Gait & Posture 72 (2019) 76–81

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Gait profile score identifies changes in gait kinematics in nonfaller, faller and recurrent faller older adults women

Guilherme Augusto Santos Bueno[a,b], Darlan Martins Ribeiro[a,b], Flávia Martins Gervásio[b], Anabela Martins Correia[c,*], Ruth Losada de Menezes[a]

[a] Postgraduate Program in Health Sciences and Technologies, University of Brasília, Federal District, DF, Brazil
[b] Movement Laboratory Dr. Cláudio A. Borges, College of Sport, State University of Goiás, Goiânia, Goiás, Brazil
[c] Physiotherapy Department, Polytechnic Institute of Coimbra ESTeSC - Coimbra Health School, Coimbra, Portugal

ARTICLE INFO

Keywords:
Fall in the elderly
Age effects
Gait
Gait profile score
Reliability

ABSTRACT

Background: Quantification of differences in gait kinematics between young and older adults provides insight on age-related gait changes and can contribute to the investigation of risk of falls. Gait Profile Score (GPS) is an index that indicates gait quality, using kinematic gait data, but so far it has not been used in an elderly population without neurological conditions.
Research question: Is the Gait Profile Score (GPS) an index that shows reliability for use in old adults? Does this index detect changes in gait quality observed by kinematic data between nonfaller, faller and recurrent faller older adults?
Methods: Forty-nine women (mean age 72,43 ± 6,44; 27 faller and 22 nonfaller) were included in the study. Intra-session reliability was obtained from the intraclass correlation coefficient (ICC) between the five strides of each session.
Results: Overall value of GPS shows no difference between nonfaller (6.65 ± 1.59º), faller (6.67 ± 2.05º) and recurrent faller (6.62 ± 0.86º) older adult. In all groups larger values of Gait Variable Scores (GVS) were observed in the hip and knee joints. Intra-session ICC values the GVS and GPS presented high stability, ranging from 0.80 to 0.99. MDC lower values in GPS were observed in the faller (0.39; ICC - 0.97) and recurrent faller (0.69; ICC – 0.90).
Significance: Due to the high reliability, GPS has proven to be a valid method to analyze the gait quality of faller and nonfaller older woman. The most sensitive indexes (GPS and GVS) are the gear changes in fallers and recurrent fallers.

1. Introduction

Gait kinematic assessment may be an important clinical tool to screen older adults with increased risk of fall [1]. However, a large amount of data is offered by kinematic gait analysis, and there is a difficulty of rapid and direct clinical interpretation [2]. In order to compare global gait scores for clinical populations to control populations, methods have been developed by incorporating a number of different kinematic parameters that would allow to quantify and compare kinematic gait characteristics in a more direct and simple way. Some popular kinematic indexes are the Gillette Gait Index (GGI) [3], the Gait Deviation Index (GDI) [4] and the Gait Profile Score (GPS) [5].

Quantification of differences in gait kinematics between young and older adults provides insight to how gait changes according to physiological changes [6]. Despite sizable interest in determining how age changes the walking mechanics, varied outcome measures have precluded a comprehensive understanding of the impact of age on lower extremity joint kinematics and kinetics [6,7]. The investigation of the influence of age on gait kinematics generates discussions about the changes that may predict future falls. In a recent study that took spatiotemporal parameters as kinematic variables, stance time variability, swing time, and stride length had sensitivity of 70% or higher to predict falls [8]. Precise differences in angular kinematic parameters between fallers and nonfallers old adults are observed [9]. Analyzing joint

* Corresponding author at: Centro Metropolitano, conjunto A, lote 01, Unidade de Ensino e Docência - UED, 1º andar, sala A1-04/67, Brasília, DF, CEP: 72220-275, Brazil.
E-mail addresses: bueno.guilherme@aluno.unb.br (G.A. Santos Bueno), darlan.ribeiro@hotmail.com (D.M. Ribeiro), flavia.gervasio@hotmail.com (F.M. Gervásio), anabelacmartins@estescoimbra.pt (A.M. Correia), ruthlosada@unb.br (R.L. de Menezes).

https://doi.org/10.1016/j.gaitpost.2019.05.029
Received 6 January 2019; Received in revised form 24 May 2019; Accepted 27 May 2019
0966-6362/

kinematic characteristics, Kerrigan [10] pointed a reduction in hip extension was the parameter that stood out in the older adults with history of fall. Gait parameters in older women are more related to the risk of falling, than the same analysis performed in men [11]. The need to concentrate the interpretation on the changes of the kinematic parameters of gait generated by the age and fall is what justifies the investigation of an index that adds kinematic parameters of gait in the three planes of movement, obtaining in the end a general measurement.

The GPS has been validated as an effective measure of gait quality [12]. Initially GPS was created to evaluate the gait of children with cerebral palsy [5]. However, some studies have used it in other populations persons with such as Parkinson's disease [13], post-stroke [2], Achondroplasia [14], and multiple sclerosis [15]. Due to the relevance of studying changes in the gait variables pattern across the lifespan, and the relevance of direct and precise measurements for clinical purposes, we believe that this index might be relevant for this population.

