait parameter for elderly females highly concerned about falls: a cross-sectional observational study

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Abstract

Objective To determine if gait parameters and the Timed Up and Go test can discriminate between elderly females with high and low concern about falls. Knowledge of these parameters could help in the development of rehabilitation programmes focused on the prevention of falls, fear of falling and functional decline.
Design Cross-sectional, observational study.
Setting Human motion laboratory.
Participants One hundred and fifty-four elderly females (aged 64 to 83 years), divided into two groups based on their Falls Efficacy Scale International score: high concern ($n = 81$) and low concern ($n = 73$) about falls.
Main outcome measures Eight gait parameters recorded with the GAITRite system and the Timed Up and Go test score.
Results Factor 2 (composed of step length, gait velocity and Timed Up and Go mobility test) explained 20% of the variability of the data and was the only factor to discriminate between the groups, with 63% correct classifications. Step length proved to be the variable with the greatest discriminant ability, with a much higher discriminant coefficient (0.889) than the Timed Up and Go test (−0.369) and gait velocity (−0.268).
Conclusions High concern about falls is primarily associated with decreased step length. Step length could be used as a screening tool to identify elderly women with low and high concern about falls in order to target these groups in a rehabilitation programme aimed to slow reduction in gait velocity and mobility.

Keywords: Gait; Fear of falling; Elderly; Measurement; Mobility test; Step length

Introduction

Fear of falling affects elderly people with and without a history of falls [1,2]. Elderly individuals concerned about falls have a reduced quality of life, decreased mobility, greater anxiety, more depressive symptoms, increased use of medication and a greater risk of falls [3,4]. Fear of falling is more prevalent among people in institutional care, elderly women and those with a previous history of falls [5,6].

One of the concepts of fear of falling refers to the concern that an individual has about falling during particular activities [7]. Such concern arises when an individual recognises the risk and the adverse effects of falls, and significantly reduces their participation in those activities [3,8]. Activity restriction leads to loss of muscle force and postural control. The mobility tasks most often avoided are reaching and walking [8].

Individuals concerned about falls also adopt a more cautious gait, characterised by a reduction in velocity and step length, an increase in the base of support and prolonging of the double support phase [9–11]. Recently, two studies have shown a strong association between a reduction in gait

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velocity and a fear of falling [9,12]. However, Delbaere *et al.* found that concern about falls was not associated with walking velocity under normal conditions. Additional changes in gait parameters were only observed in individuals who were concerned about falls when threatening conditions were imposed. These changes were more pronounced in the high concern group, increasing the risk of falls, instead of protecting against them [13]. The authors suggest that the primary causes of slower gait in individuals with concern about falls stem from physical limitations rather than actual changes in gait pattern. In addition, the relationship between gait velocity and decreased functional mobility has been highlighted in the literature [5,14]. Therefore, it is not clear if older individuals with concern about falls reduce their gait velocity to prevent falling and to become more stable performing their activities, or if they reduce their activity as an adaptation to fear of falling, resulting in alterations in gait.

Among the factors that may contribute to the lack of clarity are statistical methods that do not take into account the correlation between the gait parameters [15]. When variables are correlated but the statistical hypothesis is tested using methods appropriate for independent variables, one runs the risk of not perceiving the effects of the variables due to intercorrelations. As such, exploratory factor analysis is advantageous since the object of the analysis is to reduce the number of variables by forming subgroups of new variables – denominated factors – that are not correlated to one another and explain a large portion of the variance in the data [16]. The numerical value of factors represents the degree with which each individual in the sample is related to the factor, and can be used in hypotheses tests to detect differences between independent groups or to determine which variables best discriminate the groups by using discriminant analysis [17].

Therefore, the present study analysed temporal and spatial gait parameters and the Timed Up and Go mobility test in two groups of elderly women: one group with low concern about falls and another group with high concern about falls. Applying appropriate statistical tests, the objective of this study was to explore the inter-relations of multiple measures in the comprehension of factors, such as gait parameters and mobility, related to a group of women with low or high concern about falls, with the aim of determining which variables best discriminate between the two groups.

