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Repeatability of lower leg mechanics during gait in Parkinson's disease

Erasmia Giannakou[a], Nickos Aggeloussis[a], Vassilios Gourgoulis[a], Styliani Fotiadou[a,b], Vassilis Kalivas[a], Georgios Mavrommatis[c]

[a]Department of Physical Education and Sport Science, Democritus University of Thrace, Komotini, Greece
[b]University General Hospital of Alexandroupolis, Democritus University of Thrace, Alexandroupolis, Greece
[c]Department of Physical Education and Sport Science, Aristotle University of Thessaloniki, Thessaloniki, Greece

egiannak@phyed.duth.gr

Abstract

Aim of this work was to study the repeatability of kinematic and kinetic parameters of gait in Parkinson's disease patients. Twelve patients with Parkinson's disease performed 10 repeated gait trials at their natural speed on two different days. Lower limb kinematics were recorded by a Vicon optoelectronic system, with 6 cameras at a sampling frequency of 100Hz. Two Kistler force plates were placed in the middle of the walkway, to record the ground reaction forces with a sampling frequency of 1000Hz. The repeatability of the mechanical characteristics was estimated by the Coefficient of Multiple Correlation (CMC) for within-day and between-day measurements. The results showed high repeatability (CMC>.95) of the joint angle waveforms in all lower limb joints except pelvis (CMC>.77). The repeatability of joint moments was greater at the ankle joint (CMC>.98) and smaller at the hip joint (CMC >.90). In conclusion, most mechanical parameters of gait in patients with Parkinson's disease show significant repeatability. However, during gait analysis of Parkinson's disease patients, the minimum number of trials, which ensure very good reliability, should be performed, to avoid patients' fatigue.

Key-words: reliability, gait, kinematics, kinetics

Introduction

Gait disorders are among the most important motor problems for patients with Parkinson's disease (Giladi & Balash, 2006; Canning, Ada, Johnson, & McWhirter, 2006).Walking problems are often reported from the early stages of the disease and affect all patients as the disease progress. That's why it is assumed as one of the sensitive indicators for the disease progression (Giladi & Balash, 2006). Therefore, careful early observation of gait is clinically desirable in this population.

It is widely accepted that three-dimensional (3D) gait analysis is the most valuable tool for gait problems diagnosis and evaluation (Ferber, McClay Davis, Williams III, & Laughton, 2002; Peppe, Chiavalon, Pasqualetti, Crovato, & Caltagirone, 2007). Gait analysis is mainly used by the researchers for the estimation of therapeutic and operative interventions in patients with Parkinson's disease (Fisher, et al., 2008; Hackney & Earhart, 2008; Krystkowiak, et al., 2001; Pohl, Rockstroh, Ruckriem, Mrass, & Mehrholz, 2003; Xie, Krack, Benabid, & Pollak, 2001). It is therefore important to know when the variation between measurements performed before and after interventions is a result of intervention-triggered gait modifications, inherent biological variability or due to measurement errors.

During last two decades, Parkinson's disease researchers perceived that gait instability and rhythmicity of patients is perhaps influenced by the basal ganglia damage and focused their research in this field. However, the majority of studies regarding the affected gait instability were restricted to stride-to-stride variability and spatio-temporal gait parameters. According to our knowledge, this is the first study that investigates the repeatability of kinematic and kinetic gait parameters.

The purpose of this study was to examine the repeatability of major mechanical gait parameters in patients with Parkinson's disease and to estimate the least number of trials required to obtain reliable measurement data.

Method

Participants

Twelve patients (5 women, 7 men) diagnosed with idiopathic PD participated in the study. They had a mean age of 66,25 ± 7,9years, height 165,2 ± 13,4 cm, and a mean disease duration of 2,97 ± 3,19 years. Disease severity was characterized using the Unified Parkinson's Disease Rating Scale (UPDRS) (motor examination). The diagnosis of idiopathic PD was confirmed by a neurologist and the neurological examination performed by a movement disorders specialist. Subjects with a history of stroke, head trauma or neuromusculoskeletal injuries and abnormalities that could affect their gait patterns were excluded from the study. All subjects signed an informed consent form prior to entering the study.