Authors pointed out that for GPS values to establish their clinical utility, there is a need for a prior reliability investigation [2,12,16]. To ensure the reliability of kinematic gait data, it is recommended to include absolute measures of measurement error and the minimum detectable change (MDC) [17]. The reliability analysis of gait kinematic parameters in elderly and adult participants is present in studies such as de Kesar and collaborators [16], where they found excellent test-retest reliability for all gait variables tested (Intraclass Correlation Coefficients = 0.799-0.986) in post-stroke. Devetak and collaborators [2], analyzed the reliability of gait kinematic parameters also in post-stroke adults, but using GPS and GVS and also found high reliability (Intraclass Correlation Coefficients between 0.81 and 0.93). Other authors have reported reliability data and GPS MDC for children with cerebral palsy [12] and individuals with spinal cord injury [18]. However, we did not find studies that used GPS in the elderly without neurological conditions, nor did they investigate the reliability and MDC in this population.

The objectives of this work are to analyze the reliability of GPS, to present the MDC values for older adult women, and to identify if the GPS is an index that differentiates a profile of the kinematic parameters of gait between nonfaller.

2. Method

2.1. Study design

This study was approved by the Research Ethics Committee of the University of Brasília (n. 2.109.807). All participants provided written informed consent.

2.2. Sample

A priori the sample calculation was carried out with data from the pilot study, composed of five faller and five nonfaller older adults, using G.Power 3.1 software (Franz Faul, Universitat Kiel, Germany). For this calculation, the Gait Profile Score Overall deviations were used in the fallers (7.95 ± 0.29) and non-falers (7.76 ± 0.21). Using the *t*-test (Student's T-Test), considering a power of 0.80, $\alpha = 0.05$, and having effect size (d Cohen) of 0.89. Considering a lost of 10% of the data, the total sample size required was 47.

Inclusion criteria as follows: (i) woman; (ii) age 65 or over; (iii) independent walking without aids; (iv) absence of previous surgeries in the lower limbs, pelvis or spine; (v) body mass index (BMI) < 30 kg/m^2; (vi) preserved cognition (Mini-Mental State Examination (MMSE) > 14 [19]; (vii) have no medical diagnosis of rheumatoid arthritis, neuromuscular or neurodegenerative disease, including diabetes mellitus; (viii) no visual impairment; (ix) declare that she has not ingested alcoholic beverages within 24 h prior to data collection.

2.3. Procedure

Participants were classified according a history of falling, answering the question: During the past 12 months, have you had any falls? Yes/No. If yes, participant was further asked on number of falls. Faller was defined as an individual who had at least one fall in the past 12 months. Recurrent faller was defined as an individual who had ≥2 falls in the past 12 months. It was considered fall as “an unexpected event, in which the participant comes to rest on the ground, floor, or lower level” and “excluded coming to rest against furniture, wall, or other structure”.

The Falls Efficacy Scale-International, with its transcultural validation to the Brazilian population [20], was applied to interpret the fear of falling (FOF).

All participants underwent gait assessment. The data were captured at a frequency of 120 Hz by five Bonita B10 cameras (Vicon Motion Systems Ltd®, Oxford Metrics Group, Oxford, UK) and two cameras, model Vero v1.3x (Vicon Motion Systems Ltd®, Oxford Metrics Group, Oxford, UK). Participants were instructed to walk barefoot at a self-selected speed, on a 9 m path. Kinematic data were collected from the 3 m in the middle of the path. Data were processed by 4th order digital Butterworth filter with cut-off frequency of 10 Hz [9].

2.4. GPS and MAP calculation

The generated kinematic data graphs were normalised to a percentage of the gait cycle, using 51 time-normalized samples for each stride. The averaged values of five consistent trials from each limb were analysed. The GPS and the nine GVS domains were calculated using the spreadsheet available in [21], according to the method reported by Baker and collaborators [5]. In this study, the normal group consisted of 15 adults women with an average age of 24.8 ± 6.8 years old. The data set contained five trials from each subject, resulting in 75 cycles on each lower limb.

The GPS is a single index outcome measure that summarizes the overall deviation of a person’s kinematic gait data relatively to normative data [5,12]. The GPS can be decomposed to provide GVS index scores for nine key relevant kinematic variables, which are presented alongside the GPS in a simple figure called the Movement Analysis Profile (MAP). Specifically, GVSs were calculated for: pelvic tilt, obliquity and rotation; hip flexion/extension, abduction/adduction and internal/external rotation; knee flexion/extension; ankle plantar/dorsiflexion; foot progression; and, a total GVS for each lower limb. These variables were grouped in the MAP, which was generated for each participant [5]. The parametric Student’s *t*-test was used to compare the faller and nonfaller.

2.5. Data analysis

In order to determine within-session reliability, the intraclass correlation coefficient (ICC) of the GPS values were calculated for five strides within the same session using a two-way mixed model for absolute agreement. Intraclass reliability was estimated by calculating the ICC between the values obtained for each group (faller and nonfaller).