Methods

Study participants

The present study was approved by the Ethics Committee of the Universidade Federal de Minas Gerais, Brazil (COEP - ETIC 442/08). A convenience sample of 154 community-dwelling elderly women aged 64 years and older (range 64 to 83 years) was recruited at senior citizen centres. The inclusion criteria were women aged 64 years or older, able to walk independently with no walking aids (cane or walker), and clinically stable. The exclusion criteria were cognitive alterations, inability to walk due to orthopaedic or neurological problems, and three or more phenotype frailty parameters described according to Fried *et al.* [18].

Gait parameters

Gait parameters were obtained using a 5.6 m GAITRite instrumented walkway with embedded pressure sensors (CIR Systems Inc., Clifton, NJ, USA). As the subject walks across the walkway, the pressure exerted by the feet on to the walkway activates the sensors, and the walkway senses the geometry of the feet and the relative arrangement between them in a two-dimensional plane. The participants were asked to walk on the mat at their normal walking velocity six times. The start and end points were marked 2 m before and after the mat in order to ensure a constant walking velocity. Eight gait parameters were obtained and included: (1) velocity normalised by the average leg length was obtained directly from the GAITRite system after dividing the velocity by the average leg length (distance from the greater trochanter to the floor computed from left leg length + right leg length/2), expressed in this study as m/second; (2) stance time, the weight-bearing portion of each gait cycle, expressed in seconds; (3) swing time, the non-weight-bearing portion of the cycle, expressed in seconds; (4) double support time, measured as the two periods when both feet are in contact with the floor, expressed in seconds; (5) step length, measured on the line of progression between the heel centres of two consecutive footprints by the same foot (left to left, right to right), expressed in cm; (6) step time, measured as the time elapsed from first contact of one foot to first contact of the other foot, expressed in seconds; (7) base of support, obtained as the vertical distance from heel centre of one footprint to the line of progression formed by two footprints of the other foot, expressed in cm; and (8) cadence, number of steps per minute. The validity and reliability of the system are reported elsewhere [19,20].

Mobility measure

The Timed Up and Go test quantifies the time in seconds that a subject requires to 'rise from a standard arm chair, walk to a line on the floor 3 m away, turn, return and sit down again'. The women wore their regular footwear to perform these tests. The subjects walked through the test once before being timed in order to become familiar with the test. The time needed to complete the test reflects the functional capacity of elderly individuals [21]. In the present study, the parameters described by Bohannon [22] were used to classify the individuals as functionally dependent or independent.

Concern and fear about falls

Concern about falls was evaluated using the Falls Efficacy Scale International (FES-I) [7]. The FES-I is comprised of 16 items on a four-point scale, ranging from 1 (not at all concerned) to 4 (very concerned), and reflects confidence in performing a range of activities of daily living without falling. The scores range from 16 to 64. The higher the score, the more concerned the subject is about falling. The cross-cultural validation of the FES-I to the Portuguese language (Brazil) demonstrated good intra- and inter-rater reliability (0.836 and 0.912, respectively) [23]. Fear of falling was also assessed through a simple question (Are you afraid of falling?) with a yes/no answer.

Data analysis

To divide the subjects into two groups with high and low concern about falls, receiver-operating characteristic (ROC) curves were used to determine the cut-off point of the FES-I considering the binary variable fear of falling (yes = 1) or no fear of falling (no = 0). The optimal cut-off point was the value that maximised the sum of sensitivity and specificity. Mann-Whitney test and Student's *t*-test with Bonferroni's correction were used to compare anthropometric data. Mean differences between the groups and 95% confidence intervals were calculated for all outcome measures. Both temporal and spatial gait parameters and the Timed Up and Go test were analysed using factor analysis. Principal component analysis with varimax rotation was employed to derive orthogonally statistical independent factors, which were used as predictors in the discriminant analysis. Once a predictor was identified, the original variables that composed the factor were submitted to further discriminant analysis to determine the contribution of each variable to the discriminant function. All the data were analysed with a significance level of 0.05.

