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Evaluation of a New Gait Assessment for Clinical Practice

Patric Schubert[1], Magnus Liebherr[1], Stephanie Kersten[1], Christian T Haas[1]

[1]Hochschule Fresenius, University of Applied Sciences, Institute for Complex Health Research, Idstein, Germany

Corresponding author: Patric Schubert, Hochschule Fresenius, University of Applied Sciences, Institute for Complex Health Research, Limburger Straße 2, 65510 Idstein, Germany, Phone: 06126 – 9352293, Email: patric.schubert@hs-fresenius.de

Abstract

Objectives: Gait is often affected in people with motor disorders. Obtaining feasible parameters from gait measurements is a central issue in clinical reasoning. A key problem is that practicable tests lack sensitivity of underlying parameters and vice versa. To examine gait impairments or to evaluate interventions aimed at improving gait disorders, efficient measurements are necessary. Therefore, we developed a new device-independent gait assessment which allows the quantification of spatiotemporal parameters from over ground walking.

Methods: 37 healthy subjects (CG), 14 patients with multiple sclerosis (MS) and 20 patients with Parkinson's disease (PD) walked along a corridor at their self-paced velocity. A standardized new gait assessment without any technical devices was conducted. Subjects performed five walking trials of different lengths. Trespassing of predefined lines was used to determine real walking distance. Spatiotemporal gait parameters comprised gait velocity, stride length, and stride duration. Validity and reliability analyses were conducted.

Results: The gait assessment showed highly valid and reliable results for each parameter and for each distance. Shorter walking distances showed a higher coefficient of variation which was however consistent for distances above 20m. We found significant differences between CG and MS, but no significance between CG and PD. Specific reference data for each parameter is presented.

Conclusions: It is demonstrated that relevant biomechanical gait parameters could be derived from this new gait assessment with minimal effort. Hence, it could be easily implemented into clinical routines. We recommend performing at least five gait trials with at least 20m walking distance to achieve best results.

Keywords: Gait analysis, Biomechanical parameters, Parkinson's disease, Multiple sclerosis

Introduction

Gait can be generally described as a motor behavior controlled automatically which is based on complex anatomic-functional structures such as sensory systems (e.g. vestibular, visual and somatosensory systems), anticipation and control systems (e.g. coping processes, cerebellar coordination), motor systems (e.g. movement activation, corticospinal control), perceptive and orientation functions (e.g. cognitive brain areas, affective adaptations). In numerous research and review articles, various internal and external parameters have been identified affecting gait in healthy walking and gait disturbances.[1-6] Considering the complexity still all influencing components, specific cognitive and motor connections and interactions in physiologic and pathologic gait have not been uncovered completely. But besides that, we affirm that gait represents a fundamental condition for humans' interaction with the environment, their independency in daily routine and their quality of life.

A large number of diseases imply symptoms or disturbances in postural control and gait respectively, because motor control processes are affected by the disease. Clinical trials evaluating gait patterns in patients use both, objective and subjective assessments[7], whereas objective biomechanical measurements in laboratory situations (e.g. ergometry, force, endurance and flexibility measurement) are less common than performance-oriented assessments with half objective half subjective diagnostic tools.[8-14] Geroin et al[15] showed in their recent review that

most commonly used outcome measures in patients with strokes are 10 Meter Walking Test[16], Motoric Index[17], 6-Minute-Walking-Test[12,18], Rivermead Mobility Index[19] and Berg Balance Scale[20]. Certainly mobility tests like the Timed-Up-and-Go Test[8] and the Functional Gait Assessment[11] are often conducted for gait assessments or gait analysis and are included in disease-specific developed impact scales (e.g. UPDRS, The Scripps Neurological Rating Scale, etc. [21-23]). However, a key problem is that practicable tests lack sensitivity of underlying parameters and vice versa. On the one hand device-independent clinical gait assessments generally do not provide objective clinical outcomes. On the other hand objective measurements using biomechanical locomotor systems entail high technical, temporal, and financial effort. To examine gait impairments or to evaluate interventions aimed at improving gait disorders, effective and efficient measurements are necessary. Therefore, we developed a new device-independent gait assessment to quantify typical spatiotemporal gait parameters for daily clinical setting.

The article is separated into two parts. In part one, we present the gait method measuring healthy subjects in order to evaluate its validity and reliability. In part two, patients with neurological diseases are measured to assess the sensitivity of the gait method. Subsequently, a general discussion on the gait assessment follows.

Methods (part I)

Subjects

Inclusion criteria were: age ≥18 years, healthy, no acute or chronical diseases, written informed consent. Exclusion criteria were: age <18 years, injuries of musculoskeletal system, acute or chronic diseases, musculoskeletal or cognitive fatigue.

We measured in a first cohort 20 healthy subjects (CG1) (age: 22.0 ± 2.7years, weight: 65.9 ± 10.3[kg], height: 172.3 ± 8[cm], sex: 4 males and 16 females) and in a second cohort 17 healthy subjects (CG2) (age: 20.8 ± 1.4years, weight: 63.8 ± 11[kg], height: 172.4 ± 8.7[cm], sex: 3 females and 14 females). The subjects were recruited as they are students from the Hochschule Fresenius [Idstein, Germany] and they gave written informed consent to the study procedure.

Gait assessment

The subjects were instructed to walk at their individual self-paced velocity along an indoor corridor (5 trials, one practice trial). The instructions were standardized: "Please walk in your own comfortable velocity for which you perceive yourself as walking secure along this corridor. Do not get distracted. Do not talk while walking and look straight ahead. Two experimenters will follow you. Try to walk with a constant velocity. Do you have any questions? Do not stop walking before the experimenter advice. If you understood the instructions, you may feel free to start". The location of two lines - start and finish – defines the measurement distance (Figure 1). The lines were indiscernible for the subjects for the reason that they did not have an influence on gait performance. Two experimenters (raters) were needed. The trespassing of the predefined lines was marked visually (location of the initial contact of heel strike on the ground) by the first rater with a felt-tip pen. The number of steps n was counted by rater one and the time t from first to last heel-strike was taken by rater two by a simple stopwatch. Denote D* as the measurement distance and the trespassing at the start by S_1 and the trespassing at the finish by S_2 (trespassing is measured rectangular from the lines). Actual walking distance is then defined as $D = D^* - S_1 + S_2$. The following spatiotemporal parameters were calculated:

Gait velocity (GV):

$GV = D/t,$

Stride length (SL):

$SL = D/n,$

Strides time (ST):

$ST = t/n.$

Concerning CG2, three different predefined walking lengths D* were chosen (40.38m, 23.17m, 9.41m) to examine distance effects. CG1 was measured with 40.38m. With regard to gait initiation, Kressig & Beauchet[24] recommend starting data collection after two complete gait cycles in order to achieve steady-state walking. Lindemann et al[25] found that a 2.5m distance is sufficient even with frail people. In the present study, a distance of 5.7m was included before the subjects crossed the predefined start line to account for gait initiation phase and to achieve steady-state walking. The subjects had to walk at least 3.2m beyond the finish line, to exclude the gait deceleration/ termination phase.