Statistical calculations were performed using IBM SPSS package version 23.0 (IBM, Chicago, USA). Reliability was classified as low, moderate, or excellent, according to the following criteria: an ICC greater than 0.75 was considered excellent, an ICC between 0.40 and 0.75 was moderate, and an ICC lower than 0.40 was classified as low [22].

To calculate the MDC of the GVS and GPS for each group, the standard measurement error (SEM) was estimated using the ICC values between trials, according to Eq. (1) [23]. MDC was then obtained from the SEM according to Eq. (2) [23].

$$SEM = SD\,x\,\sqrt{1 - ICC} \quad (1)$$

Table 1
Characteristics of nonfaller (n = 27), faller (n = 12) and recurrent faller groups (n = 10).

	Nonfaller		Faller		Recurrent faller		p^a (ω)
	Mean (SD)	CI (95%)	Mean (SD)	CI (95%)	Mean (SD)	CI (95%)	
Age (years)	72.59 (6.81)	69.90 – 75.26	72.75 (5.67)	69.14 – 76.35	71.00 (6.83)	66.71 – 76.48	0.903 (0.04)
Weight (kg)	59.63 (8.63)	56.21 – 63.04	64.48 (9.42)	58.49 – 69.47	58.52 (9.01)	51.27 – 65.76	0.235 (0.02)
Height (m)	1.54 (0.05)	1.52 – 1.56	1.56 (0.05)	1.53 – 1.60	1.51 (0.07)	1.45 – 1.56	0.083 (0.08)
BMI (kg/m^2)	25.07 (3.77)	23.57 – 26.56	26.15 (3.07)	24.20 – 28.10	25.53 (3.65)	22.92 – 28.15	0.683 (0.04)
MMSE (score)	26.74 (2.75)	25.65 – 27.83	25.58 (3.92)	23.06 – 28.10	27.00 (2.16)	25.45 – 28.55	0.460 (0.07)
FES-I (score)	28.96 (7.83)	25.86 – 32.06	24.17 (5.09)	20.93 – 27.40	31.00 (5.16)	27.31 – 34.69	0.053 (0.11)
Cadence (step/min)	108.74 (10.50)	104.58 – 112.89	109.65 (10.84)	102.72 – 116.56	112.63 (7.05)	107.58 – 117.67	0.580 (0.09)
Stride Length (m)	1.02 (0.08)	0.96 – 1.10	1.10 (0.04)	1.04 – 1.16	1.04 (0.05)	0.96 – 1.12	0.326 (0.06)
Walking Speed (m/s)	1.00 (0.15)	0.94 – 1.07	1.02 (0.16)	0.91 – 1.12	0.99 (0.13)	0.89 – 1.09	0.508 (0.02)

Note: SD, standard deviation; CI, Confidence Interval for Mean.; kg, kilogram; m, meters; BMI, Body Mass Index; kg/m2, kilogram/square meters, meters/seconds [a] p value for the comparison by ANOVA one way, ω – effect size.

$$MDC = SEM * 1.983 * \sqrt{2} \quad (2)$$

The value of 1.983 corresponds to the Student's *t*-test distribution for the confidence interval adopted (95%) for this sample size.

3. Results

Forty-nine women (age 7243 ± 644 years; 27 nonfallers, 12 fallers and 10 recurrent fallers) were included in the study. The groups studied were homogeneous for the discriminative variables, FES-I score and walking speed. (Table 1).

The GPS has a reduction in the elderly population, however it is not different between nonfaller, faller and recurrent faller older adults (p = 0.969, ω = 0.08). The same finding occurs in the domains of GVS, for each lower limb. However, it is common in all groups that bilaterally hip and knee flexion and extension are the parameters of greater GVS variation (Table 2).

Table 3 shows the ICC, SEM and values between trials for each variable of interest, and individually for each group. In all groups, all variables presented high reliability between trials, with ICC values ranging from 0.80 to 0.99. With the exception of Pelvic Rotation (GVS) with ICC of 0.77 in the faller and recurrent faller groups.

Table 4 shows correlations of age, stride length and walking speed with GPS and GVS, in the total sample and in each subgroup. Age and stride length contributed a lot to the increase of GPS and some GVS variables in nonfaller. Walking speed correlated with increased ankle and knee GPS variation in the faller group, and only in the ankle joint showed correlation in the nonfaller group. Age, stride length and walking speed did not correlate with GPS and GVS of the recurrent faller group.

4. Discussion

The GVS and GPS values show changes in normal gait in both groups. Since larger GVS and GPS values indicate a more abnormal gait

Table 2
GPS and GVS values obtained for nonfaller (n = 27), faller (n = 12) and recurrent faller groups (n = 10).