Results

The ROC curves determined that subjects with total FES-I scores ≤20 were allocated to the low concern group and those with scores >20 were allocated to the high concern group. The FES-I scores for the subjects ranged from 16 to 39. The mean ROC curve value was 0.829 ($P < 0.05$) and the 95% confidence interval ranged from 0.765 to 0.894. The women in the low concern group ($n = 73$) had a mean (standard deviation) age of 71.5 (4.6) years, height of 155.3 (5.7) cm and body mass index (BMI) of 26.1 (4.5). The women in the high concern group ($n = 81$) had a mean (standard deviation) age of 71.5 (4.8) years, height of 153.5 (5.8) cm and BMI of 27.7 (4.4). BMI was the only measurement that was significantly higher in the high concern group than in the low concern group [t (152) = −2.151, $P < 0.05$].

Table 1 shows the values of the spatial-temporal parameters and Timed Up and Go test for both groups. The 95% confidence interval shows that the difference between the groups was most pronounced for step length, with a 6.0 cm shorter step length for the high concern group compared with the low concern group. Exploratory factor analysis was conducted with extraction, using principal components and varimax rotation. The sample adequacy measure (Kaiser-Meyer-Olkin), which determines the degree of intercorrelation between variables and the adequacy of the factor analysis, was 0.727, indicating that the data were adequate for the analysis. Likewise, the Bartlett sphericity test was significant ($P < 0.001$), indicating sufficient correlation between the response variables to proceed with the analysis.

Table 2 shows the results of the factor analysis, with four factors explaining 94% of the variance. The factors in Table 2 are composed of a set of variables with larger correlation coefficients which measure aspects of the same underlying dimension. The results demonstrated that Factor 1, which explained 54% of the variance in the data, was related to the duration of the swing phase, support, step time and cadence, and therefore represents the rhythm dimension. Factor 2 explained 20% of the variance and was made up of step length, gait velocity and the Timed Up and Go test, thereby representing the distance dimension. Factor 3 (duration of double support) explained 10% of the variance and represented the stance dimension. Factor 4 (base of support) explained 9% of the variance and represented the support dimension.

Discriminant analysis was conducted to determine which factors best discriminated between the two groups of elderly women. Box's M covariance test indicated equality between

Table 1
Mean (standard deviation) of the groups and mean (95% confidence interval) of the difference between groups for gait parameters of the 154 elderly participants.

Outcomes	Groups		Difference between groups*
Gait parameters	High concern about falls ($n = 81$)	Low concern about falls ($n = 73$)	(95% CI)
Swing time (seconds)	0.4 (0.3)	0.4 (0.3)	0 (−0.1 to 0.1)
Cadence (no. of steps/minute)	120.1 (7.8)	120.9 (7.9)	−0.8 (−3.3 to 1.7)
Step time (seconds)	0.5 (0.03)	0.5 (0.03)	0 (−4.5 to 4.5)
Stance time (seconds)	0.6 (0.04)	0.6 (0.05)	0 (−0.01 to 0.01)
Step length (cm)	124.8 (12.0)	130.8 (11.9)	−6.0 (−9.8 to −2.2)
Velocity (m/second)	1.5 (0.2)	1.6 (0.2)	−0.1 (−0.2 to −0.04)
Double support time (seconds)	0.2 (0.03)	0.2 (0.03)	0 (−0.01 to 0.01)
Base of support (cm)	7.6 (2.6)	7.2 (2.5)	0.4 (−0.4 to 1.2)
Timed Up and Go test (seconds)	8.4 (0.8)	8.1 (0.8)	0.3 (0.04 to 0.6)

CI, confidence interval.
* High minus low.

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Table 2
Principal components with varimax rotation factor matrix ($n = 154$).