Statistical analysis

For all statistical tests the significance level was set to a = 5%. Statistical analysis is focused on quality criteria of the underlying gait assessment. Reference data was calculated over all subjects of CG1 and CG2 (n = 37, 40m trials) (trial outcomes were averaged).

Quality criteria of the gait assessment

Validity. With respect to quality criteria, first the measurement errors (validity) using biomechanical analysis were investigated (Figure 2). Therefore, subjects of CG1 were asked to perform one extra walking trial. The error of visual marking ($|E_V|$) was checked via video analysis (Casio Ex-ZR 300, f_S=120Hz). Hence, we compared the trespassing of the predefined lines S^*_1 and S^*_2, measured by the video analysis, and the observed visual marks S_1 and S_2 which are estimations of S^*_1 and S^*_2:

$|E_V| = ||S^*_1 - S^*_2| - |S_1 - S_2||$.

The agreement between both measurements was assessed visually using a Bland-Altman-Plot expressing the error E_V through the mean of both measurements: $((S^*_1 - S^*_2) – (S_1 - S_2))/2$.[26]

Absolute time measurement error ($|E_T|$) was quantified using a pressure plate (Zebris FDM2, f_S=100Hz). When t is the time measured by the stop watch (estimator) and t* is the time measured by the pressure plate, we calculated

$|E_T| = |t^* - t|$

As well, a Bland-Altman-Plot was generated by expressing the non-absolute error E_T through the mean of both measurements: $(t^* – t)/2$.[26] For both errors E_V and E_T Shapiro-Wilk tests were performed to assess whether error values are normally distributed.

To evaluate whether within the five gait trials consistent walking distances were reached, two parameters were calculated: First, the ratio q between walking distance D* and average actual walking distance $\overline{D} = {}^1\!/_5 \sum_{k=1}^{5} D_k$ with D_k being the actual walking distance in the k^{th} walking trial: $q = \frac{D^*}{\overline{D}} \cdot (100\%)$. Second, the coefficients of variation $CV(D_k)$ over the five actual walking distances D_k (k = 1,…,5) were averaged over the subjects.

Test-retest-reliability. In order to account for test-retest-reliability over the five gait trials, the intraclass correlation coefficient $ICC_{3,1}$ (two way mixed model, single measure) was calculated for each group (CG1, CG2) and each variable (GV, SL, ST) and with respect to CG2 for different walking distances.[27]

In the use of ICC, one needs to differentiate two types of application. The absolute agreement type evaluates whether the different variable outcomes of different subjects distribute in terms of a relation of y=x. Therefore, any systematic bias has a negative influence on the coefficient. In contrast to absolute agreement, the consistency type appreciates solely the correlation agreement independently of systematic bias. The difference in calculation between both types is reflected in the definition of denominator variance which can be looked up in [28]. The intra-class correlation coefficient $ICC_{3,1}$ for consistency is defined as:

$$ICC_{3,1}^{(C)} = (MS_R - MS_E)/(MS_R + (k-1)*MS_E)$$

where MS_R (df=n-1) is the mean square for rows (subjects), MS_R is the mean square error (df=(n-1)(k-1)). Furthermore, n is the number of subjects and k is the number of the columns (here: five trials). In the case of absolute agreement the quotient is:

$$ICC_{3,1}^{(A)} = (MS_R - MS_E)/(MS_R + (k-1)*MS_E + (k/n)*(MS_C - MS_E))$$

with MS_C (df=k-1) the mean square for columns.[28] We could not exclude, whether systematic differences between the trials are relevant. Therefore, we calculated both types of $ICC_{3,1}$. The structures of the $ICC_{3,1}$ values were further used to evaluate whether walking distances affect parameter outputs. We declare values of ICC as high when located in the range of [1;0.8] and defined as fair when located in the range of (0.8;0.6]. In a next step we investigated the effects of the number of gait trials on the ICC outcome. Therefore, ICC values were calculated for trial 1 to trial i with i = 5,…,2. We further compare these outcomes with the mean coefficients of variations computed as follows. Let $cv^{(i)}$ be the coefficient of variation taken from one subject with respect to the outcomes from trial one to trial i with i=2,…5:

$$cv^{(i)} = s^{(i)} / m^{(i)}$$

where $s^{(i)}$ is the standard deviation until trial i and $m^{(i)}$ is the mean until trial i. Afterwards, we calculated the mean coefficient of variation $CV = \frac{1}{i}\sum_{k=1}^{i} cv^{(i)}$ for all subjects and its standard deviation $S = \frac{1}{i-1}\sum_{k=1}^{i}\left(cv^{(i)} - CV\right)^2$ for each group.

Objectivity. An equivalence test named two-one-sided test on the basis of a t-test (TOST) was used to verify the objectivity between CG1 and CG2 in the 40m condition.[29,30] For this purpose, the average value of the five trials was taken of each variable (GV, SL, ST). The TOST is a statistical method to evaluate whether the variable outcomes of CG1 are equivalent to the ones of CG2. It is then assumed that the outcomes are taken from the same distribution. In contrast to traditional hypothesis testing methods (e.g. t-test), in the TOST the alternative hy-

pothesis comprises equivalency of underlying topics. Equivalency means that the two investigated samples are close enough within a margin of d units.[30] In the present study, the equivalence margin was set at 5%. Hence, if the data of CG2 provide evidence that the observed variables are within 5% of the ones of CG1, equivalence of the underlying distribution could be established. This is equivalent to locating the $(1-2\alpha)*100\%$ confidence interval for group differences within the interval [-d;d].[30]

Results (part I)

Reference data

The following reference data for the variables gait velocity (GV), stride length (SL), strides time (ST) has been collected (Table 1).

