Forward versus Backward Oriented Stepping Movements in Parkinsonian Patients

Nikolai Gantchev, François Viallet, Roselyne Aurenty, and Jean Massion

The primary purpose of this paper was to compare the effect of reversing the direction of step initiation in Parkinson's disease. Forward (FDS) and backward (BDS) oriented stepping initiation analyses were conducted on combined kinematic and kinetic data recorded on Parkinsonian patients (PD) and healthy age-matched subjects. Two successive phases were examined: a postural phase from T1 (onset of the center of pressure [CP] displacement) to T2 (onset of the malleolus displacement), which was followed by a stepping phase from T2 to T3 (end of the malleolus displacement; i.e., the end of the step). In healthy subjects, the duration of the postural phase remained unchanged regardless of the direction in which the step was initiated. The stepping phase duration and the first step length were reduced in BDS in comparison with FDS. In both tasks, the absolute value of the horizontal force in sagittal plane (Fx) remained unchanged. The maximal velocity of the iliac crest marker (estimated whole body center of gravity [CG]) in the sagittal plane ($V_{\text{max CG}}$) remained within the same range regardless of direction of stepping. In Parkinsonian patients, the duration of the postural phase was markedly prolonged in both tasks in comparison with healthy subjects. The mean duration of stepping phase was approximately the same as in normal subjects, but the first step length was considerably reduced, as were horizontal force (Fx) and $V_{\text{max CG}}$. This impairment, which was due to a decrease in the propulsive forces, was significantly more pronounced in BDS that in FDS.

**Key words:** Parkinsonian patients, backward stepping, center of pressure, center of gravity

**Introduction**

Movement trajectories of the legs during forward and backward walking are practically mirror images of each other (Thorstensson, 1986). In addition, the concentric pattern of muscle activation observed in forward walking was found to
become eccentric in backward walking (Winter et al., 1989). These findings suggest that backward stepping might result from a simple but controlled adaptation of the motor program responsible for forward stepping. A similar conclusion was also reached about backward stepping in cat studies (Buford & Smith, 1990a; Buford et al., 1990b; Perell et al., 1993).

On the whole, little attention has been paid so far to the effects of reversing the direction on the initiation of stepping in healthy subjects, and data are lacking in Parkinsonian patients (PD). In recent years, several studies have focused on the initiation of forward oriented movements (FOMs), mainly gait (Carlsoo, 1966; Cook & Cozzens, 1976; Mann et al., 1979; Brenière et al., 1981; Crenna et al., 1990; Nissan & Whittle, 1990; Brunt et al., 1991; Elble et al., 1994). It was demonstrated that the initiation included a postural phase, during which the center of gravity (CG) was displaced forward and sideward, and a subsequent movement phase, characterized by the stepping movement made by the leading leg. The initiation of backward stepping can also be described as consisting of a postural phase, during which the CG is accelerated backward, and a movement phase, characterized by the backward stepping of the leading leg. By analyzing the center of foot pressure (CP), changes beneath each foot (Gantchev et al., 1996a) have shown that the initiation process is very similar in both backward directed stepping (BDS) and forward directed stepping (FDS). The onset of CP shift in FDS or BDS direction was simultaneous beneath both legs; the whole timing of CP curves is not different as a function of stepping direction. The direction for CP shift was opposite in respect to FDS or BDS initiation. So it was proposed that one and the same motor program was responsible for the stepping initiation but specifically modulated with respect to the direction.

In a previous study (Gantchev et al., 1996b) on the impairment of initiation process, we investigated the deficits affecting the initiation of various forward-oriented movements (FOMs) in Parkinson’s disease with a view to determining whether the deficits affecting the postural adjustments occurred immediately prior to any FOMs. It was observed that the postural phase in PD patients was markedly prolonged in all the various motor tasks performed. This lengthening of the postural phase was correlated with a decrease in the propulsive forces in sagittal direction, which resulted in a decrease in the maximal velocity of the center of gravity and in a striking shortening of the first step length.

Several hypothesis have been put forward in order to explain the prolonged postural phase in parkinsonian patients: (a) difficulty in “energizing” the initial EMG burst during movement initiation (Hallett, 1990; Hallett & Koshbin, 1980; Hallett et al., 1991); (b) specific postural deficit affecting the postural control mechanism (Dietz, 1994; Schieppatti et al., 1994; Stelmach et al., 1989); and (c) main deficit affecting posturo kinetic coordination in the motor act of step initiation (Gantchev et al., 1996a, 1996b).

The aim of the present study was to compare forward and backward step initiation in PD patients in order to determine whether both modes of initiation are equally severely impaired or not. Since that backward stepping initiation is known to show the same sequential pattern as forward directed stepping, we focused in particular here on establishing whether the impairment observed in Parkinsonian patients varies depending on whether the step is initiated in forward or backward direction. Thus, the following working hypotheses were put forward.
**Biomechanical Hypothesis**

BDS and FDS initiation might be expected to be equally severely impaired, given the biomechanical characteristics of the body. Step initiation depends on the propulsive forces accelerating the CG either forward or backward, and the pendular properties of the body oscillating around the ankle joint are responsible for the duration of the initiation process (Brenière et al., 1981). Therefore, there seems no reason why BDS should be more impaired than FDS in either healthy subjects or PD patients. However, if any biomechanical factors will influence the process of step initiation either in FDS and BDS, it might be reasonable to expect that this effect would equally impact PD patients and control subjects.

