Smartphone-Based Timed Up and Go Test Can Identify Postural Instability in Parkinson's Disease

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ABSTRACT:

Background: There is a need for standardized and objective methods to measure postural instability (PI) and gait dysfunction in Parkinson's disease (PD) patients. Recent technological advances in wearable devices, including standard smartphones, may provide such measurements.

Objectives: To test the feasibility of smartphones to detect PI during the Timed Up and Go (TUG) test.

Methods: Ambulatory PD patients, divided by item 30 (postural stability) of the motor Unified Parkinson's Disease Rating Scale (UPDRS) to those with a normal (score = 0, PD-NPT) and an abnormal (score ≥ 1, PD-APT) test and a group of healthy controls (HC) performed a 10-meter TUG while motion sensor data was recorded from a smartphone attached to their sternum using the EncephaLog application.

Results: In this observational study, 44 PD patients (21 PD-NPT and 23 PD-APT) and 22 HC similar in age and gender distribution were assessed. PD-APT differed significantly in all gait parameters when compared to PD-NPT and HC. Significant difference between PD-NPT and HC included only turning time ($P < 0.006$) and step-to-step correlation ($P < 0.05$).

Conclusions: While high correlations were found between EncephaLog gait parameters and axial UPDRS items, the pull test was least correlated with EncephaLog measures. Motion sensor data from a smartphone can detect differences in gait and balance measures between PD with and without PI and HC.

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KEY WORDS: gait analysis, Parkinson's disease, pull test, smartphone, Timed Up and Go test (TUG)

Gait impairment and postural instability (PI) are core features of Parkinson's disease (PD) and determine the clinical grading of disease progression at the mid to later stages [1,2].

Traditionally, gait impairment and PI have been assessed using non-instrumental semi-quantitative gait and balance clinical rating scales and were markedly influenced by inter- and intra-observer variability. Improved objectivity of these measures was obtained in gait laboratories equipped with camera-based three-dimensional motion analysis and quantitative posturography systems.

The motor examination part of the Unified Parkinson's Disease Rating Scale (UPDRS) [3] and later the revised version – the MDS-UPDRS [4] – are the gold standard tools for evaluation of motor signs of PD encompassing the core features of motor involvement, including slowness, rigidity, tremor, gait, and balance function. The Hoehn and Yahr (HY) [5] scale is a staging scale that has focused mainly on ambulatory capability, defining staging of PD motor progression from unilateral to bilateral involvement, with and without PI, and later with impaired balance and ambulation.

Several limitations of the UPDRS and HY scales have been noted, including ambiguity in definitions (e.g., inadequate instructions for raters and some metric flaws) and inter-rater variability due to subjective assessment carried out by different physicians [6].

One example is the delineation between stages II and III of the HY scale, which depends on the performance on a pull test (rated according to the original UPDRS version). Ratings were found to have sub-optimal inter-rater reliability [7]. It is clear that standardized and objective methods of measuring PI in the clinic are urgently needed to enhance the ability to monitor symptom progression and evaluate a patient's risk of falling.

Gait and balance measurement methods, such as videotape analysis, motion capture systems, and force plates in addition to a variety of electromyographic methods are used to carry out quantitative gait analysis and to determine the pathological impact on gait characteristics [8]. Because of the high costs and space requirements, these systems are in use for research in gait laboratories but not in routine clinical practice or in a patient's home.

Wearable sensor technology is now being thoroughly studied and is used to evaluate gait and balance function in PD [9].

Recent studies show that the inbuilt inertial motion sensors in smartphones have sufficient reliability and validity for

providing quantitative evaluation of kinematic tests [10,11]. Nonetheless, smartphone-based gait and posture analysis in a clinical setting has scarcely been reported [12,13].

The Timed Up and Go (TUG) test, is one of the most commonly used clinical tests for evaluating mobility and balance. TUG is a simple, quick, and validated test that was initially introduced to assess functional mobility in the elderly [14,15] and in subjects during rehabilitation [10].