Quality criteria of the gait assessment

With respect to the error of visual marking in CG1 ($|E_V|=||S^*_1 - S^*_2| - |S_1 - S_2||$), the mean error and standard deviation were 0.67 ± 0.543 [cm] (coefficient of variation, CV = 0.81). The non-absolute error values (E_V) are listed in Table 2.

No systematic bias regarding over- or underestimation could be found (#overestimations = 12, #underestimations = 7). The assumption that the error values are normally distributed could not be rejected by means of a Shapiro-Wilk-test (p = 0.692). Therefore, it is likely with a probability of 95% that errors occur within a margin of $0.67 \pm 2 * 0.543$ [cm]. The Bland-Altman-Plot of visual marking versus video analysis demonstrates a good agreement between both measurement modes (Figure 3). The average absolute time measurement error in CG1 ($|E_T| = |t^* - t|$) was 82 ± 46.52 [ms] (CV = 0.567). The non-absolute error values (E_T) are listed in Table 3.

No systematic bias regarding over- or underestimation could be found (#overestimations = 10, #underestimations = 9). The assumption that the error values are normally distributed could not be rejected by means of a Shapiro-Wilk-test (p = 0.278). Therefore, it is likely with a probability of 95% that errors occur within a margin of $82 \pm 2 * 46.52$ [cm]. The good agreement of time measurement via stop watch versus time measurement via pressure plate can be demonstrated by use of a Bland-Altman-Plot (Figure 4).

Test-retest-reliability for each group (CG1, CG2) and each variable (GV, SL, ST) and with respect to CG2 over different walking distances was evaluated. Thus, two 4 x 3 matrices of

intraclass correlation coefficients for consistency and absolute agreement ($ICC_{3,1}^{(C)}$ and $ICC_{3,1}^{(A)}$) were generated and can be looked up in Table 4. Significant values (falling into the 95% confidence interval) of ICC are marked with an asterisk (all values were significant). With our definition above, each value was high except of the fair ICC-values of CG2-10m with stride time and gait velocity.

The structure of ICC values with respect to trial number effects can be looked up in Table 5. The values show rather consistent behavior independent of trial number. However, as shown in Table 6, mean coefficient of variation increases with trial number. Taken together, despite high ICC values, a larger amount of variability could be explained by implementing more trials.

Three two-one sided tests (TOST) were calculated for each variable between CG1 and CG2 in the 40m condition to assess whether variable outcomes show consistent / equivalent results (objectivity). Table 7 demonstrates the 90% confidence intervals for the group differences based on independent samples. The hypothesis of being not equivalent (significant) is rejected when the confidence interval can be located in between the preset equivalence margin [-d;d] = [-0.05;0.05]. Therefore, we found equivalence for ST and SL, but not for GV.

The ratio q between walking distance and average actual walking distance $\overline{D}$ and the coefficients of variation $CV(D_k)$ over the five actual walking distances are listed in Table 8. All walking distances show that predefined walking distance and actual walking distance differ in a range of ±1%. Coefficients of variation are low. From 20m to 10m situation the CV value and its standard deviation are rising stronger than from 40m to 20m.

Methods (part II)

Subjects

Inclusion criteria were: clinically evidenced diagnosis of MS or PD, limitations of activities of daily living, ability of standing and walking, medically certified ability to participate on this study, neurological documentation of disease state, age ≥18 years (MS), age: 40-80 years (PD), Hoehn & Yahr stages I and II[31], written informed consent.

Exclusion criteria: negation of inclusion criteria, cortisone medication, adjustment of medication during the last month, other neurologic diseases, tumors, orthopedic diseases, musculo-

skeletal or cognitive fatigue, sport activities during the last 24hours, acute relapse or relapse during the last month (MS).

This study part comprised two subject groups: 20 patients with Parkinson's Disease (PD) (age: 60.1 ± 10.3years; weight: 81.2 ± 12.1[kg], height: 175.1 ± 8.6[cm], sex: 16 males and 4 females, UPDRS: 36.8 ± 13.5; Hoehn and Yahr stages I and II)[21,31], 14 patients with Multiple Sclerosis (MS) (age: 53.9 ±9.1years, weight: 73.2 ± 10.4[kg], height: 164.1 ± 7.9[cm], sex: 1 male and 13 females, EDSS: 3.2 ± 1.3).[32] Gait analyses of PD and MS were part of larger study protocols which were approved by the ethics committee of the Hochschule Fresenius, University of Applied Sciences, Idstein, Germany. The ethics statements comply with the scope of the declaration of Helsinki. Patients with deep brain stimulation, further neurological diseases, orthopedic impairments, with advanced dementia, and/or inability to walk autonomously were excluded. PD and MS subjects were measured under regular medication (on-state) and they gave written informed consent to the study procedure. PD was measured with 40.38m and MS was measured with 20m.

Statistical analysis

The statistical analysis is based on patient group differences between PD, MS, and healthy controls of part one.

Patient group differences

Statistical analysis was conducted to find differences between healthy and neurologically impaired subjects based on the spatiotemporal parameters. Independent samples t-tests were applied between PD and CG1, and between MS and CG2 (23.17m). For this purpose, the average values of ST, GV, and SL of each subject were calculated. Variance homogeneity was assessed via Levene-tests.

Further reliability analysis

Test-retest-reliability over the five gait trials was quantified via the intraclass correlation coefficient $ICC_{3,1}^{(C)}$ and via $ICC_{3,1}^{(A)}$ for PD and MS and each variable (GV, SL, ST).[27]

Effects of the number of gait trials on the ICC outcome were evaluated using the procedure above. Therefore, ICC values were calculated for trial 1 to trial i with i = 5,…,2. Again, we further compare these outcomes with the mean coefficients of variations computed by cv(i) being the coefficient of variation taken from one subject with respect to the outcomes from

trial one to trial i with i=2,…,5. The mean coefficient of variation for all subjects and its standard deviation were taken for each group.