The subject characteristics are presented in Table 1.

Table 1. Demographic and clinical characteristics of patients

Patient	Sex	Age (years)	Height (m)	Weight (Kg)	Disease Duration (years)	UPDRS	UPDRS-III
1	Female	74	1,47	68	1	10	6
2	Male	61	1,63	72	1	30	13
3	Male	70	1,82	96	0,25 (3 months)	16	14
4	Male	64	1,78	105	0,17 (2 months)	17	10
5	Female	70	1,48	87	0,17 (2 months)	9	5
6	Female	72	1,60	62	8	59	38
7	Male	70	1,56	86	6	14	9
8	Female	45	1,68	64	9	24	18
9	Male	67	1,70	80	1	3	2
10	Male	65	1,85	104	2	19	10
11	Male	63	1,77	85	2	20	3
12	Female	74	1,50	70	5	14	12
Mean		**66,25**	**1,65**	**81,58**	**2,97**	**19,58**	**11,67**
SD		**7,93**	**0,13**	**14,85**	**3,19**	**14,28**	**9,53**

Most of the participants were in the early stage of the disease and all but one participant were on levodopa medication. All participants that follow medication were tested in the "on" state approximately 1-1.5 hours following their last antiparkinsonian medication.

Procedure

Parkinson's patients were tested on two occasions with at least 2 days apart. There was no intervention between the sessions that could alter their gait characteristics. Except the familiarization period, the procedure for each data collection was identical.

Subjects walked on a 10m walkway at a constant speed that was different for every patient as it was computed from their mean natural walking speed. Mean walking speed was determined for each participant on the basis of 10 walking trials performed as a familiarization period before the main experiment. The target velocity was predefined by a stick, which moved in the required speed in front of the subjects along the walkway. In each day 10 valid gait trials were recorded, five from which were randomly selected for data analysis.

Gait analysis

Kinematic data were recorded using Vicon MX3 system with six cameras operating at 100 Hz that were cyclically located over the walkway. Sixteen reflecting markers were placed in anatomical landmarks of each patient's lower limbs according to the Plug-In Gait protocol (2nd metatarsal head, heel, lateral malleolus, tibia, lateral femoral condyle, thigh, anterior superior iliac spine, posterior superior iliac spine on the right and left side of the body). The markers were applied by the same experimenter in all patients.

Two force platforms placed in the middle of the walkway were used for kinetic data acquisition at a sampling frequency of 1000Hz.

Statistical analysis

The repeatability of the mechanical characteristics (kinematic and kinetic parameters) was assessed by the coefficient of multiple correlation (CMC), which is consider to be the most appropriate method available to express reproducibility of waveforms (Duhamel, et al., 2004; Growney, Meglan, Johnson, Cahalan, & An, 1997; Kadaba, Ramakrishnan, Wootten, Gainey, Gorton, & Cochran, 1989). The CMCs were calculated to check for within-day (wCMC), between-day (bCMC) and overall (oCMC) repeatability.

Root mean square (RMS) differences among trials T1-T5, T6-T10 and T1-T10, were also calculated, in each 10% interval of the gait cycle, to quantify the variability of these trials. The non-parametric one-sample Kolmogorov-Smirnov test showed that the distribution of all the RMS differences was normal. So, the analysis of variance for the repeated measures was employed to test for possible differences in the RMS differences between trials T1-T10, among the 10 time intervals. Post hoc comparisons were made with the Sidak test to determine the pairs of time intervals where those differences were statistically significant.

In addition, intraclass correlation coefficients (ICCs), for the trials of the first day (T1-T5), the trials of the second day (T6-T10) and the total number of the trials (T1-T10), were calculated to serve as an input for the Spearman-Brown prophecy formula.

Finally, the Spearman-Brown prophecy formula was used to estimate the least number (K) of trials that could provide ICC values (r_{ICC}) greater than or equal to 0.95 (Baumgartner, 1989):

$$r_{ICC} = \frac{K \cdot (ICC_1)}{1 + [(K-1) \cdot (ICC_1)]} \Rightarrow K = \frac{r_{ICC} \cdot (1 - ICC_1)}{ICC_1 \cdot (1 - r_{ICC})}$$

where, ICC_1 is the calculated intra-class correlation coefficient (ICC) for each test measurement, K is the number of trials required and, r_{ICC} the estimated ICC for K number of trials. The level of significance was set for p-values less than .05.