The aim of this study was to measure and compare balance and gait parameters obtained from patients with PD exhibiting an abnormal pull test to those with a normal pull test, as well as to healthy controls, using EncephaLog (Montfort®, http://www.mon4t.com), and a smartphone-based application for real-time monitoring of gait and balance. In addition, the study was designed to detect correlations between dynamic balance measures obtained by EncephaLog and the semi-quantitative rating on the postural stability item (question number 30) and other axial scores from the motor examination part (part III) of the UPDRS.

PATIENTS AND METHODS

STUDY POPULATION

Consecutive patients attending the Movement Disorders Institute at the Sheba Medical Center between the years 2016 and 2017, who were diagnosed with idiopathic PD according to the UK bank criteria [16] and who could walk unassisted, were recruited. Patients were excluded in case of balance disorders and lower limb or back problems not related to PD, possibly affecting gait, and in cases of previous brain surgery (including deep brain stimulation or a previous intracranial procedure).

Healthy age- and sex-matched control subjects (healthy controls [HC]) were randomly selected from the pool of hospital staff, patients' (unrelated) family members or accompanying subjects who arrived at the clinic, with younger subjects omitted from the study to match the relatively older age of the PD population.

The study was approved by the local institutional review board. All subjects signed an informed consent form.

CLINICAL DATA

Demographic data was collected from the patient's outpatient clinic medical charts and included current age, gender, age at PD symptom onset, disease duration, and anti-PD medications.

Patients were examined by a neurologist specialized in movement disorders (GY, SIK, SEB, VL, TFK, or SHB). In most cases full rating of the motor examination of the UPDRS was provided, always on the same day as the TUG test, including items 27–30 of the motor UPDRS (arising from chair, posture, gait, and postural stability). Patients were then assigned to one of two groups according to a normal pull test (score 0, group PD-NPT) or abnormal pull test (score ≥ 1, group PD-APT).

A 4-item axial motor UPDRS score was calculated for each PD patient using the sum of the scores on items 27–30.

ENCEPHALOG FUNCTIONING, TESTING PROCEDURES, AND DATA PREPROCESSING

Equipment

EncephaLog, developed by Montfort® (http://www.mon4t.com), uses the data recorded from the inbuilt tri-axial accelerometer, gyroscope, and magnetometer that are embedded in all standard smartphones. The accelerometer measures linear acceleration in all three axes. The gyroscope measures angular velocity (i.e., the speed of rotation) in all three axes: pitch, yaw, or roll. All sensors sampled data at a rate of 100 Hz.

For this study we used a standard iPhone6 smartphone (Apple®, Cupertino, CA, USA) with dimensions of $138 \times 67 \times 7$ mm.

Testing protocol

All participants were assessed during a single visit to the Movement Disorders Institute. Patients performed two trials each of a 3-meter and a 10-meter TUG, with the EncephaLog-equipped iPhone6 attached to the chest at the level of the sternum by means of an adjustable elastic strap in a horizontal orientation. Subjects sat comfortably on a chair without an armrest and the EncephaLog cued the start of the trial with a 5 seconds countdown, followed by a short audible tone and vibration. Subjects then stood up without any assistance or armrest support and walked at their natural speed straight ahead toward a cone positioned on the floor three meters away from their chair, turned around the cone (counterclockwise), walked back, and then sat down on the chair. The same procedure was conducted with a 10-meter walk. If a subject failed to perform the procedure correctly (e.g., due to poor understanding of the task or distraction) the trial was discarded and immediately repeated. The data was then uploaded to Montfort's server for analysis.

