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VARIABILITY AND RELIABILITY OF GAIT KINEMATIC PARAMETERS AFTER CONTROLLED TRIPPING IN OLDER ADULTS: A PRELIMINARY STUDY

VARIABILIDADE E CONFIABILIDADE DOS PARÂMETROS CINEMÁTICOS DA MARCHA DE IDOSOS APÓS UM TROPEÇO CONTROLADO: ESTUDO PRELIMINAR

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ABSTRACT
Approximately 21% of the falls in older adults occur due to tripping, while walking. There is a paucity of information regarding the gait variability and reliability when a tripping is induced in different days mainly with elderly. It was aimed to analyze the variability and the reliability (intra- and inter-day) of spatiotemporal gait parameters and joint angles after controlled tripping in older adults. Eight healthy older women participated. The trip was induced during the early-mid swing phase on the transposing segment and the kinematic data was obtained from trials. The variability and reliability of spatiotemporal gait parameters and joint angles during the gait cycle were checked through the coefficient of variation (CV), the intraclass coefficient correlation (ICC) and the standard error of measurement (SEM). The variability of spatiotemporal and intra- and inter-day angular parameters was low for most variables, except for plantar flexion. The SEM was low for all parameters. Intra-day reliability was moderate to high for the spatiotemporal and angular parameters. Inter-day reliability was considered low to moderate for all parameters. The variables did not differ between instants and days. Experimental procedures demonstrate that the walking pattern did not change, but should be considered with caution in studies that include intervention, particularly for angular parameters during gait.
Key words: Stumble. Falling. Elderly.

RESUMO
Aproximadamente 21% das quedas em idosos ocorrem como consequência de tropeços ao caminhar. Há uma escassez de informações referentes à variabilidade e à confiabilidade dos parâmetros cinemáticos da marcha em diferentes dias de avaliação, sobretudo com idosos. Buscou-se analisar a variabilidade e a confiabilidade (intra e inter-dia) dos parâmetros espaço-temporais e angulares da marcha de idosos, após a indução de tropeço controlado. Oito idosas participaram do estudo. O tropeço foi induzido durante o início da fase de balanço da marcha. Foram analisados os dados cinemáticos das tentativas de marcha. A variabilidade e confiabilidade dos parâmetros espaço-temporais da marcha foram verificados através do coeficiente de variação (CV), do coeficiente de correlação intraclasse (ICC) e do erro padrão de medida (SEM). A variabilidade dos parâmetros espaço-temporais e angulares intra e inter-dia foi baixa para a maioria das variáveis, à exceção da flexão plantar. O SEM foi baixo para todos os parâmetros. A confiabilidade intra-dia foi moderada a alta para os parâmetros espaço-temporais e angulares; A confiabilidade inter-dia foi baixa a moderada para todos os parâmetros. As variáveis não diferiram entre instantes e dias. Apesar do padrão de marcha não ter alterado deve ser analisado com cautela em estudos que incluam intervenção, particularmente para os parâmetros angulares.
Palavras-chave: Tropeço. Queda. Envelhecimento.

Introduction

Falls are a major public health concern[1], as the rate of older adult population and the absolute number of falls have increased in the last decades[2]. Approximately 21% of the falls in older adults occur due to tripping, while walking forward (accounting for 24%)[3] and may result in serious injury and/or even death[4]. Then, understanding the underlying mechanisms involved in tripping are required and may help to improve preventive and intervention procedures designed to reduce falls among older adults[5,6]. Most studies devoted to determine fall incidence have applied retrospective and/or prospective approaches, which are prone to a number of issues that may obscure the results[7,8]. These approaches are unable to identify nearfall or missteps, which are relevant while assessing risk of falls[9,10] and also disregard changes in physical activities with respect to time, i.e., the physical characteristics may vary from the instant they were assessed and the trip or fall occurred. In addition, retrospective studies rely on memory[11-13], which is not always reliable especially if the fall did not produce significant injuries.

