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Does gait analysis quantify motor rehabilitation efficacy in Parkinson's disease patients?☆

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Abstract

Subjects: Sixteen rigid-akinetic idiopathic Parkinson's disease patients (PD) and 13 healthy control subjects (controls) were included in this study.
Methods: Gait analysis was performed using an optoelectronic system. The experimental design involved double evaluation of PD patients (before and after motor rehabilitation program) and a single evaluation of controls. ANOVA was performed in both groups for each gait variable (kinetic and kinematic) and for clinical conditions.
Results: Analysis of kinetic data highlighted a statistically significant difference for all gait variables studied between controls and PD patients either before, or in the same PD patients before and after the motor rehabilitation program. After the rehabilitation program, natural walking speed increased ($p < .000$). The stance percentage was significantly decreased in the single support ($p < .000$). After the rehabilitation program, the double support limb phase did not show a reduction in statistical significance. Kinematic data showed statistical differences between controls and PD patients in hip, knee and ankle joint angles, both before and after the motor rehabilitation program.
Conclusion: Our results confirm that gait analysis is a valid tool for evaluating changes in PD patients' ability to walk and for quantifying the improvements gained through a motor rehabilitation program.

Keywords: Gait analysis; Physical therapy; Parkinson's disease

1. Introduction

Gait disturbance is one of the major problems in Parkinson's disease. Several studies have highlighted the typical walking pattern: reduced velocity, increased stance phase and shorter stride length, with decreased amplitude of the lower limb segment [1,2]. A few studies have analysed kinematic alterations such as forward inclination of the trunk with knee flexion in the upright position, reduced range of hip extension in mid-stance, knee flexion in swing and plantar-flexion at toe push-off [3–5]. Gait analysis has also been used to study the effects on locomotion produced by functional neurosurgery [6–8] and/or L-dopa medication [9] with and without attentional strategies [10,11].

Despite medication or surgical intervention, people with Parkinson's disease usually show deterioration in mobility. Since disease progression and a decrease in the efficacy of Levodopa therapy severely limit patients' quality of life, rehabilitation is highly recommended.

Meta-analyses of existing studies have shown the difficulty of evaluating trials based on the effectiveness of non-pharmacological rehabilitation therapies. The major problem is the wide variety of physiotherapy techniques

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Table 1
Clinical characteristics of patients and controls

Mean ± S.D.	PD (16 subjects)														Control (13 subjects)			
											UPDRS (part III)		Hoehn and Yahr					
	Age (66.5 ± 9.8)	Weight (65.4 ± 10.2)	Height (1.62 ± .09)	Sex (10F/6M)	PD duration (6.7 ± 4.2)	LD duration (5.1 ± 3.5)	R/L (7R/9L)	BRA (16/16)	RIG (16/16)	TRE (12/16)	Pre (31.3 ± 10)	Post (15.4 ± 5.3)	Pre (2.3 ± .5)	Post (1.9 ± .4)	Age (63.2 ± 11.2)	Weight (66.6 ± 8)	Height (168.3 ± 5.4)	Sex (4F/9M)
1	60	70	1.72	M	3	3	L	Y	Y	N	29	15	2.5	2	60	76	175	M
2	64	75	1.76	M	3	2	R	Y	Y	N	26	10	2	2	61	68	172	M
3	66	70	1.64	M	7	6	L	Y	Y	N	14	10	1.5	1	62	76	168	M
4	67	74	1.60	M	8	6	L	Y	Y	Y	29	13	2.5	2	63	70	169	M
5	69	70	1.77	M	12	12	R	Y	Y	N	24	13	2	1.5	64	74	173	M
6	74	62	1.61	M	6	4	L	Y	Y	N	36	20	2	2	66	68	170	M
7	43	67	1.60	F	6	6	L	Y	Y	N	34	23	2	1.5	70	71	169	M
8	49	80	1.51	F	8	7	L	Y	Y	N	62	28	3	2.5	82	58	166	M
9	61	46	1.50	F	14	8	L	Y	Y	N	39	16	3	2.5	84	75	175	M
10	66	55	1.64	F	2	0	R	Y	Y	N	31	10	3	2	46	55	164	F
11	66	63	1.70	F	13	11	R	Y	Y	N	24	12	2	2	48	56	159	F
12	74	62	1.55	F	1	1	L	Y	Y	N	28	15	2	2	52	58	158	F
13	74	45	1.60	F	12	7	R	Y	Y	N	33	15	3	2.5	63	61	170	F
14	75	78	1.70	F	4	3	R	Y	Y	Y	28	18	2	2				
15	77	60	1.51	F	6	5	L	Y	Y	Y	34	20	2	1.5				
16	79	69	1.50	F	2	0	R	Y	Y	Y	29	9	2.5	1.5				

YY: years, R: right onset, L: left onset, BRA: Bradykinesia, RIG: rigidity, TRE: tremor. PD duration: years of Parkinson's disease duration. LD duration: years of levodopa treatment duration.

employed. These techniques vary in duration and quality and include potential methodological flaws, which can introduce bias [12].