The parameters provided by the EncephaLog software are the total and segmented TUG times in seconds (standing up, walking straight away, turning, walking straight back, and sitting down), step length, mediolateral sway (in centimeters), step-to-step correlation, and cadence (steps/minute). The calculation of step-to-step correlation is clarified in detail in the attached supplementary material [Appendix A]. Posturographic measurements were recorded in three dimensions (in m/sec^2): anterior-posterior (AP), vertical (V), and mediolateral (ML).

Preprocessing

For each TUG session, the start and end of standing-up, turning, and sitting-down, were manually marked and the duration for each segment was calculated. Average step length was calculated by dividing 10 meters by the number of steps (i.e., turning was excluded from the analysis). For the mediolateral sway and step-to-step correlation, the first step after stand-up, the steps during turning, and the step before sitting-down were excluded.

The mediolateral and anterior-posterior sway was calculated by using the acceleration in each direction for those steps. In order to calculate the step to step variation, all of the steps during the straight gait (away and return) were separated from one another, and the average step pattern was generated for each of the three axes. Next, the variation of each step was computed in comparison to the average step profile, followed by calculating the average variation of all the steps (for more details, See Appendix A).

STATISTICAL ANALYSIS

Following our initial analysis, we found out that the 10-m TUG was more informative than the 3-m TUG, as seen in the preprocessing of the data, especially for the calculation of sway and step-to-step correlation. Since we had some subjects who conducted only one 10-m session, the first 10-m TUG trial of each subject was used in the analysis, even for subjects who had two trials. The differences among the three subject groups: PD-NPT, PD-APT, and HC, were calculated using one-way ANOVA for the continuous variables obtained by the EncephaLog, followed by a post-hoc Tukey analysis and Chi-square for the dichotomous variables. Correlations between EncephaLog parameters and each of four UPDRS items 27–30 were computed by the Pearson correlation. P value ≤ 0.05 was considered as statistically significant. All statistical analyses were performed using JMP 14 by SAS Institute Inc., Cary, NC, USA.

RESULTS

Fifty-six PD patients were recruited and tested; however, 12 were excluded. Ten were excluded due to incomplete TUG procedure where the subject could not complete the entire procedure without assistance and two because of failure in transmitting the data (this was later solved by adding a backup local storage). The remaining 44 patients were divided according to the pull test to the PD-NPT group (n=21, 11 males, age 67.3 ± 6.8 years) and the PD-APT group (n=23, 13 males, age 67.8 ± 6.9 years). A sample of 22 age- and sex-matched HC subjects was chosen from a larger pool of 56 HC (11 males, age 64.2 ± 8.6 years). The selection of the participants finally enrolled is presented in Figure 1. The three groups were similar in terms of demographics and PD clinical features [Table 1].

Group comparison between all PD patients (PD total) and HC showed significant differences in all EncephaLog parameters [Table 2].

Significant differences in all EncephaLog variables were found between PD-APT and HC; however, the PD-NPT group did not differ from HC in most tasks. Only turning time was significantly longer (2.2 ± 0.6 vs. 1.3 ± 0.3 seconds, $P = 0.006$) and step-to-step correlation was significantly lower (0.31 ± 0.13 vs. 0.40 ± 0.10, $P = 0.05$) in PD-NPT than HC.

The PD-NPT group differed from the PD-APT in all parameters: shorter times for total TUG ($P < 0.001$), standing-up ($P = 0.03$), sitting-down ($P = 0.02$), turning ($P = 0.003$), walking away ($P < 0.001$), and walking back ($P < 0.001$). The PD-NPT group showed a smaller mediolateral sway (6.5 ± 3.0 vs. 9.3 ± 3.7 cm, $P = 0.007$), longer step length (59.0 ± 6.3 vs. 51.1 ± 11.0 cm, $P = 0.008$), a and higher step-to-step correlation (0.31 ± 0.13 vs. 0.19 ± 0.12, $P = 0.003$).

There were significant correlations between the gait parameters recorded by EncephaLog and the 4-axial motor UPDRS item scores in all PD patients. While most EncephaLog gait measures were highly correlated with the UPDRS items "arising from chair," "posture," and "gait" [Table 3], the correlation with the pull test was marginal.