Innovative approaches to induce laboratory trip during walking include obstacle rising to obstruct the swing foot motion[14-17] or restricting the swing foot motion using a rope or similar devices[18,19]. Despite the fact that these methods can create approximate conditions that closely simulate a trip, anticipatory adjustments have been shown to influence the results when repeated trips are performed in one session (i.e., intra-session variation)[15,17]. Although intra-day gait kinematics variability has been found low (10-17%)[14], there is a paucity of information regarding to inter-day variability and reliability when an induced trip is repeated between sessions. Low variability and high reliability inter-day would entitle one to use laboratory controlled tripping tests to evaluate the effects intervention programs (i.e., training programs) on a person's ability to recover from a trip and avoid a fall.

In addition, most studies[14,15,20] that analyzed reproducibility measures in laboratory induced trips included only young subjects, rather than old adults. There are several indications that these populations differ with respect to their ability to recover from a trip[21], in which older adults are less able to regain balance and, therefore, more vulnerable to falls[20]. Although Wright and colleagues[22] showed that previous experience of falling did not result in gait pattern changes, others have reported a more cautious pattern due to fear of tripping and falling[23], which may occur within and between sessions. Older adults tend to be more susceptible to fear of falling than their young counterparts[23]. Thus, the use of a non-specific population in previous investigations (i.e., young subjects) may have clouded the results and requires further research[2].

Therefore, this study aimed to determine the variability and the reliability (intra- and inter-day) of spatiotemporal gait parameters and joint angles after a controlled laboratory tripping in older adults using a novel approach. This system may be used as a plausible method to better understand movement control and organization without some drawbacks and disadvantages of others and help to design preventive fall-related strategies. It has been hypothesized that no differences within and between sessions will be found in gait pattern. If subjects do not change their gait pattern after tripping, such test may be applied repeatedly to induce a trip on a laboratory environment.

Methods

Participants

Eight healthy older women, independent in daily activities (70.2 (5.8) years; 69.6 (10.2) kg; 1.56 (0.03) m) were recruited through advertisements at the Sports Science Department and volunteered to participate of the study after signing an informed consent form in conformity with Helsinki Declaration of 1975, as revised in 1983. The local Ethics Committee approved the experimental procedures (protocol number 664.638). The functional status of each elderly subject was assessed using the Timed-up-and-go test (TUG). The short time to perform the TUG test (7.50± 0.75 s) indicates the healthy status of our sample[24].

Procedures

Participants visited the laboratory twice to determine variability and reliability of spatiotemporal gait parameters and joint angles after the tripping simulation. In the first day, participants performed 10-15 gait trials (pre-trip). The trip was induced once between the 10^{th} and the 15^{th} trial. After tripping, an additional set of 10-15 gait trials were performed (post-trip)[1]. Three months later, identical experimental procedures were performed in a second visit to the laboratory. In both visits, participants were requested to walk using a self-selected pace on a walkway of 10 m long and 2 m wide, with a force plate (AMTI OR6-7, MA, USA) mounted after 3 m from starting position. A full-body safety harness attached to a ceiling-mounted rail was used to prevent individuals to hitting the ground after failing to recovery from the trip. Participants were instructed to walk at a self-selected velocity over the long walkway. They were advised that their balance could be perturbed during the experiment, but no information about how and the instant the perturbation would occur was provided. To induce the trip, an automated customized electronic device lifted a wire crossing the walkway (0.1 m height), catching the participant's swinging segment. The device was triggered when the participants' left foot was in the early-mid swing phase, while the right foot was in contact with the force plate. Three non-functional but identical dummy wires were placed in the walkway and were deemed not to influence gait (Figure 1). This novel approach differs from others because it uses an automated system in which a wire is raised from the ground to produce a perturbation during the early-mid swing phase of the trailing limb. It is also cheaper and easier to induce trips in a controlled laboratory scenario, as there is no need of a complex apparatus to obstruct the swinging segment during gait.