	Nonfaller		Faller		Recurrent faller		p^a (ω)
	Mean (SD)	CI (95%)	Mean (SD)	CI (95%)	Mean (SD)	CI (95%)	
GPS (º)							
Left	6.27 (1.38)	5.66 - 6.88	6.22 (1.63)	5.19 – 7.26	6.33 (1.11)	5.54 – 7.12	0.985 (0.04)
Right	6.45 (1.87)	5.63 - 7.28	6.64 (2.45)	5.08 – 8.20	6.23 (0.81)	5.65 – 6.81	0.819 (0.06)
GPS (Overall) (º)	6.65 (1.59)	5.94 - 7.35	6.67 (2.05)	5.36 – 7.97	6.62 (0.86)	6.01 – 7.24	0.969 (0.08)
GVS (º)							
Pelvic Tilt (º)	5.55 (3.92)	3.82 - 7.29	6.28 (4.04)	3.72 – 8.85	4.68 (3.79)	1.97 – 7.39	0.663 (0.01)
Hip Flex/Ext (º)							
Left	8.15 (3.97)	6.39 - 9.92	8.19 (4.33)	5.44 – 10.94	7.12 (3.73)	5.44 – 10.79	0.989 (0.03)
Right	7.92 (5.43)	5.52 - 10.33	7.66 (4.37)	5.84 – 10.83	6.63 (4.51)	5.51 – 9.71	0.754 (0.02)
Knee Flex/Ext (º)							
Left	7.57 (1.94)	6.70 - 8.43	7.12 (1.79)	5.98 – 8.25	8.10 (2.07)	6.62 – 9.58	0.688 (0.06)
Right	7.90 (2.42)	6.83 - 8.97	7.70 (2.61)	6.04 – 9.36	8.15 (2.29)	6.51 – 9.78	0.804 (0.01)
Ankle Dors/Plan (º)							
Left	4.52 (2.05)	3.61 - 5.43	4.66 (1.87)	3.92 – 5.40	4.54 (1.74)	3.29 – 5.78	0.969 (0.01)
Right	4.59 (1.27)	4.02 - 5.15	4.34 (1.40)	3.45 – 5.24	4.88 (1.09)	4.10 – 5.66	0.689 (0.02)
Pelvic Obl (º)	3.16 (1.48)	3.44 - 4.98	2.96 (1.82)	1.80 – 4.11	3.40 (1.00)	2.69 – 4.11	0.388 (0.03)
Hip Add/Abd (º)							
Left	4.21 (1.74)	2.50 - 3.82	4.67 (1.28)	3.75 – 5.58	5.22 (1.71)	3.99 – 6.45	0.562 (0.03)
Right	4.82 (2.42)	3.75 - 5.89	4.76 (2.42)	3.22 – 6.30	4.88 (2.54)	3.06 – 6.70	0.840 (0.02)
PelvicRott (º)	4.94 (1.57)	3.40 - 4.79	4.82 (1.68)	3.75 – 5.89	4.29 (0.87)	3.60 – 3.84	0.217 (0.04)
Hip Rot (º)							
Left	6.60 (1.48)	5.94 - 7.25	6.35 (1.68)	5.29 – 7.42	6.89 (1.23)	6.01 – 7.77	0.639 (0.02)
Right	6.68 (1.39)	5.69 - 6.92	6.16 (1.49)	5.21 – 7.11	6.48 (1.32)	5.54 – 7.42	0.512 (0.02)
Foot Progression (º)							
Left	5.97 (2.81)	4.72 - 7.21	5.83 (2.23)	4.41 – 7.24	6.14 (3.50)	3.64 – 8.65	0.617 (0.02)
Right	7.07 (3.44)	5.54 - 8.59	7.33 (4.02)	4.78 – 9.88	6.76 (2.77)	4.78 – 8.74	0.929 (0.01)

Note: GPS, Gait Profile Score; GVS, Gait Variable Score; PelvicTilt, pelvic tilt; PelvicObl, pelvic obliquity; PelvicRot, pelvic rotation; HipFlex/Ext, hip flexion/extension; KneeFlex/Ext, knee flexion/extension; Ankle Dors/Plan, ankle dorsi/plantarflexion; HipAbd/Add, hip adduction/abduction; HipRot, hip rotation; FootProg, foot progression angle; SD, standard deviation; CI, Confidence Interval for Mean. [a] p value for the comparasion by ANOVA one way, ω – effect size.

Table 3
Values of intrasession ICC, SEM and MDC for each variable of interest at nonfaller (n = 27), faller (n = 12) and recurrent faller groups (n = 10).