Figure 1. The pathway through which patients were selected and included in the study. The group of healthy controls was selected randomly from the older subjects in the pool in order to match the age of the relatively older Parkinson's disease (PD) population
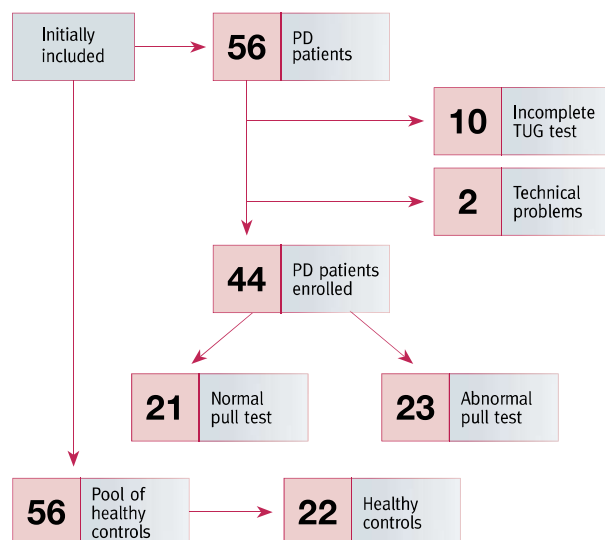
TUG = Timed Up and Go

Table 1. Study subject characteristics

	PD-NPT	PD-APT	HC	*P* value*
Number of participants	21	23	22	
Males, n (%)	11 (52.4)	13 (56.5)	12 (57.1)	0.91
Age, years	67.3 ± 6.8	67.8 ± 6.9	64.2 ± 8.6	0.80
Age at symptom onset, years	60.7 ± 8.7	59.2 ± 9.1	–	0.57
Disease duration, years	6.6 ± 3.9	8.7 ± 5.0	–	0.13
L-dopa daily dose, mg	442.6 ± 252	572.0 ± 391	–	0.40
Axial motor UPDRS sub-score	1.5 ± 1.5	4.6 ± 2.5	–	‹ 0.001

*for binary parameters
P value was calculated by Chi-square test. For all other parameters, Tukey HSD test was used

PD-NPT = PD patients with a normal pull test (UPDRS item 30 score = 0),
PD-APT = PD patients with an abnormal pull test (UPDRS item 30 score ≥ 1),
HC = healthy controls, n = number of subjects, UPDRS= Unified PD Rating Scale

Table 2. 10-meter TUG measures from EncephaLog according to groups

	PD total	PD-APT	PD-NPT	HC	P value 1	P value 2	P value 3	P value 4
N	44	23	21	22				
Total TUG time (sec)	30.3 ± 12.4	35.6 ± 14.8	24.4 ± 4.7	21.8 ± 2.9	‹ 0.001	‹ 0.001	0.64	‹ 0.001
Stand up time (sec)	1.9 ± 0.6	2.1 ± 0.7	1.7 ± 0.3	1.6 ± 0.3	0.02	0.03	0.90	0.008
Walk away time (sec)	11.0 ± 5.5	13.4 ± 6.7	8.4 ± 1.6	7.3 ± 0.8	‹ 0.001	‹ 0.001	0.67	‹ 0.001
Turning time (sec)	2.7 ± 1.1	3.1 ± 1.3	2.2 ± 0.6	1.3 ± 0.3	‹ 0.001	0.003	0.006	‹ 0.001
Walk back time (sec)	10.5 ± 4.1	12.3 ± 4.8	8.5 ± 1.8	8.0 ± 1.4	‹ 0.001	‹ 0.001	0.86	‹ 0.001
Sit down time (sec)	4.3 ± 1.8	4.8 ± 2.1	3.6 ± 1.1	3.2 ± 0.7	0.001	0.02	0.64	0.001
Mediolateral sway (cm)	7.6 ± 3.3	9.3 ± 3.7	6.5 ± 3.0	4.9 ± 1.6	0.001	0.007	0.20	‹ 0.001
Step length (cm)	54.9 ± 9.8	51.1 ± 11.0	59.0 ± 6.3	63.4 ± 7.0	‹ 0.001	0.008	0.22	‹ 0.001
Step to step correlation	0.25 ± 0.14	0.19 ± 0.12	0.31 ± 0.13	0.40 ± 0.10	‹ 0.001	0.003	0.05	‹ 0.001
Cadence (steps/ minute)	50.4 ± 8.8	46.5 ± 9.2	54.7 ± 6.1	59.5 ± 5.4	‹ 0.001	0.002	0.16	‹ 0.001