The lack of convincing evidence about the effectiveness of rehabilitation in Parkinson's disease has been noted [13]. Cochrane reviewers who assess discipline-based findings from randomised controlled trials have also noted methodological weaknesses [1,14–17].

In progressive neurological diseases, such as Parkinson's disease, it is difficult to verify the efficacy of motor rehabilitation trials. This may be because they are not based on objective measurement tools; their effect may also be underestimated due to the lack of responsive outcome measures and to the natural progression of the disease.

Indeed, in most studies subjective clinical scales (UPDRS, Webster) or questionnaires (PDQ-39) were adopted. However, in other studies objective tools were used, i.e., the timed up and go (TUG) test and a stopwatch were used to measure gait speed and pathway. Gait patterns have also been studied using footprint analysis, i.e., by applying paint or ink to the sole of a shoe or to a person's foot and analysing their footprints [18].

Other studies have attempted to quantify temporal/spatial gait parameters [2,19–20] and intermittent light photography on a walkway [21].

A few studies have also been conducted on kinematic data such as limb joint angles, trunk movement and pelvic orientation. These studies suggest that PD patients had increased joint range during ON clinical status [3,7,22].

In our study, we also considered joint ''amplitude'' related to different stride phases as an objective tool. Joint amplitude was defined as the range between minimum and maximum joint flexion in each lower limb during stride and its percentage duration in the stance phase. Possible changes in these parameters rehabilitation would suggest gait alterations in PD patients.Our aim in this study was to use objective evidence based measures to study gait alterations, quantify asymmetry and monitor the effects of a motor rehabilitation program. This consisted of exercises to improve mobility and posture, stimulate the balance response and increase motor skills.

2. Subjects and methods

2.1. Subjects

Sixteen hospitalised rigid-akinetic idiopathic PD patients (10 women, 6 men) and 13 age-matched control subjects with no neurological or orthopaedic conditions that would affect gait (4 women, 9 men) were included in this non-randomised prospective study. An expert neurologist made the diagnosis of PD based on the presence of at least two of the four cardinal Parkinsonian symptoms and on good long-term L-dopa response.

Exclusion criteria were the following: (i) presence of systemic and metabolic diseases; (ii) uncertain and unclear history of chronic L-dopa treatment responsiveness; (iii) cognitive impairment; (iv) presence of brain lesions and/or marked cortical and subcortical atrophy on computed tomography (CT) and MR scans; (v) presence