	Nonfaller			Faller			Recurrent faller		
	ICC (CI 95%)	SEM(º)	MDC(º)	ICC (CI 95%)	SEM(º)	MDC(º)	ICC (CI 95%)	SEM(º)	MDC(º)
GPS (º)									
Left	0.92 (0.86 – 0.96)	0.51	1.34	0.92 (0.81 – 0.97)	0.32	0.83	0.94 (0.84 – 0.98)	0.28	0.72
Right	0.95 (0.92 – 0.98)	0.35	0.92	0.97 (0.93 – 0.99)	0.15	0.38	0.81 (0.75 – 0.95)	0.35	0.91
GPS (Overall) (º)	0.96 (0.93 – 0.98)	0.32	0.84	0.97 (0.93 -0.99)	0.15	0.39	0.90 (0.76 – 0.97)	0.27	0.69
GVS (º)									
Pelvic Tilt (º)	0.98 (0.97 – 0.99)	0.62	1.61	0.87 (0.74 – 095)	1.37	3.57	0.99 (0.99 – 0.99)	0.27	0.70
Hip Flex/Ext (º)									
Left	0.95 (0.90 – 0.97)	0.59	1.51	0.92 (0.82 – 0.97)	1.04	2.71	0.98 (0.96 – 0.99)	0.50	1.30
Right	0.99 (0.98 – 0.99)	0.54	1.40	0.99 (0.98 – 0.99)	0.38	0.99	0.98 (0.94 – 0.99)	0.55	1.43
Knee Flex/Ext (º)									
Left	0.89 (0.80 – 0.92)	0.93	2.43	0.84 (0.71 – 0.92)	0.85	2.13	0.91 (0.78 – 0.98)	0.62	1.61
Right	0.90 (0.81 – 0.95)	0.89	2.32	0.92 (0.81 – 0.97)	0.65	1.69	0.86 (0.75 – 0.96)	0.85	2.22
Ankle Dors/Plan (º)									
Left	0.97 (0.95 – 0.99)	0.32	0.84	0.98 (0.96 – 0.99)	0.25	0.64	0.96 (0.90 – 0.99)	0.35	0.92
Right	0.89 (0.82 – 0.95)	0.42	1.12	0.93 (0.83 – 0.98)	0.30	0.77	0.81 (0.62 – 0.95)	0.48	1.24
Pelvic Obl (º)	0.80 (0.72 – 0.91)	0.45	1.18	0.81 (0.70 – 0.92)	0.76	1.97	0.94 (0.85 – 0.98)	0.43	1.12
Hip Add/Abd (º)									
Left	0.97 (0.95 – 0.99)	0.35	0.91	0.94 (0.87 – 0.98)	0.42	1.08	0.98 (0.95 – 0.99)	0.24	0.63
Right	0.95 (0.90 – 0.97)	0.45	1.16	0.91 (0.79 – 0.97)	0.78	2.02	0.99 (0.98 – 0.99)	0.28	0.69
PelvicRot (º)	0.83 (0.79 – 0.92)	0.86	2.24	0.77 (0.69 – 0.93)	0.41	1.08	0.77 (0.67 – 0.94)	0.42	1.08
Hip Rot (º)									
Left	0.85 (0.82 – 0.95)	0.52	1.34	0.82 (0.72 – 0.87)	0.52	1.35	0.85 (0.75 – 0.91)	0.48	1.26
Right	0.88 (0.81 – 0.93)	0.50	1.30	0.81 (0.68 – 0.88)	0.57	1.49	0.83 (0.70 – 0.87)	0.55	1.43
Foot Progression (º)									
Left	0.94 (0.89 – 0.97)	0.69	1.80	0.91 (0.79 – 0.97)	0.65	1.73	0.96 (0.90 – 0.99)	0.69	1.80
Right	0.96 (0.92 – 0.98)	0.69	1.81	0.88 (0.72 – 0.92)	0.50	1.18	0.93 (0.83 – 0.98)	0.73	1.91

Note: ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard measurement error; MDC, minimal detectable change; Gait Profile Score; GVS, Gait Variable Score; PelvicTilt, pelvic tilt; PelvicObl, pelvic obliquity; PelvicRot, pelvic rotation; HipFlex/Ext, hip flexion/extension; KneeFlex/Ext, knee flexion/extension; Ankle Dors/Plan, ankle dorsi/plantarflexion; HipAbd/Add, hip adduction/abduction; HipRot, hip rotation; FootProg, foot progression angle.

Table 4
Correlation the age, stride length and walking speed for the GPS and GVS values obtained for nonfaller (n = 27), faller (n = 12), recurrent faller groups (n = 10) and total (n = 49).

	Nonfaller			Faller			Recurrent faller			Total		
	Age	Stride Length	Walking Speed	Age	Stride Length	Walking Speed	Age	Stride Length	Walking Speed	Age	Stride Length	Walking Speed
GPS (º)												
Left	0,639*	−0,542*	−0,339	0,365	−0,093	0,197	0,027	−0,120	−0,066	0,489*	−0,416*	−0,199
Right	0,408*	−0,338*	−0,140	0,508	−0,201	0,054	−0,125	−0,316	−0,150	0,462*	−0,465*	−0,078
GPS (Overall) (º)	0548*	−0,465*	−0,257	0,450	−0,141	0,142	−0,040	−0,213	−0,128	0,435*	−0,349*	−0,134
GVS (º)												
Pelvic Tilt (º)	0,363	−0,459*	−0,284	0,415	−0,232	−0,091	−0,049	−0,166	0,054	0,301	−0,342*	−0,183
Hip Flex/Ext (º)												
Left	0,469*	−0,478*	−0,291	0368	−0,155	0,019	−0,468	−0,103	−0,042	0,296*	−0,368*	−0,195
Right	0,372*	−0,442*	−0,024	0,382	−0,189	0,036	−0,439	0,162	0,305	0,274*	−0,158*	0024
Knee Flex/Ext (º)												
Left	0,455*	−0,439*	−0,337	−0,199	0,514	0,680*	0,278	0117	0,068	0,280	−0,196	−0,061
Right	0,408*	−0,461*	0,032	0,301	−0,043	0,632*	0,341	0,142	0227	0,242	−0,0243	0,107
Ankle Dors/Plan (º)												
Left	0,467*	−0,532*	−0,460*	−0,092	0,314	0,573*	−0,220	−0,361	−0,317	0,197	−0,322*	−0,110
Right	0,452*	−0,523*	−0,449*	−0,312	0,484	0,684*	0083	−0,253	−0,005	0,245	−0,347*	−0,182
Pelvic Obl (º)	0,314	0083	0069	0,192	0,015	0,120	−0,112	−0,245	−0,414	0,172	0,0274	0,045
Hip Add/Abd (º)												
Left	0,314	0083	0069	0,192	0,015	0,120	−0,112	−0,245	−0,414	0,172	0,0274	0,045
Right	0,207	−0,272	−0,201	0,410	−0,112	−0,057	0,276	−0,373	−0,472	0,262	−0,227	−0,190
Pelvic Rott (º)	0409*	−0,093	−0,036	0,171	−0,163	−0,043	0,301	0,228	0,041	0338*	−0,069	−0,052
Hip Rot (º)												
Left	0,063	0,133	−0,117	−0,135	−0,086	0,030	0,572	0,055	0,081	0093	−0,098	−0,048
Right	0,068	0,131	0,187	−0,343	0,512	0,573	0,817	−0,276	−0,125	−0,174	0,063	0,167
Foot Progression (º)												
Left	0,389*	0,136	−0,054	0,696*	−0,080	0,139	0,406	0,438	0,395	0368*	−0,045	0,031
Right	0,327*	0043	−0,010	0,732*	−0,489	−0,295	0,197	−0,126	−0,286	0,317*	−0,070	−0,112