Gait parameters	Factor 1Rhythm	Factor 2Distance	Factor 3Stance	Factor 4Support	Communality
Swing time (seconds)	0.975	−0.030	−0.163	−0.041	0.981
Cadence (no. of steps/minute)	−0.922	0.149	−0.347	−0.009	0.993
Step time (seconds)	0.921	−0.152	0.351	0.012	0.994
Stance time (seconds)	0.748	−0.215	0.621	0.046	0.993
Step length (cm)	0.030	0.885	−0.276	0.016	0.860
Timed Up and Go test (seconds)	0.137	−0.858	−0.010	0.145	0.776
Velocity (m/second)	−0.504	0.715	−0.354	−0.061	0.895
Double support time (seconds)	0.203	−0.248	0.932	0.079	0.977
Base of support (cm)	−0.015	−0.108	0.067	0.989	0.994

Table 3
Normalised discriminant function of original variables from Factor 2.

Outcomes	Gait parameters	Normalised discriminant function
Step length (cm)		0.889[a]
Timed Up and Go test (seconds)		−0.369
Velocity (m/second)		−0.268

[a] Step length parameter with higher discriminant value between groups.

the matrices of both groups ($P = 0.353$). Wilks' lambda was significant ($P = 0.006$), thereby rejecting the null hypothesis that the value of the discriminant function is the same for both groups. The results revealed that only Factor 2 (distance dimension) remained in the model, with 63% (97/154) of the observations correctly classified by the discriminant function.

In order to determine which variables in Factor 2 were more important in the discriminant function, Fisher's linear coefficient values for step length, gait velocity and Timed Up and Go test score were obtained through discriminant analysis. The variables were first standardised by dividing by the global standard deviation, thereby conserving the original mean of the variables and facilitating the discrimination process. The linear coefficients were then transformed into a normalised interval spanning from −1 to 1. Step length was the variable that best discriminated between elderly women with low and high concern about falls (Table 3).

Discussion

The association between ageing and fear of falling is strong. Since women live longer than men, the risk for women across the life course is higher [24]. The present study investigated if gait parameters and the Timed Up and Go mobility test could discriminate between elderly women with low and high concern about falls. As gait parameters are highly correlated variables, the application of multivariate analysis is appropriate for determination of the independent effect of these parameters on concern about falls [15].

The discriminant model revealed that step length had greater power to discriminate than either gait velocity or the Timed Up and Go test score. Gait velocity is directly proportional to step length in the gait cycle. A reduction in step length, and consequently stride, is one of the strategies used to reduce gait velocity [25,26]. This reduction in step length has been observed in elderly individuals concerned about falls [12]. However, the findings described by Delbaere *et al.* suggest that, under conditions of normal gait, the primary cause of a reduction in gait velocity among elderly individuals is physical limitation [27]. It has recently been demonstrated in a group of elderly individuals (adjusting for age) that the factors most strongly associated with a reduction in gait velocity are reaction time and quadriceps muscle strength [28].

In the present study, physical mobility was determined using the Timed Up and Go test which describes the degree of functional capacity [17] and, as a discriminant tool, the test identifies elderly individuals with difficulties in mobility associated with balance and future falls [23]. Based on the reference parameters described by Bohannon [22], elderly people aged between 60 and 69 years who required, on average, less than 8.1 (range 7.1 to 9.0) seconds to complete the Timed Up and Go test and elderly people aged 70 to 79 years who required less than 9.2 (range 8.2 to 10.2) seconds are identified as independent. Those who require more time are classified as dependent. In the present study, the groups with low and high concern about falls had average scores ranging from 7.1 to 9.4 seconds, with the mean score slightly higher in the group with high concern about falls than in the group with low concern about falls (8.4 and 8.1 seconds, respectively). Therefore, individuals in the high concern group would be classified as dependent, according to Bohannon's classification meta-analysis results [22]. The fact that the Timed Up and Go test was a discriminatory tool between groups highlights the existence of some differences in physical mobility between the groups. However, as the power of discrimination was less than that of step length, it is considered that high concern about falls is primarily related to spatial alterations in gait, such as reduction in step length. However, it is possible that as the group of elderly women investigated in this study gets older, the discriminatory power of these gait parameters might change [29].