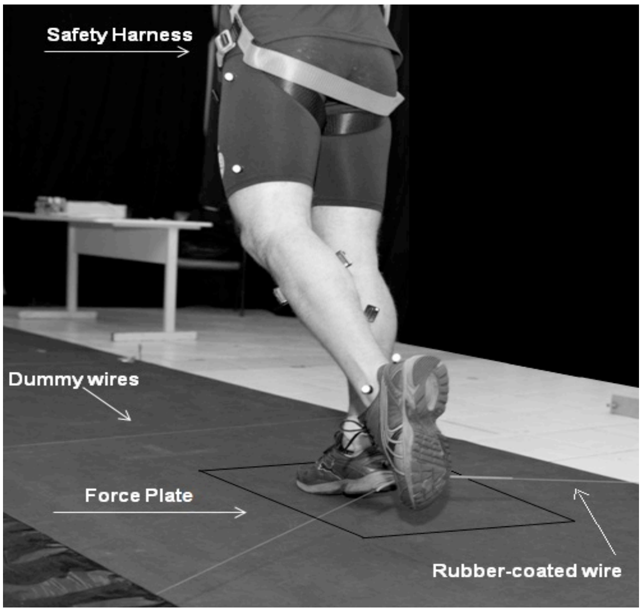

Figure 1. Experimental setup representation
Source: The authors

During the gait trials, kinematic data were collected using nine infrared opto-electronic cameras (MX13/T10, Vicon, Denver, USA) sampling at 100 Hz. Fifteen landmarks (sacrum, right and left anterior superior iliac spines, thighs, knees, tibias, lateral malleolus, toes and heels) were placed on participants' lower limb according to the Helen Hayes Sacrum Plug-in-gait model. The spatiotemporal gait parameters (walking speed, stride time, stance time and stride length) and joint angles (peak flexion and extension of hip and knee joints, and ankle dorsiflexion and plantarflexion) during the gait cycle were measured. Data processing was performed through a specific routine in Matlab® (MathWorks, Inc., version 7.8.0-R2009a). The time series were normalized by the gait cycle (100%) using the Spline function, considering two successive contacts of the heel of the same limb. The three-dimensional coordinates were filtered with a low pass 2nd order Butterworth filter with a cutoff frequency of 10 Hz. Then, the ensemble average of three trials immediately before the trip was calculated to represent the pre-trip data set. The ensemble average of three trials immediately following a trip was calculated to determine the effects of tripping on walking parameters (post-trip).

Statistical Analysis

Intra- and inter-day variability of spatiotemporal gait parameters and joint angles were calculated using the mean coefficient of variation (CV), calculated from the three trials (ensemble average) of each subject. In addition, the intraclass correlation coefficient ($ICC_{3,k}$) and standard error of measurement (SEM) were used to check the reliability intra-subject (three trials), intra- (pre- and post-trip for each day) and inter-day (day 1 and day 2 at pre-trip and post-trip instants). As suggested by Portney and Watkins, ICC values above 0.75 indicated good reliability, those between 0.5 and 0.75 moderate reliability and those under 0.5 poor reliability[25]. After determining data normality, a two-way repeated measure ANOVA was performed, having instant (pre- and post-trip) *vs.* day (first and second days) as inputs. In order to support rejection or acceptance of the null hypothesis (considering the current sample size) or to support results from descriptive statistics the partial eta squared effect size (η^2) and power were calculated[26]. All analyses were performed using SPSS version 20.0 (SPSS Inc., Chicago, IL) with the significance level set at $p < 0.05$.

Results

The CV intra- and inter-day ranged from 1.3 to 4.0% to the spatiotemporal parameters of gait. The CV intra- and inter-day of the joint angles ranged from 1.7 to 33.0%, with the highest CV% for the plantar flexion angle. There was only significant interaction effect between instant and day to the absolute values of stride time ($F_{(1,7)}$=6.89, p=.03, η^2=0.49, power=0.62), increasing in average 1% from the 1st to the 2nd day (Table 1).