Results (part II)

Reference data

The following reference data for the variables gait velocity (GV), stride length (SL), strides time (ST) has been collected (Table 9).

Patient group differences

Concerning independent samples t-tests between PD and CG1 (df = 20+20-2 = 38) for each variable (GV, SL, ST), no significant values were found (GV: $p = 0.394$, $T_{38} = -0.862$; SL: $p = 0.753$, $T_{38} = -0.318$; ST: $p = 0.412$, $T_{38} = 0.829$). Concerning independent samples t-tests between MS and CG2 (20m condition) (df = 14+17-2 = 29) for each variable (GV, SL, ST), significant results were found for GV ($p = 0.02$, $T_{29} = -2.581$) and SL ($p = 0.028$, $T_{29} = -2.445$), and no significance was found for ST ($p = 0.392$, $T_{29} = 0.869$).

Further reliability analysis

Test-retest-reliability for MS and PD and each variable (GV, SL, ST) was evaluated by use of intraclass correlation coefficients ($ICC_{3,1}^{(C)}$ and $ICC_{3,1}^{(A)}$) and can be looked up in Table 10. Significant values (falling into the 95% confidence interval) of $ICC_{3,1}^{(C)}$ and $ICC_{3,1}^{(A)}$ are marked with an asterisk (all values were significant).

From Table 11 it could be deduced that even two trials lead to good reliability coefficients (in the variable stride time in MS the ICC is even rising). However, as presented in Table 12, mean CV values increase with increasing number of trials that is analogue to the CG1 and CG2 group statistics (except of a slight decrease in CV of stride time in MS).

All walking distances show that predefined walking distance and actual walking distance differ in a range of ±1% (Table 13). Coefficients of variation are low and comparable to the outcomes of the healthy cohort.

Discussion

Gait assessments have a high impact on clinical decision making.[7] As in the clinical context, assessments should be meaningful, time-efficient, and non-expensive, the typical procedure to evaluate gait performance does not use intricate devices. For instance, the Dynamic Gait Index (DGI) comprises specific items to get an insight into individual mobility abilities.[10] This rather rough estimation pictures an overall disease state, however, from a biomechanical point of view, it is inappropriate to assess fine graduations in the disease process. Hence, the generally used clinical gait assessments lack sensitivity, while intricate biomechanical tools are time-consuming and expensive. For instance, it is argued that sophisticated quantitative (high-tech) gait assessments are too expensive, time-consuming, and require specific equipment and technical expertise which is not applicable for clinical practice.[33,34] Therefore, in this work we present an efficient and device-independent method to simply attain valuable biomechanical gait parameters in order to easily implement it into clinical data recording.

Comparable gait analyses

As in the recent years new technologies and devices for biomechanical measurements have been generated which are per se not comparable to our method, we first discuss early low-tech findings of the literature. Öberg & Lamoreux[35] created a very similar gait assessment. Participants had to walk a distance between two photoelectric sensors. As the subject passed the first sensor, the number of steps was taken until the last sensor was activated. However, on the one hand the authors did not include trespassing values in their calculation of average gait values, which leads to parameter errors because the real time and the measured effective time between the first and the last heel strike do not coincide. On the other hand the measurement distance was kept low (approx. 5,5m) which may be criticized because of the few number of strides (approx. 10) that are not enough to represent the individual average gait characteristics.[36,37] Later this work was used to provide reference data for different age and gender groups.[1] Holden et al[33] used a 6m paper walkway to record stride characteristics of neurologically impaired individuals via ink footprints. In a similar way, Cerny[38] suggested to measure gait on a 6m walkway by using a stop watch and two pens that were mounted on the subjects' shoes. However, both studies did not incorporate strict procedures, for instance the precise time when starting to measure, and related error estimations as it is documented in the present study. In general, the ink method dates back to the procedure of [39]. It is possible to trace the individual stride-to-stride variability which is a valuable biomechanical characteristic.[40,41]

However, the data recording of stride-to-stride variability, again, is time-consuming and therefore impractical in a clinical context.

From a biomechanical point of view, modern gait analysis is associated with technical equipment that produces highly exact measurement outcomes. Since the mid 20th century, progress in this field has led to various measurement devices, e.g. 3D-motion analysis, electromyography, kinetics, etc. (for detailed review see [42-44]). The present study does not constitute a step backwards. It could be seen as an expansion of prevailing clinical assessment methods with the advantage to achieve biomechanical gait parameters at all. For instance, the DGI rely on a great amount on subjective classifications of the experimenter.[10] On contrary, within the Timed-up-and-Go test time measurement or instructions given to the subjects lack standardisation.[8] Therefore, biomechanical analysis cannot be usually combined with prevailing clinical analysis of gait.

Quality criterions, reference data and sensitivity

The device-independent gait assessment enables to simply detect typical spatiotemporal parameters from gait recordings. It is typical – so in the Timed-up-and-Go test – to use stopwatches or visual inspections in clinical settings.[8] The present method combines these simple procedures to obtain objective, valid, and reliable outcome measures as has been outlined by validity and test-retest-reliability analyses. As demonstrated by the data, measurement distance has negligible influence on reliability within 20m and 40m, however produced only fair correlation coefficients in the 10m walkway situation. Hence, we recommend using at least a distance of 20m, which is also confirmed by the rapid increase of the value $CV(D_k)$ from 20m to 10m. At a first glance, the number of trials had an inferior influence on test-retest reliability. However, with increasing trial number an increase in the coefficient of variation (CV) is observable which indicates that a greater amount of information is included when more trials were included (this is consistent within the healthy controls and neurologically impaired). It could be speculated that a further increase in trial number would lead to higher variability which has to be further analyzed. Therefore, the trial number should be set to at least five which is accomplishable within a 15min. session (without large resting periods). Furthermore, the errors that could occur from the measurement procedure, that are stop watch handling and visual tracking with the pen exhibit very low values that further decrease with increasing walkway length (a 20m trial has a visual error of 0.03% and a time error of 0.6%). As the er-

rors are normally distributed, the errors could be reliably estimated within specific confidence intervals.