Results

Example data sets of all calculated parameters from a patient, during the 10 gait trials are presented in the lower down figures. Figure 1 shows the typical values of ankle, knee, hip and pelvis angles, Figure 2 provides all the calculated moments' parameters waveforms.

Figure 1. Typical values of ankle, knee, hip and pelvic angles during the 10 gait cycles for the first day (T1-T5) and for the second day (T6-T10).

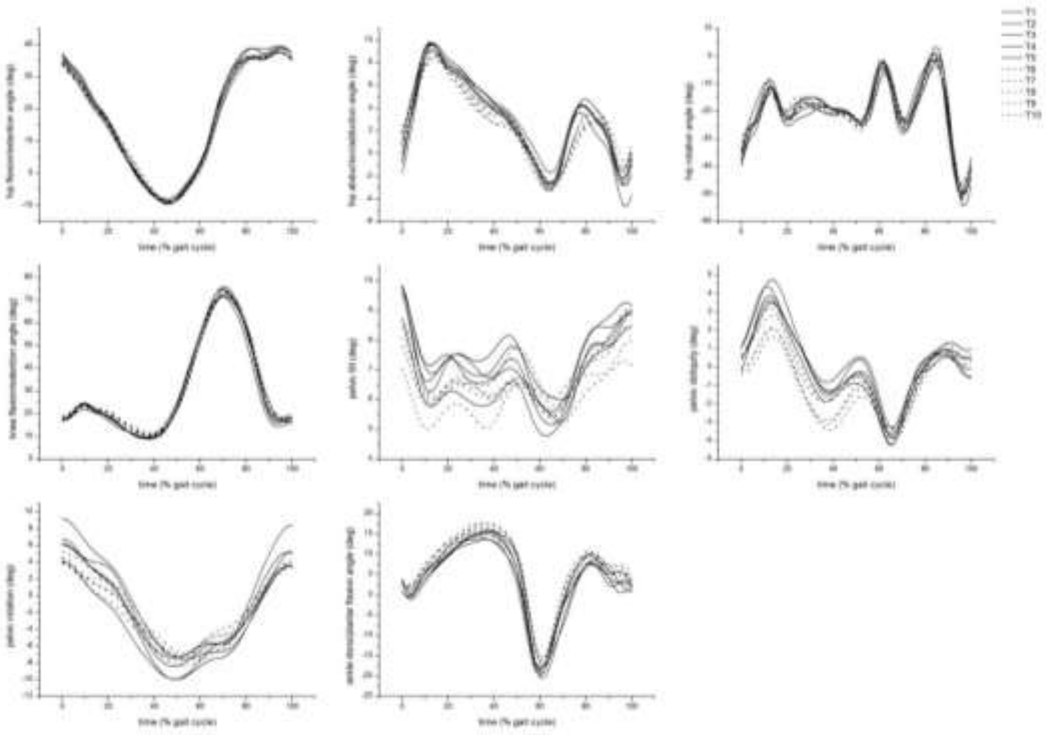
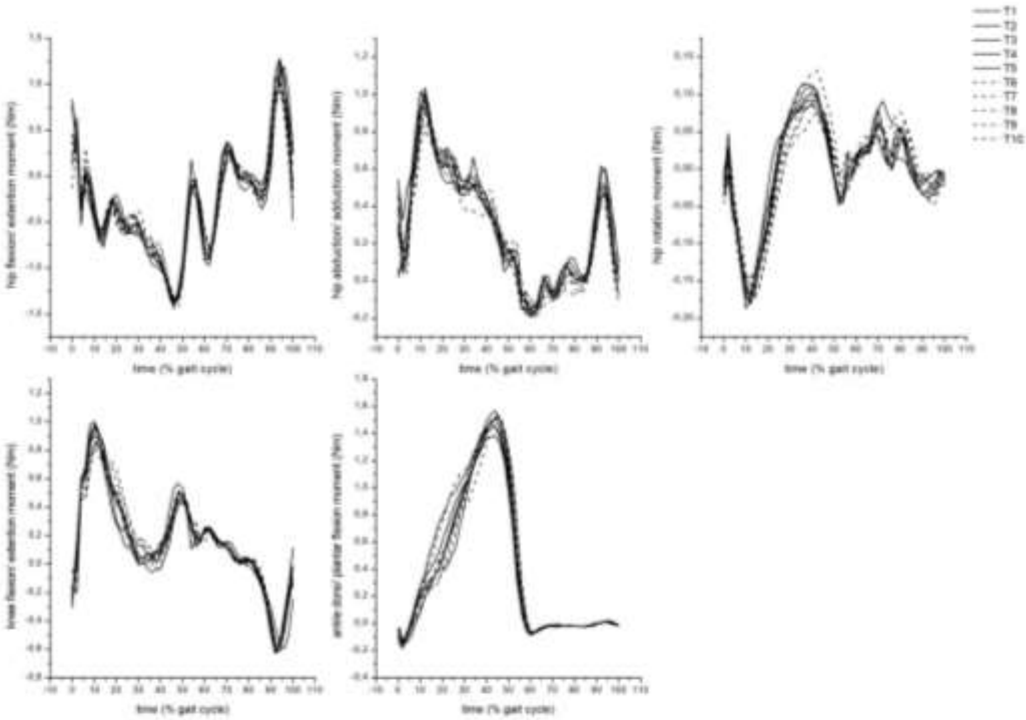