Table 1. Mean (SD), 95% confidence interval ($CI_{95\%}$), and mean coefficient of variation (CV) of spatiotemporal gait parameters and joint angles at pre- and post-trip measurements in different days (n=8)

	DAY 1				DAY 2				
	Pre-Trip		Post-Trip		Pre-Trip		Post-Trip		
Variables	Mean(SD) ($CI_{95\%}$)	Mean CV%	Mean(SD) ($CI_{95\%}$)	Mean CV%	Mean(SD) ($CI_{95\%}$)	Mean CV%	Mean(SD) ($CI_{95\%}$)	Mean CV%	*F*
Walking speed (m/s)	1.18 (0.14) (1.06-1.30)	3.61	1.18 (0.14) (1.06-1.30)	3.73	1.15 (0.12) (1.05-1.25)	3.32	1.17 (0.14) (1.05-1.29)	2.57	1.32
Stride time (s)	1.06 (0.08) (1.00-1.12)	2.47	1.06 (0.08) (1.02-1.15)	2.13	1.08 (0.08) (1.02-1.15)	1.81	1.07 (0.07) (1.00-1.13)	1.37	6.90*
Stance phase (% of cycle)	62.10 (2.49) (60.02-64.18)	1.78	62.16 (2.73) (60.92-64.66)	1.39	64.35 (3.66) (61.28-67.41)	1.40	64.17 (2.03) (62.48-65.87)	1.90	0.08
Stride length (m)	1.25 (0.08) (1.18-1.31)	2.62	1.25 (0.08) (1.18-1.31)	2.67	1.25 (0.08) (1.18-1.31)	2.51	1.24 (0.10) (1.16-1.33)	2.37	0.02
Peak hip Flexion (°)	29.50 (5.66) (24.76–34.23)	2.84	30.76 (6.12) (25.65–35.88)	5.39	26.04 (9.31) (18.26-33.83)	2.87	26.13 (10.10) (17.69–34.58)	3.54	1.60
Peak knee Flexion (°)	58.15 (4.42) (54.46 –61.85)	1.76	59.96 (4.91) (55.85–64.03)	2.44	59.54 (3.95) (56.23-62.84)	2.07	60.42 (5.03) (56.21-64.62)	2.27	1.12
Peak ankle dorsiflexion (°)	18.12 (3.08) (15.55–20.70)	3.05	18.25 (2.46) (16.19–20.31)	3.89	18.31 (3.68) (15.23-21.39)	4.27	18.77 (3.63) (15.74–21.80)	4.50	0.25
Peak plantar flexion (°)	-7.76 (4.09) (-11.18- -4.34)	31.02	-7.46 (4.66) (-11.36- -3.56)	32.49	-6.87 (2.02) (-8.56– -5.18)	16.33	-6.22 (3.40) (-9.06- -3.73)	3.00	0.16

Note: *Significant interaction between session and day. F values referent to interaction effect
Source: The authors

The calculated SEM presented low values for all analysis. The ICC intra-day ranged from 0.66 to 0.97 for the spatiotemporal parameters, considering the lowest ICC to stance phase variable and from 0.66 to 0.99 to joint angles, with the lowest ICC value to plantar flexion. In addition, the ICC inter-day ranged from 0.44 to 0.65 to spatiotemporal gait parameters and from 0.16 to o.67 to joint angles (Table 2).

Table 2. Intraclass correlation coefficient ($ICC_{3,k}$) and Standard error measurement (SEM)of spatiotemporal gait parameters and joint angles at pre- and post-trip measurements in different days (n=8).

	Day 1			Day 2			
	Pré-Trip	Post-Trip		Pré-Trip	Post-Trip		
Variables	ICC^a SEM^a	ICC^a SEM^a	ICC^b SEM^b	ICC^a SEM^a	ICC^a SEM^a	ICC^b SEM^b	ICC^c SEM^c
Walking speed	0.89	0.95	0.97	0.93	0.94	0.94	0.52
(m/s)	0.05	0.03	0.00	0.03	0.04	0.00	0.01
Stride time	0.86	0.91	0.97	0.93	0.92	0.96	0.54
(s)	0.03	0.02	0.00	0.02	0.02	0.00	0.01
Stance phase	0.67	0.89	0.93	0.93	0.44	0.66	0.44
(% of cycle)	1.43	0.91	0.01	0.97	1.52	0.07	1.13
Stride length	0.82	0.89	0.93	0.89	0.90	0.92	0.65
(m)	0.03	0.03	0.00	0.03	0.03	0.00	0.00
Peak hip Flexion	0.97	0.88	0.94	0.99	0.99	0.99	0.40
(°)	0.98	2.12	0.22	0.93	1.01	0.01	2.21
Peak knee Flexion	0.94	0.85	0.91	0.85	0.81	0.86	0.28
(°)	1.08	1.90	0.38	1.53	2.19	0.23	0.55
Peak ankle	0.96	0.90	0.95	0.95	0.94	0.92	0.67
dorsiflexion (°)	0.62	0.78	0.02	0.82	0.89	0.09	0.14
Peak plantar flexion	0.96	0.86	0.94	0.74	0.91	0.66	0.16
(°)	0.82	1.75	0.05	1.03	1.02	0.27	0.69