Table 2
Time line of study design

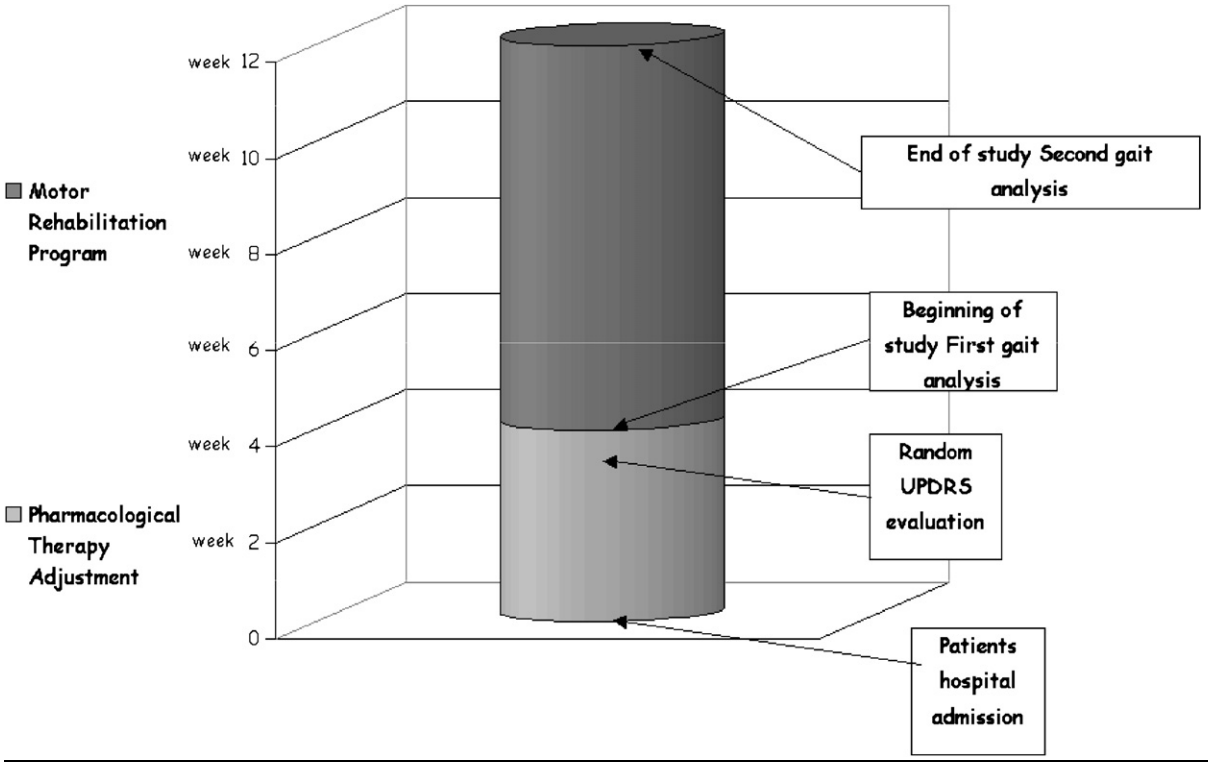

Table 3
Description of anthropometric parameters and how we measured them

Measure	Description
Body mass (1)	Subject's mass was measured with all clothes removed except underwear
ASIS breadth (1)	With a beam calliper, horizontal distance between anterior superior iliac spines was measured
Thigh length (2)	With a beam calliper, the vertical distance between the superior point of the greater trochanter of the femur and the superior margin of the lateral tibia was measured
Mid thigh circumference (2)	With a tape perpendicular to the long axis of the leg and at a level midway between the trochanteric and tibial landmarks, circumference of the thigh was measured
Calf length (2)	With a sliding calliper, the vertical distance between the superior margin of the lateral tibia and the lateral malleolus was measured
Calf circumference (2)	With a tape perpendicular to the long axis of the lower leg, the maximum circumference of the calf was measured
Knee diameter (2)	With a spreading calliper, the maximum breadth of the knee across the femoral epicondyles was measured
Foot length (2)	With a beam calliper, the distance from the posterior margin of the heel to the tip of the longest toe was measured
Malleolus height (2)	With the subject standing, use a sliding caliper the vertical distance from the standing surface to the lateral malleolus was measured
Malleolus width (2)	With a sliding calliper, the maximum distance between the medial and lateral malleoli was measured
Foot breadth (2)	With a beam calliper, the breadth across the distal ends of metatarsals I and V was measured

1: single measure, 2: double measure for right and left body side.

of dementia on the basis of clinical examination or a Mini Mental State Examination score of 24 [24].

Table 1 presents patients' clinical characteristics at the time of the study as well as their scores on the Unified Parkinson's Disease Rating Scale (UPDRS part III) [25] and Hoehn and Yahr rating [26].

Five PD patients were being treated with L-dopa alone (mean daily dosage: 400 mg + peripheral inhibitor; range 200–600mg/die), four patients with dopaminergic agonist monotherapy (Pergolide 3 mg/die, Pramipexolo 2.1 mg/die), and seven patients were being treated with L-dopa plus dopaminergic agonists.

All PD patients were stable responders to antiparkinsonian therapy. Their medication dose was constant for at least 30 days before the study and for the entire period between initial and final trials. All patients completed the motor rehabilitation program; none showed other clinical problems during this period.

2.2. Study design

Clinical data, including UPDRS part III [25] and Hoehn and Yahr's [26] scale, were collected from patients twice. i.e., at the beginning and the end of the motor rehabilitation study. The patients enrolled in this clinical protocol were hospitalised for the entire duration of the study (12 weeks). The best chronic anti Parkinsonian therapy was obtained during the 4 weeks before the study. When the UPDRS part III score had been constant for at least a week, the Gait Analysis was recorded and the motor rehabilitation study started. The second clinical assessment was made after eight consecutive weeks of the rehabilitation program (Table 2).

Patients were blinded as to when gait analysis recording would take place. The mean results of the clinical evaluation are presented in Table 1.

All testing was carried out 2 h after the first morning drug administration [in ON clinical status].

Controls subjects ranged in age from 46 to 84 years (mean 63.2 ± 11.2 years), had an average height and weight of 168.3 ± 5.4 cm and 66.6 ± 8 kg respectively, had performed only a Gait Analysis recording as out-patient clinic subjects. All subjects gave their informed consent to participate in the study, which was approved by the Local Ethics Committee.

2.3. Methods

2.3.1. Protocol and anthropometric measures

Gait analysis was performed using the equipment and procedures developed at the motion laboratory of I.R.C.C.S. Fondazione Santa Lucia in Rome. The instruments included an optoelectronic system (SMART system, BTS Padova, Italy) to measure the three coordinates of retroreflective markers. Six video cameras (Teli 8320BC), placed along an 8 m walkway with a sampling rate of 50 Hz, a 640 pixel × 286 pixel of resolution and a 6 mm lens, were used for the study. The working volume (2 m × 3 m × 6 m) was calibrated by sweeping it with the three markers wand provided, i.e., by moving the wand up and down several times parallel to each axis. After three-dimensional (3D) calibration, the spatial accuracy of the system was less than .5 mm.