Note: GPS, Gait Profile Score; GVS, Gait Variable Score; PelvicTilt, pelvic tilt; PelvicObl, pelvic obliquity; PelvicRot, pelvic rotation; HipFlex/Ext, hip flexion/extension; KneeFlex/Ext, knee flexion/extension; Ankle Dors/Plan, ankle dorsi/plantarflexion; HipAbd/Add, hip adduction/abduction; HipRot, hip rotation; FootProg, foot progression angle; * correlation is significative at the $p \leq 0.05$.

pattern, this result suggests that the compensatory mechanisms present in the older adults gait patterns have a strong influence on the GPS and GVS.

No difference was found between nonfaller, faller and recurrent faller. This indicates that the "fall" factor is weak in the investigation of gait adaptations, when studied in isolation. Agreeing with Kerrigan [10] findings, which in the kinematic parameters studied in the sagittal plane, observed only a slight reduction of hip extension, and also with Benson [24], where the same groups were used to compare the kinematic modifications in the gait with obstacles, not observing difference between faller and nonfaller. It is possible to infer that the joint movements that contribute to the greater GPS in the older women are those from hip and knee. These results agree with Boyer [6] in a meta-analysis, emphasizing that with the advancement of age, hip articulation increases his contribution to gait in an attempt to maintain quality. However, none of the studies included in the meta-analysis used GPS.

Regarding intra-session reliability, all GVS and GPS exhibited ICC ranging from 0.80 to 0.99, which are classified as excellent [22]. In general, the ICCs were similar between nonfallers, fallers and recurrent fallers. The reliability found for GPS and GVS in both groups confirms the use of these indices even in a population that is often studied about the variability of gait parameters [6,25,26].

Comparing our results with those reported by Hafer and Boyer [25], it can be concluded that, in general, GPS and GVS are more reliable measures than those proposed by these authors to describe gait quality, and joints involved. Although, as found in our findings, the authors also highlight the contribution of the hip joint in gait variation [25]. Their study was conducted on a treadmill, what should reduce variability in gait performance [25]. In order to reach the final data the authors had to resort to an advanced level of processing their data. This fact may hinder the use of these data by clinical professionals. GPS and GVS are more robust measures compared to those of, as well as being easier to interpret clinically, as well as the ease of calculation that authors have offered [5,21].

The MDC values were found for GPS for the nonfaller, faller and recurrent faller were 0.84°, 0.39° and 0.69°, respectively, which decreased and recurrent declines GPS is more sensitive as changes. The same occurred with the MDV of the GVS, with greater sensitivity of changes for the fallers and recurrent fallers groups. In the study of Baker and collaborators, the MCID of 1.6° was found for the GPS of children with cerebral palsy [12]. Wedege [18] found satisfactory ICC values and an MDC less than 4.7° for the subjects with spinal cord injury, and Devetak [2] found satisfactory values na MDC, less than 1.7°, for the post-stroke patients.

One possible limitation of this study is the lack of other variables related to the ageing process, which contribute to the modification of gait parameters. Indeed, it has been demonstrated that there is no difference between faller and nonfaller. A number of authors have related changes in gait parameters in older adults with factors other than a history of falls, such as reduced muscle strength [27], imbalance [28], poor health perception [28], and even fear of falling [29]. In any case, the authors stated that GPS was a valid measure in the study of gait quality of faller and recurrent faller old adults, since in these participants the MDC of GPS and GVS is smaller, demonstrating greater sensitivity to changes in gait after falls. In the study of fall risk, evaluation tools had to be objective, but with the maximum information of the subject [30].