HC = healthy controls; N = number of subjects; PD = Parkinson's disease; PD-NPT = PD patients with normal pull test, no postural instability; PD-APT = PD patients with abnormal pull test, postural instability; TUG = Timed Up and Go test

P value 1 = comparison between all PD patients and HC groups
P value 2 = comparison between groups PD-NPT and PD-APT
P value 3 = comparison between groups PD-NPT and HC
P value 4 = comparison between groups PD-APT and HC

Table 3. Correlations between axial motor UPDRS scores and EncephaLog measures

Measures obtained from EncephaLog	Arising (0–4) (item 27)	Posture (0–4) (item 28)	Gait (0–4) (item 29)	Pull test (0–4) (item 30)	Axial motor UPDRS score (0–16)
Stand-up time (sec)	0.37 (‹ 0.001)	0.32 (0.002)	0.22 (0.005)	0.10 (0.05)	0.39 (‹ 0.001)
Walk away time (sec)	0.42 (‹ 0.001)	0.29 (0.004)	0.28 (0.001)	0.10 (0.06)	0.46 (‹ 0.001)
Rotation time (sec)	0.46 (‹ 0.001)	0.37 (‹ 0.001)	0.43 (‹ 0.001)	0.05 (0.18)	0.39 (‹ 0.001)
Walking back time (sec)	0.38 (‹ 0.001)	0.28 (0.005)	0.32 (‹ 0.001)	0.09 (0.07)	0.48 (‹ 0.001)
Sit-down time (sec)	0.26 (0.001)	0.29 (0.004)	0.41 (‹ 0.001)	0.04 (0.25)	0.14 (0.04)
Total TUG time (sec)	0.42 (‹ 0.001)	0.31 (0.003)	0.34 (‹ 0.001)	0.09 (0.06)	0.43 (‹ 0.001)
Cadence (steps/minute)	0.42 (‹ 0.001)	0.26 (0.007)	0.14 (0.03)	0.11 (0.04)	0.31 (0.001)
Medio-lateral sway (cm)	0.09 (0.07)	0.07 (0.17)	0.005 (0.69)	0.10 (0.05)	0.08 (0.12)
Step length (cm)	0.007 (0.62)	‹ 0.001 (0.92)	0.10 (0.07)	‹ 0.001 (0.98)	0.41 (‹ 0.001)
Step-to-step correlation	0.19 (0.007)	0.25 (0.008)	0.39 (‹ 0.001)	0.07 (0.10)	0.08 (0.14)

The numbers represent the r-square and the P value is in parenthesis. Numbers in bold are statistically significant
Axial motor score is the sum score of items 27–30 from the motor UPDRS

The timed EncephaLog segments correlated better with the UPDRS items than some of the other EncephaLog gait measures. Step-to-step correlation and cadence correlated significantly with the axial UPDRS measures.

DISCUSSION

In this cross-sectional comparative observational study, we used a standard iPhone6 smartphone equipped with a software application (EncephaLog) to quantify gait and balance in a sample of patients with early and middle stages of PD and age-matched controls.