Figure 2. Typical values of the kinetic parameters waveforms during the 10 gait cycles, for the trials of the first day (T1-T5) and the trials of the second day (T6-T10).



Moreover, Table 2 shows the mean ± SD of the within-day CMC (wCMC), between-day CMC (bCMC) and the overall CMC (oCMC) for the joint angles.

Table 2. Mean and standard deviation for within-day CMC (wCMC), between-day CMC (bCMC) and overall CMC (oCMC) of joint angles.

Angle	Axis	CMC					
		wCMC		bCMC		oCMC	
		L	R	L	R	L	R
Pelvis	Tilt	.809 ± .094	.809 ± .089	.841 ± .157	.856 ± .155	.776 ± .112	.781 ± .098
	obliquity	.950 ± .025	.935 ± .036	.934 ± .063	.906 ± .093	.922 ± .040	.895 ± .059
	Rotation	.920 ± .049	.900 ± .065	.948 ± .030	.934 ± .042	.903 ± .044	.884 ± .066
Hip	X	.996 ± .003	.996 ± .003	.995 ± .004	.993 ± .006	.994 ± .005	.991 ± .009
	Y	.978 ± .017	.976 ± .022	.908 ± .175	.927 ± .172	.939 ± .082	.948 ± .081
Knee	X	.995 ± .002	.993 ± .005	.992 ± .008	.987 ± .012	.991 ± .006	.985 ± .014
Ankle	X	.983 ± .008	.984 ± .006	.980 ± .021	.978 ± .021	.975 ± .015	.975 ± .012

The results showed that all joint angle waveforms showed CMC values greater than .90, except the pelvis kinematic parameters that had CMC values greater than .77. Among all the assessed kinematic parameters hip flexion/extension showed the highest repeatability, with CMC values greater than .99, and pelvic tilt was the least reliable parameter, with mean CMC values between .77 and .85, for within-day, between-day and overall CMC.

Mean and standard deviation of the within-day CMC, between-day CMC and the overall CMC for the joint moments are provided in Table 3.

Table 3. Mean and standard deviation for within-day CMC (wCMC), between-day CMC (bCMC) and overall CMC (oCMC) of joint moments.

Moment	Axis	CMC					
		wCMC		bCMC		oCMC	
		L	R	L	R	L	R
Hip	X	.970 ± .017	.961 ± .015	.967 ± .042	.925 ± .081	.956 ± .036	.925 ± .048
	Y	.988 ± .005	.987 ± .006	.980 ± .026	.981 ± .011	.978 ± .017	.978 ± .010
Knee	X	.984 ± .008	.978 ± .006	.988 ± .010	.952 ± .059	.980 ± .012	.955 ± .031
Ankle	X	.989 ± .009	.989 ± .006	.994 ± .006	.993 ± .007	.987 ± .011	.986 ± .009

In addition, all joint moments showed high reproducibility with CMC values greater than .90. The most reliable kinetic parameter was ankle dorsi/plantar flexion moment (CMC>.98) while the lowest repeatability was found for hip flexion/extension moment (CMC>.92).