Note: ICC^a and SEM^a intra-subjects reliability; ICC^b and SEM^b: intra-day reliability; ICC^c and SEM^c: inter-day reliability
Source: The authors

Discussion

This is the first study to determine the variability and the reliability (intra- and inter-day) of spatiotemporal gait parameters and joint angles after a controlled tripping in older adults. Such results are relevant as previous studies are limited because young subjects are known to present substantial differences in their ability to recover from a trip when compared to older adults. Considering the intra- and inter-day analyzes, the variability of spatiotemporal gait parameters was low and joint angles variability varied from low to moderate[27]. Furthermore, reliability of gait and joint angles was moderate to high[25].

The mean walking speed (1.18±0.14 m/s), stride time (1.06±0.08 s) and stride length (1.25±0.08 m) are comparable to those reported by Hollman and colleagues[28] for women of similar age (1.16±0.20 m/s; 1.06±0.13 s; 1.23±0.17 m). These results are also similar to the group that experienced a previous fall due to tripping (1.19±0.20 m/s; 1.06±0.08 s; 1.26±0.17 m)[22]. The findings of Wright and colleagues[22] showed no differences in gait kinematics when non-fallers were compared to individuals with a fall history, irrespective of the cause of the event (i.e., trip or slip). Therefore, the idea that a conservative or cautious gait pattern emerges after a trip was also discarded in the present study, even when tripping is repeated after a brief period of time, i.e., within session. It is likely that tripping was not a significant event (i.e., did not cause an injury) when compared to a fall.

The significant interaction found in the stride time may have occurred due to the high variability between individuals (i.e., large standard deviations), although the average change was low. Indeed, a similar stride time CV (2.2±1.3%) was reported in a previous study for healthy elderly[29]. In addition, the spatiotemporal gait parameters presented lower mean variability (1-4%) in comparison to the study performed by Hollman and colleagues[28] for older women (3-8%), but similar to previous that included young and older adults[30]. Moreover, most gait variables used to determine gait pattern remained stable (intra-day variability) after participants' tripping and indicated gait pattern consistence[31].

The low intra-day variability of knee and hip joint angles displacements are in agreement with previous experiments[14]. On the other hand, the ankle joint variability was high (~32%), but non-significant and stable between pre- and post-tripping in the first day, considering the respective coefficients of variation. These results are in agreement with Pijnappels and colleagues[14], who reported high ankle joint variability for young adults (37-53%).

The intra- and inter-day reliability of spatiotemporal gait parameters varied from moderate to high (ICC: 0.66-0.99) and were comparable to those reported by Menz and colleagues[31], in which the gait pattern of older adults was analyzed in different days. In general, joint angles presented moderate to high intra- and inter-day reliability, except during plantar flexion and knee and hip flexion in the inter-day assessment. These results do not represent a strategy change, considering the intra-day stability and the low error measurements. In addition, these low to moderate ICC values indicated greater within-subjects variance. In fact, part of the variability between individuals may have occurred from particular characteristics of walking pattern[14].

Conclusions

In conclusion, the findings of spatiotemporal gait parameters and joint angles suggests that such approach can be applied to determine changes in response to intervention programs (e.g. dancing, strength, power, etc.) designed to improve gait and reduce the risk of falls in older adults. Importantly, however, that you must be careful when analyzing the results from interventions, particularly for angular parameters. Therefore, the experimental procedures applied to induce a trip in a laboratory controlled condition were deemed not to affect gait pattern within and between sessions and allowed to confirm our experimental hypothesis. The experimental approach did not cause any discomfort or injuries and was proven to be a safe, cheap and useful strategy to test the ability of older adults to regain balance in a condition that closely mimics a real trip situation.

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