Subjects performed a TUG test and the application presented the TUG segments and several gait and balance parameters that differed between the PD and HC groups. Furthermore, PD patients with PI, as defined by an abnormal response according to the postural stability item of the UPDRS, showed worse scores on most TUG variables. The results obtained by EncephaLog were less discriminating in testing NPT-PD patients versus HC. Only step-to-step correlation and turning time were different between PD patients with a normal pull test and HC. Similar findings were also demonstrated in a previous study of gait analysis in early stage PD using an electronic walkway [17].

Salarian et al. [18] used seven inertial sensors attached to the forearms, shanks, thighs, and sternum to show differences in turning time ($P < 0.02$) and turn-to-sit duration ($P = 0.02$) between early stage PD and controls. In that study, cadence was also significantly different.

These results emphasize the notion that EncephaLog using a standard smartphone with built-in sensors can provide valuable and clinically relevant objective quantitative measures of gait and balance similar to those obtained with complex and expensive instruments and software used in motion labs.

The individual UPDRS item scores 27, 28, and 29 and the calculated axial motor UPDRS score correlated highly with the EncephaLog measures while the score of UPDRS item 30 (pull test) did not, suggesting that the ambiguous instructions and semi-quantitative 0 to 4 rating may not provide reliable information on PI in PD. However dichotomous classification of patients into those with a normal or abnormal pull test was in accordance with the EncephaLog measures.

Other technologies that have been previously and currently implemented for motion analysis are electronic walkways such as GAITRite [19] or treadmill force platforms [20]; wearable (non-smartphone) tri-axial accelerometers attached to parts of the body such as OPAL™ (APDM, Inc, Portland, OR, USA), DynaPort© (McRoberts BV, The Hague, The Netherlands), three-dimensional (3-D) motion capture systems [21] or shoe-mounted devices such as eGait© [22] or Physiolog sensors (Physiolog4, GaitUp system, Lausanne, Switzerland). These devices are neither practical nor commonly used in clinical settings as they are large, expensive, and require special training to operate, maintain, and analyze recorded data.

While the use of instrumental TUG has become prevalent, particularly for research, studies on smartphone-based gait analyses have been scarcely published. Madhushri et al. [23]

performed smartphone-based gait assessment in an elderly population, including TUG segmentation, step count, and balance tests. Kim et al. [13] studied freezing in PD patients in a corridor, not based on a TUG protocol, using three smartphones at a time for each trial. Capecci et al. [12] also studied freezing of gait in PD patients by a smartphone attached to the waist in a TUG protocol with and without dual tasking and focused mainly on freezing episodes and not on other gait parameters.

LIMITATIONS

This study has some limitations. There are some inherent drawbacks of the smartphone as a portable motion analysis laboratory: upper body movements and arm swing data are unavailable as is stance width. Furthermore, while smartphone sensors have been previously validated and proved to be accurate [24,25], EncephaLog was not validated against gait monitoring devices such as GAITRite© or APDM OPAL©. Nonetheless, looking into the data in other studies with validated tools, our numbers are more or less similar. The early staged PD patients in a study by Grajić et al. [17] showed stride length of 122 cm vs. 129 cm for the HC, using GAITRite electronic walkway, while our NPT-PD had a calculated stride length of 118 cm vs. 127 cm for the HC. In the study of Salarian [18], using Physilog (BioAGM, Switzerland) as a measuring tool, turning duration was 2.18 seconds for early PD and 1.79 seconds for HC while our numbers are 2.2 seconds for NPT-PD and 1.3 seconds for HC.

Furthermore, the EncephaLog software is not fully automated and some human preprocessing of each acquisition is still mandatory prior to analysis. Moreover, there is additional important data in the recordings that has not yet been calculated or presented, such as the first step after arising or after turning, the turn before sitting down, and asymmetry indices.

