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The reliability of gait variability measures for individuals with Parkinson's disease and healthy older adults – The effect of gait speed

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ABSTRACT

Background: Step-to-step variability is a marker of reduced motor control and a frequently studied outcome measure in neurodegenerative disorders such as Parkinson's disease (PD) as compared to healthy older adults (HOA). To challenge motor control of gait, walking should be tested at different gait speeds. Good reliability is essential, and gait variability estimates show good reproducibility when sampled at normal gait speed. The aim was therefore to investigate if gait variability could be reliably sampled at slow and fast speeds for individuals with PD and HOA by evaluating test-retest reliability.

Methods: 29 (14 males) subjects with idiopathic PD, Hoehn &Yahr 2 (n = 18) and 3, ≥ 60 years, and 25 age matched HOAwere included. Spatiotemporal gait data was collected (GAITRite) during slow, normal, and fast walking on two occasions.

Results: Measurement error was lowest for gait variability estimates based on 40 steps in both groups. This was true across all speeds in HOA, but only for normal and fast gait speeds in the PD cohort. Due to increased homogeneity in the variability estimates intraclass correlation coefficients (ICC) were low for HOA, except for step width variability. In the PD cohort ICCs were good to excellent for temporal- and step width gait variability across speeds.

Conclusion: HOA demonstrated reliable gait variability estimates across all speeds, whereas Individuals with PD were reliable at normal and fast gait speeds only Estimates should be based on at least 40 steps. Step width variability was overall the most reliable variable across groups and speed conditions.

1. Introduction

A much studied outcome measure in gait research over the past two decades is step-to-step fluctuations found in spatiotemporal gait variables. Neurodegenerative disease will invariably affect motor output and control, leading to increased variability from one step to the next during walking [1]. The measure is commonly reported as the within-subject standard deviation or coefficient of variation of multiple steps or strides [2].

Studies investigating the gait of individuals with PD, a neurodegenerative disease affecting the basal ganglia, show increased variability for step length and swing time in newly diagnosed individuals compared to healthy older adults (HOA) [3]. Further, variability in step and stride time, and double support time increased with disease severity in this group [4], and stride time variability was significantly associated with fall frequency [5]. Lord et al. [6,7] showed that variability was an independent domain of gait both for individuals with PD and HOA. The associated variables were step velocity-, step length-, step time- and stance time variability for individuals with PD, and step velocity-, step length- and step width variability for HOA.

To establish what constitutes significant change in a measurement over time the test-retest reliability must be established. This will allow

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clinicians and researchers the means of discerning meaningful change from random measurement fluctuations when evaluating an individual or group over repeated measures. Central to test-retest reliability is firstly absolute reliability, or agreement parameters, which assesses how close the results of the repeated measurements are by estimating the level of measurement error. Secondly, relative reliability assesses whether study objects, often persons, can be distinguished from each other despite measurement error [8,9]. It has been shown that reliable gait variability estimates, sampled at self-selected walking speeds, are best achieved when based on at least 30, and up to 50 steps, using combined information from the left and right side [10,11]. Further, step width variability was identified as the most reliable variable to sample both in HOA and individuals with PD [10,12].

It has recently been suggested that clinicians should challenge the motor control of gait by testing under various walking speeds to better expose a declining gait function. [13]. Slow and fast walking is less conducive to the storage and recovery of elastic energy, and therefore mechanically less efficient altering gait- and muscle activation patterns [14]. Slow gait speed will place higher demands on postural stability through stabilizing muscle activation, due to increased time spent in single limb stands and increased mediolateral displacement of the center of mass (COM) [15]. Walking faster requires elevated muscle activity for propulsion and stability to drive increased joint range and motion for longer steps and higher cadence, as well as increased demands on eccentric muscle function for shock absorption [14,16].

Level of gait variability at slower and faster gait speeds has been investigated in individuals with PD and in healthy older adults generally showing increased gait variability associated with slower gait speeds as compared to normal and fast [13,17]. However, the reliability of gait variability measures at slow and fast gait speeds has not yet been reported. The purpose of this study was therefore to evaluate the effect of (1) gait speed and (2) pathology on test-retest reliability in individuals with PD as compared to healthy older adults (HOA), and (3) identify the optimal number of steps for acceptable levels of reliability at slow, normal and fast gait speed conditions.