For correct positioning of markers, the Davis protocol was used [23]. This required obtaining the subjects' anthropometric measures (see Table 3) and placing 15 retroreflective markers on pelvis and lower body segments (see Table 4).

Fifteen spherical markers (10 mm in diameter) were attached to the subject's body (except for the calves and thighs) with double-sided tape, according to the marker configuration of the "Davis"

Table 4
Marker positioning based on "Davis" model

Position	Description
Sacrum	At level of vertebra S1
ASIS (L/R)	Points where anterior superior iliac spine distance was taken
Femoral wand (L/R)	At level where circumference of thigh was measured
Femoral epicondyle (L/R)	External femoral condyle
Tibial wand (L/R)	At level where maximum circumference of calf was measured
Heel (L/R)	At back of heel bone
Lateral Malleolus (L/R)	On lateral malleolus protuberance
Metatarsal head II (L/R)	On the head of second metatarsal bone

Markers were aligned on sagittal plane (among femoral wand, femoral epicondyle, tibial wand and lateral mallelolus) and frontal plane (between left and right equivalent markers).

model [23] (Table 3); thigh markers were attached approximately 7–10 cm away from the skin on iron sticks. This system provided more accurate orientation of the segment in three-dimensional space.

2.3.2. Motor rehabilitation program

Experienced therapists treated the patients individually. All patients received exactly the same treatment program. For a period of eight consecutive weeks, 45-min treatment sessions were held in the morning five times a week and 45-min group therapy sessions in the afternoon six times a week. In this study, each PD patient performed 66 h of physical therapy.

The exercises were aimed at limb co-ordination and muscle stretching, including active or assisted limb mobilisation, exercises to stimulate postural control, exercises for articulation and pendular movement in various positions and deambulation exercises. The main items of the rehabilitation program are listed in Table 5.

The therapists who undertook the gait assessment were different from those who administered the rehabilitation treatment.

2.3.3. Gait analysis recordings

Spatio-temporal gait measurements were taken as patients walked on a walkway. This consisted of a long, soft blue carpet (length 8 m, width 2 m) rolled out on a well lit laboratory floor. Before the walking trials began, the patients' upright posture was recorded. They performed six consecutive gait trials, each of which included two/four strides. The instructions were the following: ''Walk at your normal speed to the end of the walkway''. No additional instructions were given during the recording and no necessary physical support was needed.

Each trial was recorded and the average analysed.

Working volume was calibrated prior to each acquisition session by performing an axis and a wand capture. These acquisitions were stored in a dedicated data block and automatically embedded in every gait acquisition. The whole gait acquisition process involved three steps: (1) subject gait capture with video cameras; (2) transformation, using tracker software, of 2D acquired data into a 3D model by applying the ''Davis'' model; (3) stride analysis using the ''Davis'' protocol [23]. The application software used for analysis was ''SMART'' (BTS Padova, Italy) Version 1.10.221.0.

2.4. Variables

2.4.1. Kinetic variables

The following kinetic variables were studied: gait velocity; stride length and width; step length; step frequency—cadence; stance, swing and double stance percentage with respect to stride phase.

2.4.2. Kinematic variables

The range of amplitude for each lower limb joint (hip, knee, ankle), calculated as the difference between the minimum and maximum flexion angles in the whole stride and in the stance and swing phase, was taken into account separately.

Table 5
Main items of the rehabilitation program

Individual training	
Exercises to promote relaxation and awareness of using the diaphragm in respiration	Hands placed on abdomen. Slow breathing through the nose, feeling expansion of diaphragm during inhalation. Then slow exhalation through the mouth
Exercises to promote neck flexibility	Patients were requested to turn head slowly from side to side, look over each shoulder, feel a gentle stretch in neck muscles. They were also requested to look straight ahead and move head sideways bringing ear toward shoulder and feel a gentle stretch in neck muscles
Segmental exercises of active or assisted mobilization (flexo-extension, pronosupination) to increase strength, motility, and coordination of four limbs	With open eyes, patients were requested to actively and attentively control movements
Exercises to improve equilibrium (in quadrupedic position)	Patients were requested to extend one upper limb together with the contralateral lower limb (alternating the side) while supporting themselves on the other two limbs
Exercise to improve control of posture in different positions	Patients were requested to maintain balance during unexpected pushes on a basculating plane, with advanced knowledge of perturbation direction
Training exercises for walking on level ground or between parallel bars	Patients were requested to walk keeping space between feet to promote better balance support, taking a longer stride, allowing heel to strike floor first with each step, allowing arms to swing freely at sides, avoiding putting hands in pockets or behind the back, turning corners in a wide arc, avoiding crossing one foot over the other when turning and trying to make the first step a long one. If short, shuffling steps occurred, they were to stop and start over, making first step long enough to strike heel down first
Group training	
Exercises to promote pectoral and hip girdle releasing	Patients sitting in circle were requested to pass a different size and weight ball sideways to a person with increasing velocity. The same exercise was performed with a cane, emphasizing trunk rotation
Exercises to promote control of strength and movement velocity	Patients sitting in circle were requested to throw a different size and weight ball to any person, increasing velocity. This exercise was also performed by rolling the ball on the floor

Moreover, the range of duration, considered as the minimum and maximum flexion angle related to percentage of stride cycle, was taken into account separately in both stance and swing phases. The experimental design involved a double evaluation of PD group (before and after motor rehabilitation program) and a single evaluation of controls.