Other limitations of this study, focusing on PD patients, included a small sample and an incomplete range of gait and balance dysfunction severity in PD patients, as patients with HY stage 4 were excluded.

CONCLUSIONS

Motion sensor data, obtained during a 10-m TUG test, which was recorded and analyzed on smartphone-based system, differentiated between PD patients with and without abnormal pull test response, who were able to walk unassisted, and HC was correlated with several relevant UPDRS items. Furthermore, in addition to our study results, we have shown the potential of EncephaLog in assessing multidimensional data regarding gait and postural function in PD. While as of today, motion capture sensors such as EncephaLog may be complementary to the clinical assessment of gait, posture, and balance performed by the physician, this system displays several advantages over the clinical evaluation as it is based on quantitative rich and objective motion measures that can be easily standardized to minimize intra- and inter-observed variability bias. In addi-

tion, the data acquisition by the smartphone can take place in the clinic as well as independently in the patient's natural environment at home, work, or any place, at several time points (e.g., morning before medication, on and off states repeatedly following interventions).

Future studies may establish the use of EncephaLog in short- or long-term monitoring of patients with PD for clinical and research purposes. They may also provide standardization in the test procedure, show increased validity of in-clinic or home-based monitoring assessments, and replace the traditional semi-quantitative scales such as the HY scale and the motor examination of the UPDRS.

Furthermore, we believe that the use of smartphone motion sensors with applications, such as EncephaLog to develop advanced computation algorithms (e.g., machine learning), may favor early identification of patterns of gait dysfunction for different patient groups.

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Appendix 1. Preprocessing and signal analysis

For each TUG session, the start and end of stand-up, turning and sit-down, were manually marked and the duration for each segment was calculated. Average step length was calculated by dividing 10 meters (in case of 10m TUG) or 3 meters (in case of 3-meter TUG) by the number of steps (i.e., turning was excluded from the analysis). The straight-walking time, cadence, and step count were computed as the average of the away and return segments of the TUG. For the ML-sway and step correlation (in AP and ML directions), the first step after stand-up, the steps during turning, and the step before sitting-down were excluded. The ML and AP sways were calculated by using the acceleration in each direction for those steps and it was measured in distance units (cm). The device was first aligned in the real 3D space, using gravity to orient the device. Our reference point was the point of zero acceleration when the subject sits still. Then, we recorded the accelerations in each direction, integrated the accelerations to calculate velocity and then distance.

To calculate the step correlation, all the steps during the straight gait (away and return) were separated (manually) from one another, and the average step pattern was generated for each of the three axes. Then, the variation of each step was computed in comparison to the average step profile, followed by calculating the average variation of all the steps. Step correlation included both step time and step length which were integrated together into one formula. We conduct the following analysis for the data captured in each direction: First, we identify the step cadence by using autocorrelation:

$$A_{x,x}(l) = \sum_{n=-\infty}^{+\infty} x(n)x(n-l)$$

Where $x(n)$ is the signal analyzed (e.g., medio-lateral accelerometer) and l is the number of samples we shift $x(n)$ relative to itself for the correlation calculation (thus obtaining the autocorrelation). The l that provides the first maxima in the autocorrelation function $A_{x,x}(l)$, is the average step to step interval in samples, which is converted to average step to step time interval by dividing it by the sample rate.

We also obtained a typical step pattern as it crossed an adaptive threshold up and down. We started with the first step, looking for that particular pattern, and marked the end of the first step, which is the beginning of the next one. The exact duration of each step was compared to the average step duration to make sure it was within a small margin to that average. After all the steps were thus marked, we generated a typical step pattern by summing all the steps and averaging by the number of steps to generate X_{av}. We then took all the steps Xs and calculated $r_{x,x_{av}}$, where r is the Pearson product-moment correlation coefficient between the average step and each step, thus indicating the degree of linear relationship between the two. We then calculated the average of all rs for each patient. The higher the average is, the more the steps resembles each other.