2. Methods

2.1. Participants

29 individuals (14 males) with mild to moderate PD were included based on the following criteria; a clinical diagnosis of idiopathic PD according to the UK PD Society Brain Bank criteria [18], be classified as Hoehn & Yahr (H&Y) stage 2 (n = 18) or 3 (n = 11) and be 60 years or older. The clinical presentation seen at these stages is bilateral or midline involvement of symptoms, with postural instability found in those classified as H&Y 3, but not in H&Y 2 [19]. Participants were excluded if they had a history suggesting atypical PD symptoms as defined by Hughes et al. [18], a Mini-Mental State Examination (MMSE) score ≤24 [20], or other existing neuromuscular disorders or medical conditions that influenced their gait and balance performance. Recruitment was done in collaboration with the Norwegian Parkinson's Disease Association through advertisement on the web-site and via e-mail to its members in the vicinity of Oslo, Norway.

A control group of 25 healthy, age matched adults (9 males) were recruited on the basis of no on-going or recent history of neuromuscular conditions or illness, and no previous joint replacements. Ethical approval was given by the Regional board of Research Ethics in the south east region, Norway, and all participants gave their written informed consent. Demographic descriptions of participants are shown in Table 1.

2.2. Procedures

Participating individuals with PD used their regular medication during the study and were tested in their medication "ON" phase. The Unified PD Rating Scale (UPDRS) motor examination score and H&Y score were determined. Participants were tested on two occasions no more than one week apart at the same time of day. The mean (SD) number of days between tests was 1.6 (1.4) for the PD group, and 3.3 (2.8) for the control group. Spatiotemporal gait variables were collected during intermittent walking on a 10 m pressure sensor mat (active zone 8.3 m) (GAITRite, CIR Systems Inc., Franklin, NJ, USA).

Table 1
Participant Characteristics (means and standard deviations).

	PD	HOA	p-value
Number of participants	29	27	
Sex (male/female)	14/15	10/17	
Age (years)	70.9 (5.5)	68.3 (5.2)	0.08
Height (cm)	171.9 (10.9)	174.5 (9.8)	0.35
Weight (kg)	77.4 (17.3)	74.9 (9.5)	0.51
Years since diagnosis	7.6 (4.0)	–	
Hoehn & Yahr (2/3)	18/11	–	
UPDRS subscale III (0–108 points)	32.0 (6.9)	–	

Abbreviations: PD = Parkinson's disease; HOA = Healthy older adults: UPDRS = Unified Parkinson's Disease Rating Scale

The following instructions were given to facilitate self-selected, normal, fast and slow walking speeds in this specified order, by the same tester, on the two test occasions; (1) "walk at your normal comfortable pace", (2)"walk as fast as you can, in a safe manner, without running", (3)"walk slowly, like you would do if you were taking a slow stroll without a specific place to go". To facilitate a steady state walking speed, a distance of 2.5 m was available on each side of the mat for acceleration and deceleration. At least six valid trials for each walking speed condition were collected per subject on each test occasion.

2.3. Data processing

Gait variability was calculated for the following variables: step velocity, step length, step width, step time, stance time and swing time. This was done in Excel (Excel®, Microsoft, USA) as described by Galna et al. [10] where the combined standard deviation (SD) of left and right steps was determined by taking the square root of the within-subject variance of the left and right steps as follows:

$$SD_{Left\ \&\ Right} = \sqrt{\frac{(Variace_{Left\ steps} + Variance_{Right\ steps})}{2}} \quad (1)$$

This method avoids confounding step-to-step variability with variation originating from asymmetry between left and right steps [10]. The $SD_{Left\ \&\ Right}$ was calculated based on 10, 20, 30, 40 and 50 included steps, for each gait speed condition, for each test day.

2.4. Statistical analysis

Histograms and normal probability plots showed normal distribution of the spatiotemporal mean variable values for the two groups. Mean gait velocity and cadence, together with mean values for step velocity, step length, step width, step time, stance time and swing time were calculated for slow, normal and fast gait conditions for individuals with PD and HOA. The same was done for the mean $SD_{Left\ \&\ Right}$. Differences in mean values between gait speeds and groups were investigated using a two way mixed ANOVA.

The variability estimates for test 1 and 2were inspected for positive or negative trends and the agreement measures for heteroscedasticity. To establish to what degree gait variability measures were repeatable over two test occasions the absolute and relative reliability were determined based on $SD_{Left\ \&\ Right}$ calculated from 10 and up to 50 included steps, for each gait speed condition.

For absolute reliability the measurement error for repeated measurements (S_w) was computed as the square root of the mean between