2.4.3. Statistical data analysis

For the statistical analysis, we averaged data collected in all six trials. The spatial-temporal data regarding stride kinetic and kinematic variables were analysed.

The cross-sectional comparison between PD and controls was performed by one-way analysis of variance (ANOVA) using 'group' as *between subjects* factor. A two-way ANOVA with repeated measures was used for each gait variable and for each PD group condition (before, after) to analyse the main effects of group and time, the interaction between group and time, to verify any similar results between controls and PD group after the motor rehabilitation program and, finally, to quantify the effects of therapy.

An ANOVA for repeated measures was also used to compare PD patients' kinematic data before and after the motor rehabilitation program with that of controls.

To test the hypothesis of significant side differences related to body side more affected, a two-way ANOVA with 'side' as *within subjects* factor was used for both kinetic and kinematic data.

All analyses were performed with the significance level set at .05; all results were expressed as estimated mean values (M) and standard deviations (S.D.).

The statistical analysis was performed with SPSS for Windows (SPSS Inc., Chicago, IL).

3. Results

The clinical characteristics of all patients who participated in the study are reported in Table 1. All patients showed a statistically significant reduction of extrapyramidal symptoms. The statistical data pertaining to clinical characteristics (UPDRS III and H&Y scale) showed significant differences between pre- and post-rehabilitation program (Student's t-test: $p < .0001$).

The differences in gait variables between PD patients before the motor rehabilitation program and controls and the same PD patients after the motor rehabilitation program are reported in Table 6.

Kinematic data concerning stride range of amplitude and duration in stance phase are reported in Figs. 1 and 2.

3.1. Differences in kinetic gait variables in PD patients before and after the motor rehabilitation program and in controls

Before the motor rehabilitation program, self-selected walking speed was reduced in PD patients compared to controls ($p < .000$); this reduction was due to PD patients' shorter stride length ($p < .000$), slower cadence ($p < .002$) and longer stance duration and double limb support in the gait cycle compared to controls (stance = 68.1% (PD) versus 63.6% (C), $p < .000$, double limb support = 17.9% (PD) versus 14.1% (C), $p < .001$). The efficacy of motor rehabilitation was quantified by means of gait analysis performed after the physiotherapy cycle. All gait measures were improved and, for the most part, PD patients' results approached those of controls' although statistical significance difference was still present. Patients acquired greater confidence and ease of movement. Their own natural walking speed increased ($p < .000$); this resulted from concomitant, statistically significant improvements in both stride length and cadence ($p < .000$ and $p < .000$, respectively). Step width was not significantly modified in PD group at baseline and post motor rehabilitation program. Before the motor rehabilitation program, PD patients' stride data (length, time, stance, swing) were different for each foot, reflecting the characteristic asymmetry of the disorder; however, differences were not statistically significant. After the motor rehabilitation program, we found a reduction in asymmetry of parameters.

Data obtained from recordings made after the motor rehabilitation program show a stance percentage reduction (68.1% pre, 65.6% post) due to a significant decrease in single supports ($p < .000$). The Swing phase showed a significant increase (32% pre versus 34.4% post, $p < .000$), while the double support limb phase was reduced but did not reach statistical significance.

Table 6
Gait variables, PD group pre and post motor rehabilitation program and control group (ANOVA one-way; p)

Mean ± S.D.	Control (13 subjects)	PD pre MRP[a] (16 subjects)	PD post MRP[a] (16 subjects)	Pre vs. control (p)	Pre vs. post (p)	Post vs. control (p)
Velocity (m/s)	1.163 ± .12	.760 ± .23	.902 ± .23	<.000	<.000	<.000
Cadence	111.54 ± 7.59	105.13 ± 7.26	111.56 ± 8.32	<.002	<.000	NS
Stride width (mm)	165.82 ± 28.8	142.32 ± 30.7	145.31 ± 24.59	<.004	NS	<.005
Stride length (mm)	1274.88 ± 120.61	869.65 ± 244.6	979.68 ± 234.6	<.000	<.000	<.000
Anterior step length (mm)	556.38 ± 79.95	410.09 ± 118.16	448.83 ± 128.0	<.000	<.021	<.000
% stance	63.667 ± 1.15	68.118 ± 3.34	65.655 ± 2.72	<.000	<.000	<.001
% swing	36.015 ± 1.75	32.056 ± 3.36	34.466 ± 2.75	<.000	<.000	<.016
% double support limb	14.184 ± 1.87	17.992 ± 3.73	16.966 ± 8.27	<.000	NS	NS
Stride velocity (m/s)	1.179 ± .12	.760 ± .23	.902 ± .23	<.000	<.000	<.000
Swing velocity (m/s)	2.852 ± .26	2.078 ± .50	2.303 ± .50	<.000	<.000	<.000

[a] MPR: Motor Rehabilitation Program.