In situations of threat or instability, it is natural for an individual to protect themselves by reducing their walking velocity. However, normal (or preselected) velocity is that which produces the most reproducible cycle and at which stability is greatest [30]. Latt *et al.* [31] found that a reduction in step length leads to instability of the head and pelvis in

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the vertical and anterior–posterior directions, thereby affecting the stability of the gait cycle. In a cohort study involving 597 elderly individuals over 70 years of age, Verghese *et al.* [15] found that a reduction in gait velocity of 0.1 m/second increases the risk of falls by 7%, and that participants with a gait velocity equal to or less than 0.7 m/second had a 1.5-fold greater chance of falling than those with a normal velocity. Thus, although it may be a normal reaction, high concern about falls leads to a reduction in step length which contributes towards a more unstable gait and an even greater risk of falling.

The step length difference found between the two groups was 6.0 cm, which could clearly affect gait stability [31]. In clinical settings, step length can be measured easily with simple instruments such as paper and ink. Therefore, step length could be used as a screening tool to identify those with low and high concern about falls. In addition, exercise prescription is the most important tool that physiotherapists have in their arsenal [32]. Adding specific exercise programmes to improve step length could target those groups more prone to falling by preventing reduction in gait velocity and loss of mobility.

The fact that the base of support and duration of double support were isolated in separate factors demonstrates that these gait parameters do not correlate with one another or with the other variables, since grouping into factors is achieved by correlation. Even as independent variables, the analysis did not indicate these factors to be discriminant. An association between the duration of double support and stride width has been reported in individuals with a fear of falling [9,10]. In one study, differences in double support time between a group with low concern about falls and another with high concern about falls were only found when walking was performed in elevated walkway conditions [27]. Therefore, it is believed that the increase in both the base of support, which is a measure of stability, and double support time when walking in normal conditions could be used as characteristics of individuals with less concern about falls that are not accentuated in individuals with high concern about falls.

In the present study, the intensity of the fear of falling was assessed using the FES-I [7]. The FES-I is an expanded version of the original FES designed in 1990 by Tinetti *et al.* [33], and involves different activities of daily living, thereby portraying the concern an individual has upon performing these activities. The self-report of falls was used as the classification variable for the cut-off point of the FES-I, which, although it has been considered to have poor sensitivity for the degree of concern an individual has when performing particular activities [2], reflects a specific fear to some extent. The result was a cut-off point of 20. Sixteen of the 81 elderly women who reported not being afraid of falling were included in the high concern group. Delbaere *et al.* [27] classified individuals who marked seven or more items on the FES-I as having high concern about falls, which resulted in a cut-off point of 22. The present authors believe that both methods were adequate for the decision regarding the cut-off point. An advantage of the present study was the addition of two scales that reflect fear and concern about falls to the cut-off point.

Limitations

The specific reasons why step length, gait velocity and Timed Up and Go test score discriminated between groups of women with low and high concern about falls could not be determined due to the cross-sectional nature of the study. It is possible that other factors not measured in the present study, such as loss of range of motion, reduced strength, sedentary lifestyle, etc., may have contributed to this outcome [28,34]. Thus, longitudinal studies are needed to clarify these aspects. In addition, to extend the present results to other groups of individuals, it is important to carry out studies involving elderly men, as the gender factor changes the association between gait parameters and fear of falling [35].

Conclusion

The present study adds to existing knowledge about gait parameters that are more sensitive to concern about falls, and may be useful in the identification of elderly women with high concern about falls. Fear of falling, activity restriction and gait alterations are important variables in the transition toward frailty [8]. As rehabilitation programmes for elderly individuals should include gait training or have a gait parameter as the response variable, knowledge regarding these parameters can assist in decisions involving intervention programmes designed to prevent falls, fear of falling and functional decline.

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