5. Conclusion

The GPS and a MAP of nonfaller, faller and recurrent faller old adults have satisfactory reliability. The MDC of this index in this population, whose average GPS_O was approximately 0.5° in fallers, with higher values for the index subdivisions (GVS), varying from 0.5° to 2.4°. The GPS can be a useful tool in gait analysis of the older adults, as well as in clinical practice to rank the overall quality of walking before and after falls. Future research is required to assess the practical implications of these findings, in other conditions of the elderly public, as well as the use of GPS in other populations, since the index optimizes and facilitates the interpretation of the gait profile through GVS and MAP.

Authors' contribution and roles

GUILHERME AUGUSTO SANTOS BUENO: Conception and design of the study, acquisition and interpretation of data, drafting the manuscript and revising it critically for important intellectual content, final approval of the version to be submitted.

DARLAN MARTINS RIBEIRO: Conception and design of the study, acquisition and interpretation of data, revising the manuscript critically for important intellectual content, final approval of the version to be submitted.

FLAVIA MARTINS GERVÁSIO: Conception and design of the study, acquisition and interpretation of data, revising the manuscript critically for important intellectual content, final approval of the version to be submitted.

ANABELA MARTINS CORREIA: Conception and design of the study, acquisition and interpretation of data, revising the manuscript critically for important intellectual content, final approval of the version to be submitted.

RUTH LOSADA DE MENEZES: Conception and design of the study, revising the manuscript critically for important intellectual content, final approval of the version to be submitted, supervision of the whole process.

Each of the authors has read and concurs with the content in the final manuscript. The material within has not been and will not be submitted for publication elsewhere except as an abstract.

Funding

This study was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – funding code 001.

Conflict of interest statement

The authors declare no conflict of interest.

Acknowledgements

We acknowledge all the subjects who participated in this study, and we thank the Dr Claudio de Almeida Borges Movement Analysis Laboratory team for their work and support.

References

[1] M.L. Callisaya, L. Blizzard, M.D. Schmidt, M.K. L, J.L. Mcginley, L.M. Sanders, V.K. Srikanth, Gait, gait variability and the risk of multiple incident falls in older people : a population-based study, Age Ageing 40 (2011) 481–487, https://doi.org/10.1093/ageing/afr055.
[2] G.F. Devetak, S.K. Martello, J.C. de Almeida, K.P. Correa, D.D. Iucksch, E.F. Manffra, Reliability and minimum detectable change of the gait profile score for post-stroke patients, Gait Posture 49 (2016) 382–387, https://doi.org/10.1016/j.gaitpost.2016.07.149.
[3] L.M. Schutte, U. Narayanan, J.L. Stout, P. Selber, J.R. Gage, An index for quantifying deviations from normal gait, Gait Posture 11 (2000) 25–31.
[4] M.H. Schwartz, A. Rozumalski, The gait deviation index : A new comprehensive index of gait pathology, Gait Posture 28 (2008) 351–357, https://doi.org/10.1016/j.gaitpost.2008.05.001.
[5] R. Baker, J.L. Mcginley, M.H. Schwartz, S. Beynon, A. Rozumalski, H.K. Graham, O. Tirosh, The gait profile score and movement analysis profile, Gait Posture 30 (2009) 265–269, https://doi.org/10.1016/j.gaitpost.2009.05.020.
[6] K.A. Boyer, R.T. Johnson, J.J. Banks, C. Jewell, J.F. Hafer, Systematic review and meta-analysis of gait mechanics in young and older adults, Exp. Gerontol. 95 (2017) 63–70, https://doi.org/10.1016/j.exger.2017.05.005.
[7] D.M. Ribeiro, G.A.S. Bueno, F.M. Gervásio, R.L. De Menezes, Foot-ground clearance characteristics in women: a comparison across different ages, Gait Posture 69 (2019) 121–125 doi:S0966636218304831.