Comparing our results to reference data of healthy subjects from literature, all variables are in good agreement to the ones of other studies that were obtained by a variety of comprehensive devices. Samson et al[45] report the following values: GV 1.42-1.46 m/s, SL 0.7-0.75 m, ST 0.47-0.5 s (via force plate measurement). Bugané et al[46] come to similar values GV 1.3 m/s, SL 0.7 m, ST 0.54 s (inertial sensors). Givon et al[47] present GV 1.39 m/s, SL 0.72 m, ST 0.52-0.57 s (n=25, GAITRite©).

However, there are also diverging results: Al-Obaidi et al[48] GV 1.1-1.2 m/s, SL 0.6-0.7m, ST 0.58 s (measured via pressure mat), Öberg et al[1]: GV 1.2 m/s, SL 0.6m, ST 0.5 s (similar method to ours). In a study of Lee et al[49] the values were: GV 1.2 m/s, SL 0.68 m, ST 0.58 s by use of the GAITRite© and the OPTOgait© system. These diverging results may be due to the instruction "walk slowly at a comfortable speed". Therefore, it is very important to standardize the instructions to attain comparable results.

With respect to sensitivity (discriminant validity), the proposed method could distinguish persons with MS from healthy subjects concerning gait velocity and stride length which therefore grants a more detailed insight into underlying biomechanical properties. However, it could be found that subjects with MS comprise an even slower walking speed which affects other gait parameters. For instance, reference data in MS are presented by Givon et al[47]: GV 0.85 m/s, SL 0.45–0.46 m, ST 0.65-0.67 s (EDSS = 2.8, GAITRite©).

A difference between PD and healthy controls could not be established. It could be speculated that on the one hand our PD group had no significant gait disturbances which could be due to rather low UPDRS scores (especially in the motor part) and is in agreement with reference data in literature: Hass et al[50] report the values: GV 0.92 m/s, SL 0.55 m, ST 0.6 s which obviously was a slower cohort compared to our subjects (GAITRite©) despite a comparable Hoehn & Yahr state of 1.5. The study of Morris et al[51] confirms the above stated values: GV 0.83 m/s, SL 0.48 m, ST 0.58 s. On the other hand, the parameters (gait velocity, stride length, stride time) might not have discriminative power in PD. For instance, Nelson et al[52] found that normalized gait velocity (average gait velocity divided by leg length) is a more powerful discriminator between PD and controls. This variable could also be implemented in our procedure, thus this fact has to be elucidated.

To address to secondary quality criterions, we conclude that the test is time-efficient, non-expensive, feasible, and does not demand manpower or expertise. We did not afford interrater reliability which is an important quality criterion, as well. It is contrivable for time measurement, but there will be a direct interaction in the visual marking. To achieve further insight into sensitivity of this very simple method, besides neurological patients, orthopedic patients could be another topic of interest. With respect to greater study cohorts and other disease relationships, further research has to be conducted with this measurement method.

Conflict of interest

The authors declare that there is no conflict of interest.

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Figures and Tables

Table 1. Basic gait parameters (n = 37, 40m trials) and 95% confidence intervals in brackets.

Group	gait velocity (GV) [m/s]	stride length (SL) [m]	strides time (ST) [s]
CG1, CG2	1.47 ±0.11 [1.438;1.498]	0.75 ±0.04 [0.738;0.76]	0.51 ±0.03 [0.503;0.522]

Table 2. Error values of visual marking in CG1.

Subject No.	Difference (S^*_1 - S^*_2) [cm]	Difference (S_1 - S_2) [cm]	Error (E_V) [cm]
1	4.5	3.1	1.4
2	20.8	20.3	0.5
3	19.3	17.1	2.2
4	2.5	3.7	-1.2
5	0.5	0.3	0.2
6	2.5	3.5	-1
7	2.8	2.8	0
8	15.3	14.9	0.4

Subject No.	Difference (S^*_1 - S^*_2) [cm]	Difference (S_1 - S_2) [cm]	Error (E_V) [cm]
9	7.3	6.5	0.8
10	10.1	11.5	-1.4
11	3	3.4	-0.4
12	7.4	7	0.4
13	2.2	2.5	-0.3
14	7.7	7.5	0.2
15	31.1	30.4	0.7
16	27.7	28.5	-0.8
17	1.5	1	0.5
18	26.3	25.7	0.6
19	15.4	15.3	0.1
20	17.2	17.5	-0.3

Table 3. Error values of time measurement in CG1.

Subject No.	Pressure plate time (t*) [s]	Stop watch time (t) [s]	Error (E_T) [ms]
1	11.27	11.16	110
2	8.58	8.69	-110
3	8.96	9.01	-50
4	8.85	8.97	-120
5	9.32	9.17	150
6	11.92	11.89	30
7	11.5	11.49	10
8	13.12	13.23	-110
9	11.29	11.36	-70
10	13.06	12.97	90
11	12.21	12.27	-60
12	13.02	13.16	-140
13	12.26	12.26	0
14	10.78	10.73	50
15	11.31	11.15	160
16	12	12.03	-30

17	17.29	17.17	120
18	9.88	9.94	-60
19	11.93	11.87	60
20	11.49	11.38	110

Table 4. Intraclass-correlation-coefficients of CG1 and CG2 with respect to the different walking distances. ICC consistency values ICC3,1(C) and ICC absolute agreement values ICC3,1(A) in brackets.

variable	CG1	CG2-10m	CG2-20m	CG2-40m
distance [m]	40	10	20	40
stride time [s]	0.954*(0.95*)	0.668*(0.676*)	0.919*(0.916*)	0.901*(0.903*)
gait velocity [m/s]	0.925*(0.871*)	0.739*(0.742*)	0.849*(0.852*)	0.84*(0.846*)
stride length [m]	0.941*(0.894*)	0.91*(0.911*)	0.888*(0.888*)	0.998*(0.998*)

Table 5. Structure of ICC values in dependence of trial number effects. ICC values for consistency (ICC3,1(C)) are shown. ICC values for absolute agreement (ICC3,1(A)) are shown in brackets.