Table 4, shows the mean of the trials number (K) needed to provide reliable parameters values for all kinematic and kinetic variables measured, for the right and left lower limb.

Table 4. Mean of the trials number (K) needed to provide reliable parameters values for all kinematic and kinetic variables measured, for the right and left lower limb.

	Variable	Axis	Left leg	Right leg
Angle	**Pelvis**	tilt	13	12
		obliquity	4	4
		rotation	5	6
	Hip	X	1	1
		Y	3	3
	Knee	X	1	1
	Ankle	X	1	1
Moment	**Hip**	X	2	3
		Y	1	1
	Knee	X	1	2
	Ankle	X	1	1

Finally, Spearman Brown prophecy formula revealed that reliable parameters values required the recording of 1-3 trials for joint angles, 4-13 trials for pelvic kinematic parameters and 1-3 trials for joint moments.

The RMS differences of all measured parameters, calculated in each 10% interval of the gait trial, between all trials for each leg, are provided in Figure 3 and Figure 4.

Figure 3. RMS differences of joint angles measured for the total number of trials, calculated in each 10% interval of the gait cycle. Statistical significant differences ($p<.05$) to the other intervals are marked with (*) for the left leg and (+) for the right leg.

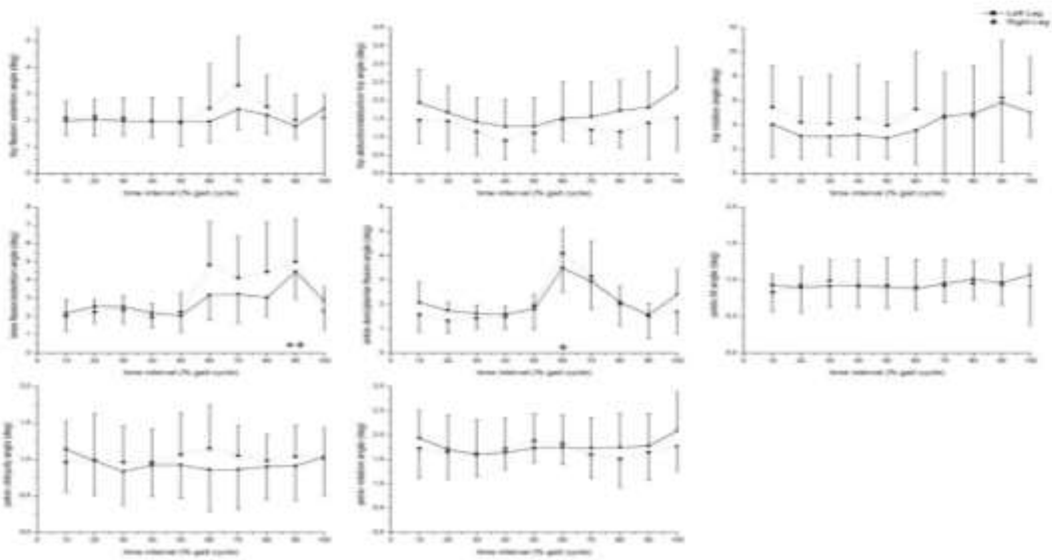
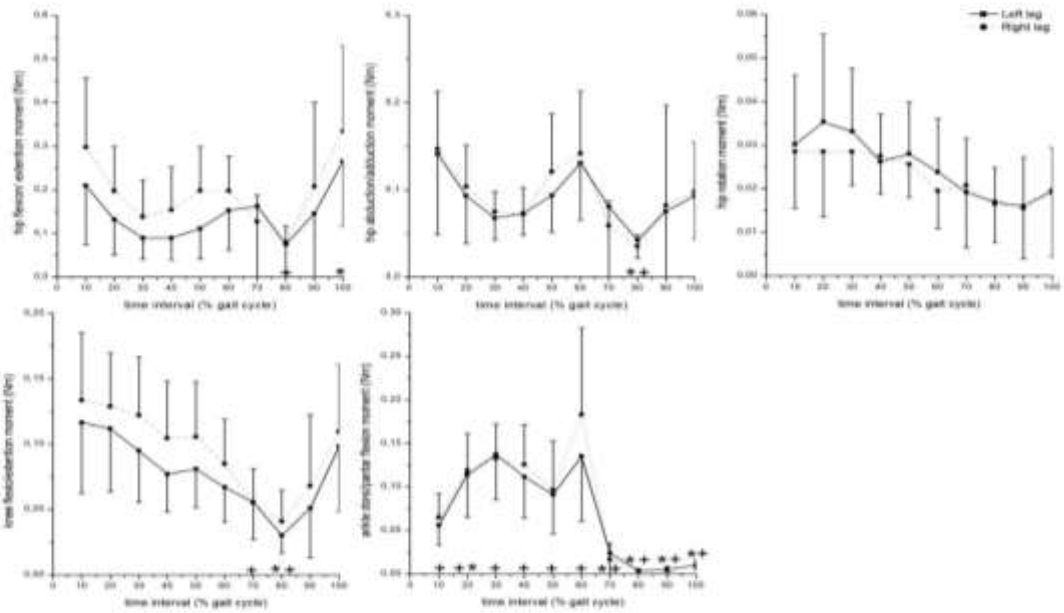