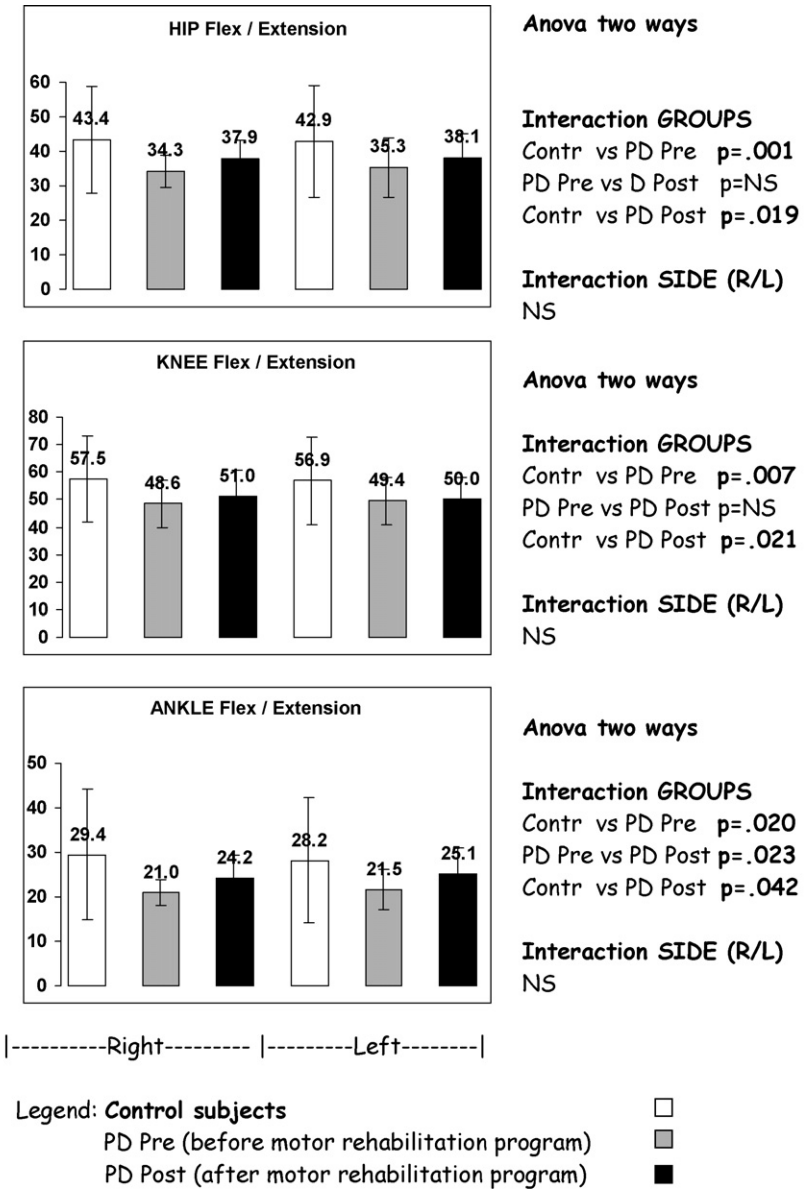

Fig. 1. Lower limb range of amplitude (stride) controls vs. PD pre and post motor rehabilitation program.

Moreover, no statistical differences were found in body side gait data or in extrapyramidal symptoms, respectively.

3.2. Differences in kinematic gait variables in PD patients before and after the motor rehabilitation program and in controls

Analyses of controls and PD patients before the motor rehabilitation program were statistically significant for range of amplitude and range of duration in stance phase. PD patients showed a reduced range in all joints studied (see Fig. 1). Differences between controls and PD patients for range of duration were obtained only in the stance phase (see Fig. 2).

After the motor rehabilitation program, except for the knee joint ($p = .001$) no statistical differences emerged between controls and PD patients for the swing phase. The motor rehabilitation program improved the amplitude range of all joints studied. However, statistical significance was reached only for the ankle joint ($p = .023$), (see Fig. 2). Moreover, motor rehabilitation did not modify the range of duration in any of the joints studied.

4. Discussion

To our knowledge, the objective method we adopted in this study to investigate the effects of a motor rehabilitation program on PD patients has not been previously used.