Trial		1 to 2	1 to 3	1 to 4	1 to 5
stride time	CG1	0.934 (0.936)	0.944 (0.941)	0.957 (0.954)	0.954 (0.95)
	CG2-10m	0.797 (0.805)	0.727 (0.737)	0.663 (0.669)	0.668 (0.676)
	CG2-20m	0.891 (0.896)	0.914 (0.918)	0.914 (0.912)	0.919 (0.916)
	CG2-40m	0.901 (0.902)	0.917 (0.918)	0.908 (0.91)	0.901 (0.903)
gait velocity	CG1	0.888 (0.871)	0.908 (0.845)	0.919 (0.865)	0.925 (0.871)
	CG2-10m	0.794 (0.797)	0.769 (0.773)	0.723 (0.725)	0.739 (0.742)
	CG2-20m	0.831 (0.838)	0.848 (0.855)	0.856 (0.857)	0.849 (0.852)
	CG2-40m	0.880 (0.883)	0.859 (0.864)	0.847 (0.853)	0.840 (0.846)
stride length	CG1	0.939 (0.924)	0.932 (0.881)	0.936 (0.887)	0.941 (0.894)
	CG2-10m	0.929 (0.932)	0.919 (0.922)	0.907 (0.91)	0.910 (0.911)
	CG2-20m	0.917 (0.91)	0.850 (0.852)	0.879 (0.881)	0.888 (0.888)
	CG2-40m	0.936 (0.94)	0.938 (0.941)	0.929 (0.932)	0.916 (0.919)

Table 6. Mean values of CV in [%] and standard deviation S in [%] of the groups for different trial constellations.

Trial		1 to 2	1 to 3	1 to 4	1 to 5
stride time	CG1	1.34 ±1.55	1.52 ±1.42	1.45 ±1.1	1.57 ±1.13
	CG2-10m	2.08 ±2.06	2.59 ±1.95	2.69 ±2.25	2.86 ±2.06
	CG2-20m	1.36 ±1.42	1.41 ±1.21	1.64 ±1.06	1.69 ±0.97
	CG2-40m	1.21 ±1.24	1.18 ±0.97	1.36 ±0.82	1.48 ±0.6
gait velocity	CG1	2.22 ±1.82	2.92 ±1.63	2.8 ±1.36	2.8 ±1.3
	CG2-10m	2.67 ±1.86	3.1 ±1.96	3.35 ±2.38	3.44 ±2.01
	CG2-20m	1.79 ±1.48	1.82 ±1.13	1.92 ±1.03	2.08 ±0.92
	CG2-40m	1.89 ±1.43	2.03 ±1.35	2.11 ±1.26	2.15 ±1.19
stride length	CG1	1.21 ±1.14	1.81 ±1.05	1.77 ±0.99	1.72 ±0.97
	CG2-10m	0.95 ±0.96	1.21 ±0.89	1.4 ±0.85	1.44 ±0.75
	CG2-20m	0.98 ±0.6	1.26 ±0.94	1.18 ±0.78	1.22 ±0.72
	CG2-40m	0.88 ±0.9	0.95 ±0.77	1.09 ±0.73	1.24 ±0.69

Table 7. 90% Confidence intervals and TOST (CG1 versus CG2). Significance is denoted by an asterisk.

	Lower limit	Upper limit
equivalence margin	-0.05	0.05
stride time (ST)*	-0.027	0.019
gait velocity (GV)	-0.0467	0.0997
stride length (SL)*	-0.0167	0.039

Table 8. Ratio q and coefficients of variation $CV(D_k)$. (Mean ±Standard deviation).

Cohort	Ratio q [%]	$CV(D_k)$ [%]
CG1	99.937 ±0.684	0.292 ±0.219
CG2-10m	99.155 ±2.384	2.328 ±1.439
CG2-20m	99.7 ±0.994	0.67 ±0.502
CG2-40m	99.814 ±0.568	0.431 ±0.232

Table 9. Basic gait parameters and 95% confidence intervals (in brackets) for PD (n = 20, 40m trials) and MS (n = 14, 20m trials). Significant differences to healthy controls are marked with an asterisk.

Group	gait velocity (GV) [m/s]	stride length (SL) [m]	strides time (ST) [s]
PD	1.41 ±0.22 [1.32;1.49]	0.73 ±0.12 [0.69;0.78]	0.53 ±0.05 [0.51;0.544]
MS	1.34 ±0.23* [1.23;1.45]	0.69 ±0.11* [0.64;0.744]	0.52 ±0.02 [0.51;0.531]

Table 10. Intraclass-correlation-coefficients of MS and PD.

variable	MS	PD
Distance [m]	20	40
stride time	0.809* (0.804*)	0.967* (0.967*)
gait velocity	0.952* (0.94*)	0.964* (0.955*)
stride length	0.976* (0.97*)	0.983* (0.978*)

Table 11. Structure of ICC values in dependence of trial number effects. ICC values for consistency (ICC3,1(C)) are shown. ICC values for absolute agreement (ICC3,1(A)) are shown in brackets.

Trial		1 to 2	1 to 3	1 to 4	1 to 5
stride time	MS	0.641 (0.654)	0.753 (0.755)	0.783 (0.782)	0.809 (0.804)
	PD	0.973 (0.974)	0.974 (0.973)	0.966 (0.966)	0.967 (0.967)
gait velocity	MS	0.948 (0.939)	0.964 (0.951)	0.964 (0.95)	0.952 (0.94)
	PD	0.951 (0.949)	0.959 (0.951)	0.964 (0.955)	0.964 (0.955)
stride length	MS	0.987 (0.98)	0.987 (0.98)	0.986 (0.978)	0.976 (0.97)
	PD	0.983 (0.981)	0.982 (0.978)	0.983 (0.978)	0.983 (0.978)

Table 12. Mean values of CV in [%] and standard deviation S in [%] of the groups for different trial constellations.

Trial		1 to 2	1 to 3	1 to 4	1 to 5
stride time	MS	2.16 ±2.1	1.98 ±1.66	1.96 ±1.52	2.02 ±1.3
	PD	0.99 ±1.14	1.2 ±0.99	1.37 ±0.99	1.45 ±0.81
gait velocity	MS	3.3 ±2.65	3.27 ±1.93	3.32 ±2.04	3.57 ±2.67
	PD	2.68 ±1.94	3.07 ±1.55	2.99 ±1.49	2.98 ±1.42
stride length	MS	1.7 ±1.56	1.94 ±1.25	2.05 ±1.29	2.41 ±1.7

	PD	1.73 ±1.45	2.09 ±1.46	2.1 ±1.49	2.11 ±1.43

Table 13. Ratio q and coefficients of variation $CV(D_k)$. (Mean ± Standard deviation).