Figure 4. RMS differences of joint moments measured for the total number of trials, calculated in each 10% interval of the gait cycle. Statistical significant differences ($p<.05$) to the other intervals are marked with (*) for the left leg and (+) for the right leg.



The results showed significant differences in RMS differences between the 10 time intervals for all kinetic parameters and for hip abduction/ adduction angle in left leg, for knee and ankle angle in both legs concerning angle parameters.

Discussion

The purpose of the present study was to examine the repeatability of mechanical gait parameters in patients with Parkinson's disease. To our knowledge, this is the first study that examines the repeatability of lower limb joint moments and pelvic angles waveforms in Parkinson's disease patients.

Concerning gait kinematic characteristics, the results of the current research showed excellent repeatability for hip, knee, and ankle joint angles in the sagittal plane of movement. Pelvic obliquity, pelvic rotation, and hip abduction/adduction angle showed moderate repeatability, while pelvic tilt had a low reproducibility. Delval et al. (2008) also reported very high reproducibility for hip and knee angles but low reproducibility for ankle angle in Parkinson's disease patients. High ankle angle variability may be attributed to the disease severity (mean UPDRS-III > 45) of the patients examined by Delval et al. or due to the fact that they all were in the "off – phase" of medication during the testing procedure.

Kinetic characteristics also revealed great repeatability for all parameters measured except hip flexion/extension moment (moderate reproducibility) even though CMC values were in general lower comparing to the joint kinematic parameters. Parkinson's disease patients produce significantly lower maximum hip flexion moment in the stance phase due to the decreased maximum hip extension, comparing to healthy controls of the same age (Sofuwa et al., 2005). According to Winter (1984), hip moment signifies the role of hip extensors during loading response phase and especially after heel contact. Consequently, small heel contact alterations may have caused the variation in the hip flexion/extension moment that was observed in this study.

All the above CMC values are in close agreement with the respective values reported by previous studies (Kadaba et al.,1989; Growney et al., 1997), for healthy adults. A likely explanation for this fact is that Parkinson's disease is a slow progressive neurodegeneration disease and our patients had short disease duration and low disease severity. Perhaps, however, Parkinson's disease patients have lost their optimal gait variability, related to health, and have been come more rigid and periodic in their movements (like a robot) (Stergiou, Harbourne, & Cavanaugh, 2006).

Conclusion

In summary, all kinematic and kinetic variables, except of pelvic kinematic variables, showed moderate to high reproducibility during gait in patients with Parkinson's disease. At least 3 trials should be performed and calculated in every gait analysis of Parkinson's disease patients in order to have reliable results, for angle and moment waveforms. However, this number has to be increased to 13 repeated trials if pelvic kinematic waveforms are required.

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