Gait characteristics in Parkinson's disease are well documented [2,21,27–31]. In particular, Knutsson [2] showed that all major characteristics of gait are affected

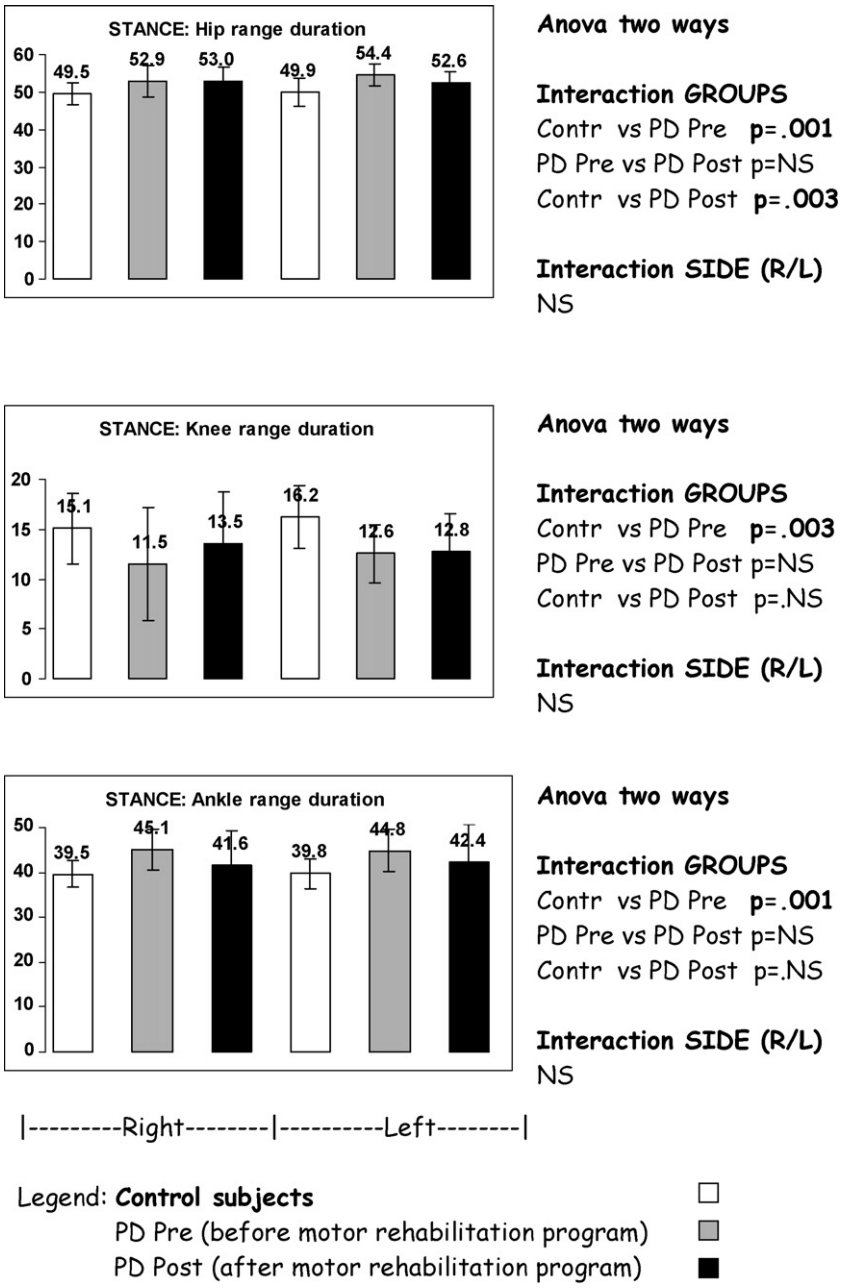

Fig. 2. Lower limb range duration (stance) controls vs. PD pre and post motor rehabilitation program.

during walking. PD patients show decreased foot clearance, demonstrated by reduced stride length and gait velocity. Affected parameters include the absence of arm swing, decreased rotation and increased forward inclination of the trunk, i.e., all expressions of bradykinesia and rigidity in PD.

The spatial-temporal parameters obtained in our study confirm findings reported in previous studies [20].

Analysis of two stride components confirmed that the stance phase was significantly longer in PD patients compared to controls. This was an expression of reduced speed as well as a symptom of bradykinesia.

We also considered the percentage of the double support time. This small component in controls (14.1%) significantly increased in PD patients (17.9%, $p > .001$). Indeed, this increase is known to be present in PD gait and may indicate postural instability. This may also be explained as an incomplete shift of the centre due to deficient strength, slower forward displacement of the centre mass and slower unloading of limb swing. Finally, the increase in double support could reflect the patients' inability to adequately transfer their weight in preparation for stepping [32].

The motor rehabilitation program significantly reduced spatial-temporal and kinetic variables and the stance phase and increased the swing phase. Analysing the stance data after the motor rehabilitation program, only the single support phase was decreased, while the double support phase

was not significantly changed. Our results indicate that the bradykinesia in PD patients' gait requires increased double support time.