Cohort	Ratio q [%]	$CV(D_k)$ [%]
PD	100.07 ±0.682	0.366 ±0.24
MS	100.55 ±1.083	0.664 ±0.428

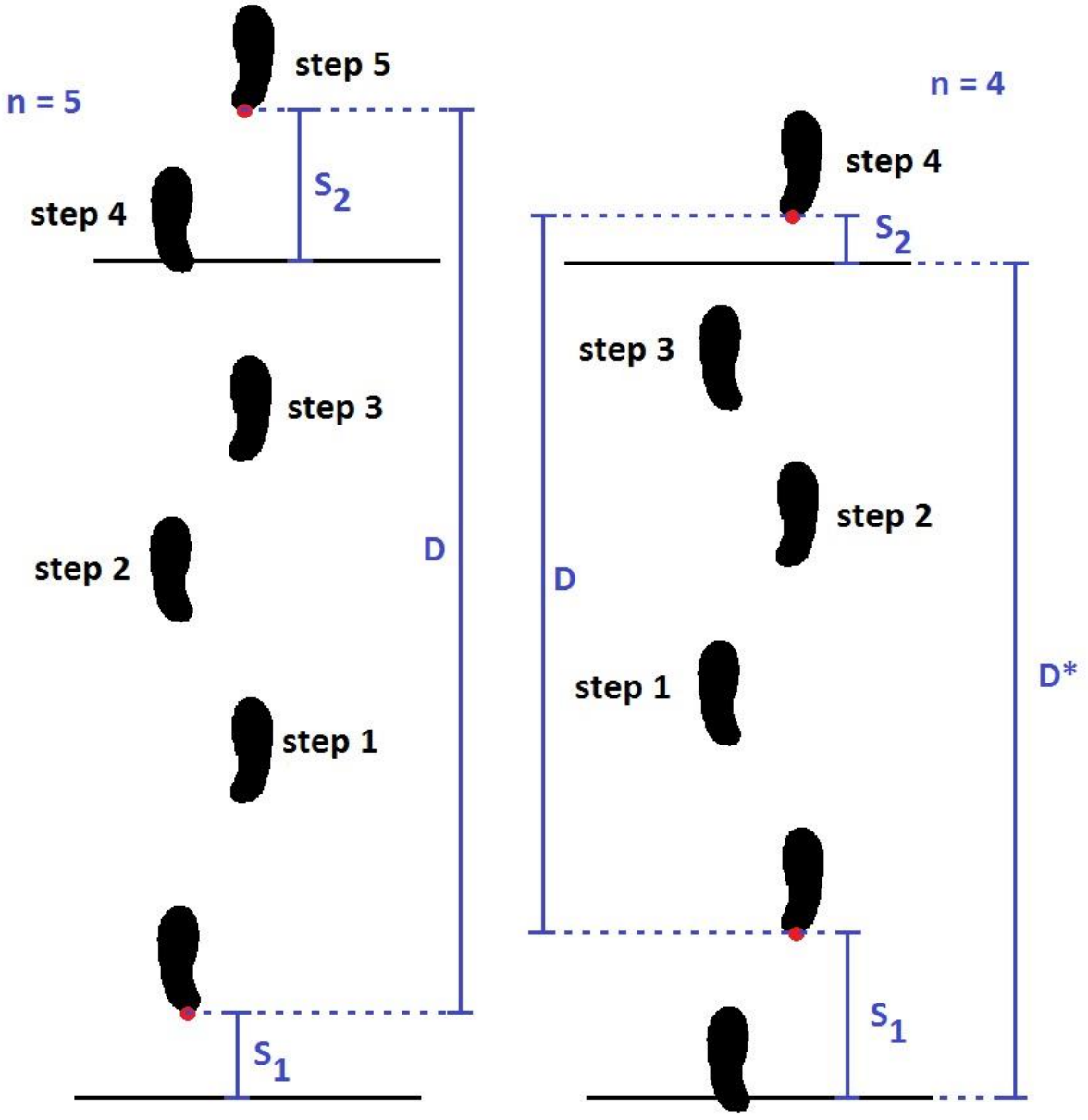

Figure 1. Two exemplary scenarios of the gait assessment. Trespassing of start and finish lines are denoted by S1 and S2, respectively. The real walking distance thus is given by D = D* - S1 + S2.

Figure 2. Validity Analysis. Left: Initial step onto the pressure plate. Right: Visual marking.