[8] N.R. Marques, D.H. Spinoso, B.C. Cardoso, V. Christianini, M. Hiromi, M. Tavella, Is it possible to predict falls in older adults using gait kinematics? Clin. Biomech. 59 (2018) 15–18, https://doi.org/10.1016/j.clinbiomech.2018.08.006.
[9] Y. Kobayashi, H. Hobara, S. Matsushita, M. Mochimaru, Key joint kinematic characteristics of the gait of fallers identi fi ed by principal component analysis $, J. Biomech. 47 (2014) 2424–2429, https://doi.org/10.1016/j.jbiomech.2014.04.011.
[10] D.C. Kerrigan, L.W. Lee, J.J. Collins, P.O. Riley, L.A. Lipsitz, Reduced hip extension during walking: healthy elderly and fallers versus young adults, Arch. Phys. Med. Rehabil. 82 (2001) 26–30, https://doi.org/10.1053/apmr.2001.18584.
[11] J. Johansson, A. Nordström, P. Nordström, Greater fall risk in elderly women than in men is associated with increased gait variability during multitasking, J. Am. Med. Dir. Assoc. 17 (2016) 1–6, https://doi.org/10.1016/j.jamda.2016.02.009.
[12] R. Baker, J.L. Mcginley, M. Schwartz, P. Thomason, J. Rodda, H.K. Graham, The minimal clinically important difference for the Gait Profile Score, Gait Posture 35 (2012) 612–615, https://doi.org/10.1016/j.gaitpost.2011.12.008.
[13] D.S. Speciali, E.M. Oliveira, J.R. Cardoso, Gait profile score and movement analysis profile in patients with Parkinson' s disease during concurrent cognitive load, Braz. J. Phys. Ther. 18 (2014) 315–322.
[14] D.T. Sims, A. Burden, C. Payton, C.I. Morse, A quantitative description of self-selected walking in adults with Achondroplasia using the gait profile score, Gait Posture 68 (2019) 150–154, https://doi.org/10.1016/j.gaitpost.2018.11.019.
[15] M. Pau, G. Coghe, C. Atzeni, F. Corona, G. Pilloni, M. Giovanna, E. Cocco, M. Galli, Novel characterization of gait impairments in people with multiple sclerosis by means of the gait pro fi le score, J. Neurol. Sci. 345 (2014) 159–163, https://doi.org/10.1016/j.jns.2014.07.032.
[16] T.M. Kesar, S.A. Binder-Macleod, G.E. Hicks, D.S. Reisman, Minimal detectable change for gait variables collected during treadmill walking in individuals post-stroke, Gait Posture 33 (2011) 314–317, https://doi.org/10.1158/0008-5472.CAN-10-4002.BONE.
[17] S.M. Haley, M.A. Fragala-pinkham, Interpreting change scores of tests and measures used in physical therapy, Phys. Ther. 86 (2006) 735–743.
[18] P. Wedege, K. Steffen, V. Strøm, A.I. Opheim, Reliability of three-dimensional kinematic gait data in adults with spinal cord injury, J. Rehabil. Assist. 4 (2017) 1–10, https://doi.org/10.1177/2055668317729992.
[19] S.M.D. Brucki, R. Nitrin, P. Caramelli, P.H.F. Bertolucci, I.H. Okamoto, Suggestions for utilization of the mini-mental state examination in Brazil, Arq. Neuropsiquiatr. 61 (2003) 777–781, https://doi.org/10.1590/S0004-282X2003000500014.
[20] F.F.O. Camargos, R.C. Dias, J.M.D. Dias, M.T.F. Freire, Cross-cultural adaptation and evaluation of the psychometric properties of the Falls Efficacy Scale – international among Elderly Brazilians (FES-I-BRAZIL), Rev. Bras. Fisioter. 14 (2010) 237–243.
[21] wwrichard.net [Internet]. MAP and GDI calculators, (n.d.). http://wwrichardnet/resources/gps-map-and-gdi-calculators/ (Accessed 21, November 2018).
[22] J.L. Fleiss, The Design and Analysis of Clinical Experiments, John Wiley & Sons, New York, 1999.
[23] I. Campanini, A. Merlo, Reliabilty, smallest real difference and concurrent validity of indices computed from GRF components in gait of stroke patients, Gait Posture 30 (2009) 127–131, https://doi.org/10.1016/j.gaitpost.2009.03.011.
[24] L.C. Benson, S.C. Cobb, A.S. Hyngstrom, K.G. Keenan, J. Luo, K.M. O'Connor, Identifying trippers and non-trippers based on knee kinematics during obstacle-free walking, Hum. Mov. Sci. 62 (2018) 58–66, https://doi.org/10.1016/j.humov.2018.09.009.
[25] J.F. Hafer, K.A. Boyer, Age related differences in segment coordination and its variability during gait, Gait Posture 62 (2018) 92–98, https://doi.org/10.1016/j.gaitpost.2018.02.021.
[26] M. Qiao, J.A. Feld, J.R. Franz, Aging e ff ects on leg joint variability during walking with balance perturbations, Gait Posture 62 (2018) 27–33, https://doi.org/10.1016/j.gaitpost.2018.02.020.
[27] B.D.S. Moreira, R.F. Sampaio, J. Bergamas-, M. Diz, A.D.C. Bastone, E. Ferriolli, L. Neri, R.A. Lourenc, N. Kirkwood, Factors associated with fear of falling in community-dwelling older adults with and without diabetes mellitus: findings from the Frailty in Brazilian Older People Study (FIBRA-BR), Exp. Gerontol. (2017), https://doi.org/10.1016/j.exger.2017.01.004.
[28] O.T.T. Hoang, P. Jullamate, N. Piphatvanitcha, E. Rosenberg, Factors related to fear of falling among community-dwelling older adults, J. Clin. Nurs. 26 (2016) 68–76, https://doi.org/10.1111/jocn.13337.
[29] T. Asai, S. Misu, R. Sawa, T. Doi, M. Yamada, The association between fear of falling and smoothness of lower trunk oscillation in gait varies according to gait speed in community-dwelling older adults, J. Neuroeng. Rehabil. 14 (2017) 1–9, https://doi.org/10.1186/s12984-016-0211-0.
[30] C. Sherrigton, A. Tiedemann, Physiotherapy in the prevention of falls in older people, J. Physiother. 61 (2015) 53–60.