Several studies indicate that external, as well as visual and auditory, cues may modify the gait parameters documented by gait analysis [9,33–34].

Concerning rehabilitation programs, recently Fernandes del Olmo and Cudeiro [35] used rhythmical auditory cues to study PD gait before and after a motor rehabilitation program. To our knowledge, there are no reports of other studies that compared gait analysis and a motor rehabilitation program in PD patients.

Our data indicate that motor rehabilitation activity helps PD patients to achieve a more confident and fluent gait.

Although our patients had a stable medical treatment dosage and showed therapeutic response improvement of extrapyramidal signs throughout the study, the double support limb percentage was reduced but did not reach statistical significance.

Animal studies indicate that basal ganglia may be involved in internal cue production to string successive elements together in a movement sequence [36,37]. Failure to produce internal cues to integrate a sequence of gait cycles may cause an ever-dismissing stride length and gait akinesia. Although basal ganglia cannot initiate movements, they play a monitoring role in automatic movement sequences by matching performance outcomes with original plans [38]. It is known that the premotor cortex sets motor plans, such as stride length, and that the basal ganglia provide the SMA with the correct motor set and appropriate way-timed phase cues to enable the motor plan to run to completion [5,39,40].

In short, PD patients' gait disorders in general and the double support limb in particular could be due to inadequate preparatory processes involving interaction between SMA and basal ganglia. This mismatch is generally reversed by STN DBS + LD [41], a suprathreshold L-dopa dosage [42] or by external cues [9,10]. This is an extremely important gait parameter, which is probably not modified by the motor rehabilitation program.

Moreover, it is possible that the double support limb is not only directly related to stride length and then to dopaminergic pathways such as the cortex, Centrum medianum/parafascicular nucleus Complex and Peduncolo Pontine Nucleus. However, this component mainly concerns the posture and postural stability benefits of the levodopa therapy and the motor rehabilitation program, but to a lesser degree compared to akinesia and rigidity of all four limbs.

The absence of statistical differences in stride asymmetry in patients who show predominant side extrapyramidal symptoms led us to postulate that gait alteration in PD patients results from the sum of parameters of different levels at which supraspinal input from cortical regions appears to establish the final goal, i.e., stride length. It is also true that the PD patients in this study showed extrapyramidal symptoms characterised by bilateral body involvement; however, the left side of the body was more involved than the right side. Statistical analysis did not show significant differences. This suggests that gait analysis may be unhelpful in investigating extrapyramidal symptom asymmetry when the disease shows bilateral involvement. However, the relatively small sample in this study and the PD patients' low disease severity may not have provided enough range for symptom asymmetry. In fact, other studies involving a PD population with greater extrapyramidal symptom severity are needed to better clarify this issue.

Recent studies suggested that motor rehabilitation was ''unhelpful'' in improving PD patients' extrapyramidal symptoms in terms of cost-benefit analysis because clinical improvement is strictly related to the length of the motor rehabilitation program [12–17]. Further studies have demonstrated that this improvement is not maintained at follow-up. Indeed, few studies have reported any long-term follow-up since it is well known that Parkinson's disease is degenerative and that its natural history is somewhat unpredictable [12–17].

In our study, PD patients were assessed only after establishing their optimal antiparkinsonian therapy. Furthermore, the patients did not know when their performance would be assessed. Finally, we used objective gait analysis rather than subjective evaluation methods.

The follow up assessment in this study was 2 months. However, further studies are needed for a more in-depth investigation of this issue.

This study showed that gait variables improved after PD patients underwent rehabilitation. Further, it highlighted the efficacy of a rehabilitation intervention aimed at improving mean and temporal parameters and at decreasing stride asymmetry. This information may be useful in developing a more objective evaluation of motor rehabilitation programs and for revealing their effectiveness in neurodegenerative disorders such as Parkinson's disease.

Our results on kinematic lower limb data agree with those reported in the literature. They confirm PD patients' increased hip, knee and ankle flexion, both when upright and walking, compared to controls. In both stance and swing phases, we found that PD patients had a smaller range of amplitude in lower limb joints than controls. After the motor rehabilitation program (with the exception of knees) the angle values of PD patients approached those of controls.

Nevertheless, after rehabilitation their ankle angle was larger than before, and this may be considered an indication of gait improvement.

In conclusion, gait analysis provides objective outcome measures of a rehabilitation program. It also contributes additional information on specific gait deviations. Detailed analysis of gait is useful in understanding the complex pathophysiology of gait disturbances in Parkinson's disease patients.

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We (author and co-author) have not received honoraria (personal compensation) from any sponsor during the course of this study. We (author and co-author) are not a current or former employee of any sponsor.

We (author and co-author) have not given expert testimony related to the subject of this article.

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