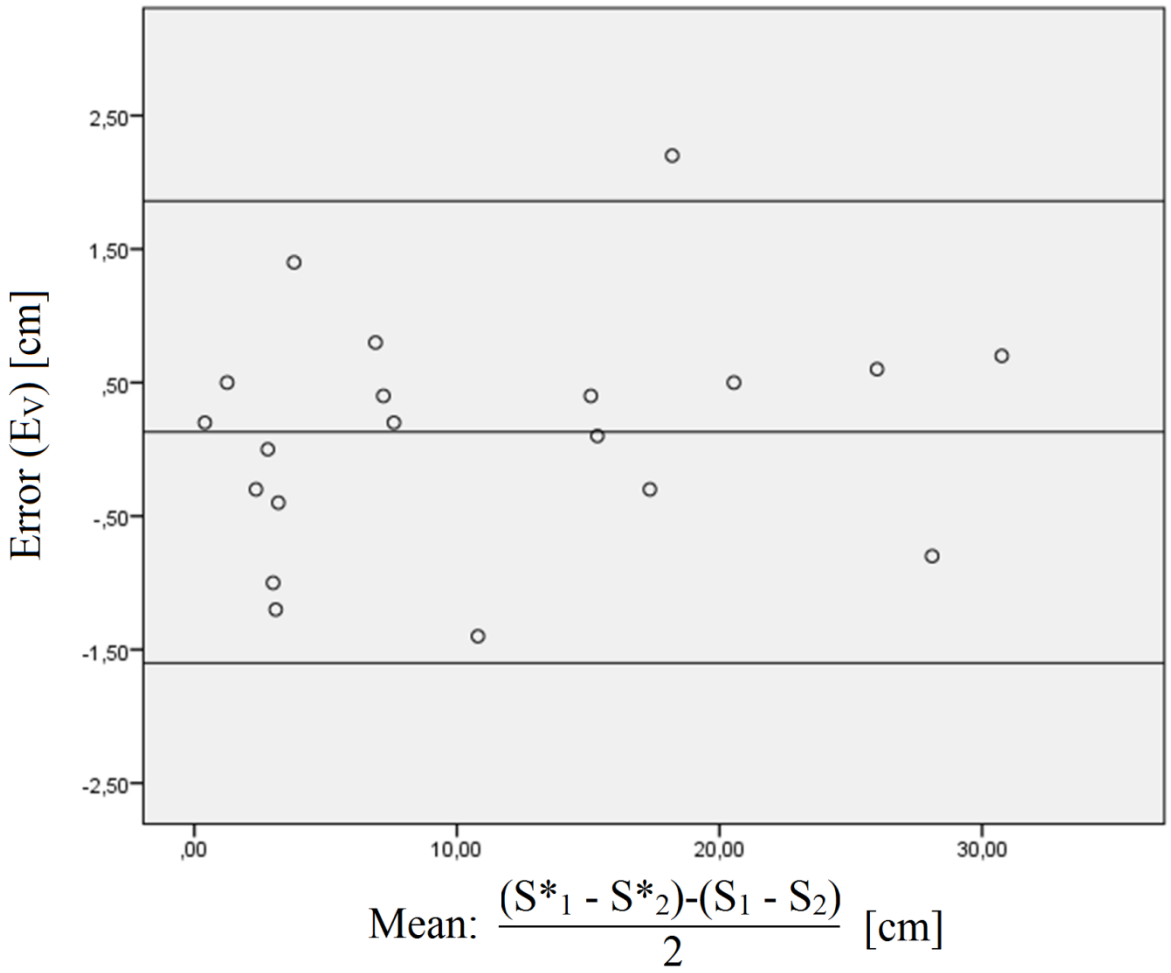

Figure 3. Bland-Altman-Plot of visual marking versus video analysis.

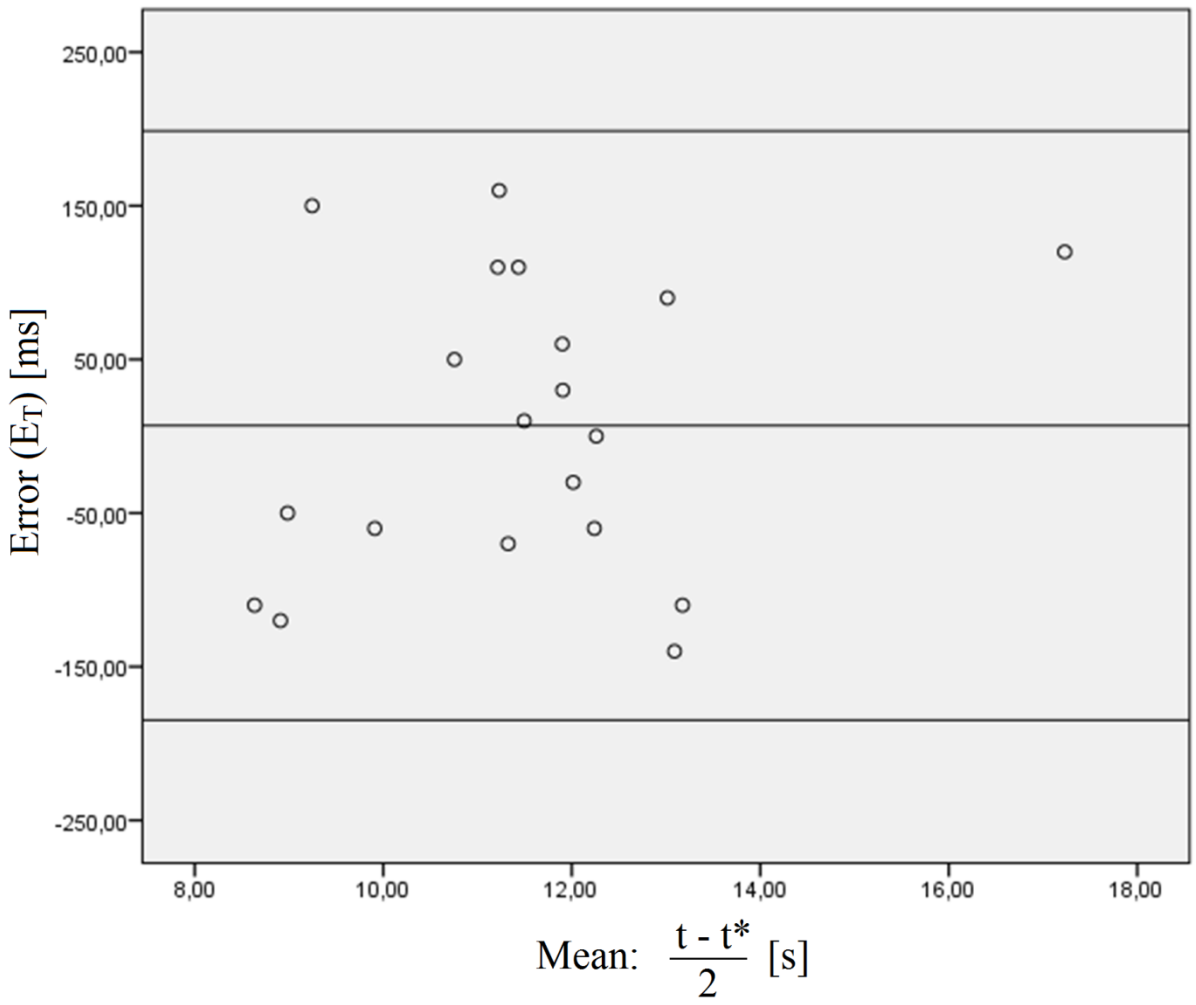

Figure 4. Bland-Altman-Plot of time measurement via stop watch versus pressure plate analysis.

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