**Visual Feedback Hypothesis**

The opposite argument is that, unlike healthy subjects who have no motor initiation deficit, the PD patients can compensate for their motor initiation impairments by using visual feedback or by using visual information about the forthcoming movement and then reducing their movement variability in general (Sheridan & Flowers, 1990; Viallet et al., 1987) as well during gait (Morris et al., 1994a, 1994b). In line with this argument, it has previously been reported that visual markings in the form of bold transverse lines could substantially improve gait performance in PD patients (Azulay et al., 1996, 1999; Blin et al., 1991; Forssberg et al., 1984). Interestingly the motion related to visual inputs are specifically important in improving the performances (Azulay et al., 1999). In BDS, the visual environment is still present with two kinds of changes. First, the visual motion of the subject’s own leg movement is not perceived in backward movement. Second, retinal images of the surrounding objects are not increasing as during forward stepping, but they are decreasing. The change in the dynamic visual optic flow in BDS are liable to induce more severe impairment than in FDS, where visual feedback and visual cues about the floor are both present.

**Triceps Sural Activation Reduced “Gain” During Backward Step Initiation**

In PD patients, step initiation deficit is associated with a reduced capacity to exert ground reaction forces (Stelmach et al., 1989). Recently it was proposed that the “gain” of the motor program responsible for the step initiation in PD is reduced as a function of their status (Halliday et al., 1998). This defective force control in PD (Crenna et al., 1990; Gantchev et al., 1996b; Stelmach et al., 1989) seems directly responsible for a decreased acceleration of CG and a shorter step length than in age-matched controls (Gantchev et al., 1996b). One possible factor for this reduced capacity to exert ground reaction forces is an impaired capacity to evaluate gravity due to an impaired load receptor function (Delwaide et al., 1991; Dietz, 1993). This impaired function of extensor load receptors is also suggested to be involved in the inappropriate activation pattern of Gastrocnemius during walking (Dietz et al., 1995) and in a decreased sensitivity of extensors’ load reflex mechanisms contributing to impaired gait in PD patients (Dietz & Colombo, 1998). As gastrocnemius activation is primarily involved in BDS, it is more likely to expect that the initiation of BDS will be more impaired than FDS in PD patients.
In these experimental series, it will be shown that backward step initiation is more impaired than forward step initiation in PD, which is in favor of the hypothesis related to visual feedback and/or impaired load receptor function. A preliminary report related to part of this study has been published in an abstract form (Viallet et al., 1996a).

Materials and Methods

Seven Parkinsonian patients, aged between 55 and 74 years (mean age: 62 years) and 5 healthy controls, aged between 54 and 74 years (mean age: 60 years), participated in these experiments after giving their informed consent and the approval of the local ethical committee was obtained. Clinical status of PD patients was documented: duration of the disease, stage of disease (Hoehn & Yahr, 1967), UPDRS motor score (Fahn et al., 1987), and usual drug therapy (Table 1). The group of patients under study was homogeneous in terms of their UPDRS motor score (range: 18–39); all had experienced some periods of the so called “freezing gait” during their everyday activities.

Apparatus, Task, and Procedure

The PD patients were taking their usual replacement L-DOPA therapy and were clinically at an ON-phase when the UPDRS motor score was assessed and during the experimental session. The healthy control subjects were male and were recruited after checking that they had no previous neurological or other disease liable to affect their postural stability and their gait initiation ability.

Table 1 Individual Characteristics of the Disease in the Seven Parkinsonian Patients: Age, Disease Duration, Hoehn and Yahr Stage, UPDRS Motor Score, Duration of L-DOPA Therapy, and Daily Dosage of L-DOPA and Other Drugs

<table>
<thead>
<tr>
<th>Parkinsonian patients</th>
<th>Duration of Disease (years)</th>
<th>Hoehn-Yahr stage</th>
<th>UPDRS score part III max = 108</th>
<th>L-DOPA therapy (years)</th>
<th>L-DOPA mg/day</th>
<th>Other DRUGS mg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1</td>
<td>5</td>
<td>II</td>
<td>18</td>
<td>4</td>
<td>1200</td>
<td>Lisuride 0,5 Selegiline 10</td>
</tr>
<tr>
<td>P 2</td>
<td>1</td>
<td>II</td>
<td>27</td>
<td>1</td>
<td>750</td>
<td>none</td>
</tr>
<tr>
<td>P 3</td>
<td>12</td>
<td>III</td>
<td>39</td>
<td>11</td>
<td>2000</td>
<td>Bromocriptine 40 Piribedil 100</td>
</tr>
<tr>
<td>P 4</td>
<td>9</td>
<td>III</td>
<td>29</td>
<td>7</td>
<td>600</td>
<td>Bromocriptine 25 Tolcapone 600</td>
</tr>
<tr>
<td>P 5</td>
<td>15</td>
<td>III</td>
<td>33</td>
<td>12</td>
<td>650</td>
<td>Bromocriptine 30 Tolcapone 600</td>
</tr>
<tr>
<td>P 6</td>
<td>5</td>
<td>III</td>
<td>27</td>
<td>4</td>
<td>650</td>
<td>Tolcapone 600</td>
</tr>
<tr>
<td>P 7</td>
<td>15</td>
<td>III</td>
<td>28</td>
<td>14</td>
<td>1400</td>
<td>Cabergoline 6</td>
</tr>
</tbody>
</table>
The subjects, standing barefoot on a Kistler force platform, were instructed to adopt their normal erect posture. In response to a tone signal, they had to initiate a step either forward or backward with a "leading" leg—that which is normally used by the subject to initiate walking. In order to ensure that the foot position was the same before each trial, marks were drawn around the subject's feet on the force platform. In each motor task, 8 consecutive trials were run, starting with the FDS series and followed by BDS. No practice was given before the experimental session. To avoid fatigue, a 5-min rest period was introduced between the two motor tasks. The instructions were as follows:

1. Forward oriented step (FDS): initiation of a single step forward with the "leading" leg, ending with the "trailing" leg placed parallel to the "leading" leg.
2. Backward oriented step (BDS): initiation of a single step backward with the "leading" leg, ending with the "trailing" leg placed parallel to the "leading" leg.

**Recording Parameters**

In each trial, the total duration of the kinetic and kinematic data recordings was 4 s.

- Vertical and horizontal ground reaction forces were recorded from a Kistler force platform. The center of foot pressure (CP) was calculated from the vertical reaction forces exerted in the sagittal plane before and during the movement of the body.

- Kinematic profiles (3D) were monitored by two TV cameras placed in front of the subject at a sampling rate of 100 Hz and reconstructed with the E.L.I.T.E. TV image processing system (Ferrigno & Pedotti, 1985). Twelve reflective markers were glued symmetrically at the level of the lateral edge of the eye orbit, on the acromion, the anterior-superior iliac crest, the great trochanter, the knee, and the ankle (external malleolus; Figure 1).

**Data Analysis**

**Center of Gravity (CG).** The approximate instantaneous position of the CG was estimated indirectly from the trajectory of the marker placed on the iliac crest on the side of the "leading" leg. The maximum velocity of the CG ($V_{\text{max CG}}$) was estimated from the velocity curve of the same marker (Figure 1).

**Center of Pressure (CP).** The CP shift in the sagittal plane was assessed from the vertical ground reaction forces recorded by a Kistler force platform. The onset of CP shift was used to determine the onset of the movement initiation ($T_1$; Figure 1).

**Horizontal Force (Fx).** The area under the curve formed by the horizontal reaction force in the sagittal plane (Fx), was measured in each motor task during each of the phases ($T_1$–$T_2$ and $T_2$–$T_3$) and during the total period extending from $T_1$ to $T_3$ (Figure 1).
Figure 1 — Right: experimental device and location of markers. Left: recordings of one forward and one backward directed stepping in a control subject. Top to bottom: velocity curve of the malleolus marker of the leading leg (higher amplitude curve) superimposed on the velocity curve of the iliac crest marker, (pelvis velocity) itself equals an estimation of the antero-posterior velocity of the center of gravity in sagittal plane; pelvis displacement in the direction of the step (same scaling of CP shift); initial CP displacements in the opposite directions to the step initiation; horizontal ground reaction force (in black) in sagittal plane. Note: T1 = onset of the force change on the horizontal ground reaction force and in CP curve (onset of the postural phase); T2 = onset of the change in the velocity curve (onset of the stepping phase); and T3 = time of crossing with the zero value (end of the stepping phase).

First Step Length and Duration. The step duration was measured on the velocity curve derived from the antero-posterior trajectory of the ankle marker of the "leading" leg. The horizontal shift of the same marker was used to measure the step length.

Statistical Analysis. Statistical significance was based on the student's unpaired \( t \) test and ANOVA procedure. The level of significance adopted for the whole analysis was \( p < .05 \).

Results

In each forward (FDS) or backward (BDS) stepping initiation trials, two successive phases were defined on the basis of the kinetic and kinematic parameters (Figure 1).

During the postural phase, an initial shift of the CP (T1) occurred in the opposite direction to that of the step. In other words, in FDS the first deviation of the CP was backward, in BDS it was forward, and in both directions it was towards the leading leg. This was responsible for the CG displacement in the direction of the step and towards the supporting leg. The horizontal ground reaction forces were exerted in the direction of the step and contributed to accelerating the CG in
that direction. During the stepping phase from T2 to T3, the horizontal propulsive forces were still exerted in the direction of the step, and the maximal velocity of the CG was reached. On the whole, gait initiation in FDS and BDS was symmetrical.

The mean values obtained on healthy subjects and PD patients during the postural phase of forward or backward stepping initiation are given in Figures 2 and 3, respectively.

![Histograms showing comparison in control subjects between the various recorded parameters in forward (FDS) and backward (BDS) step initiation. Maximal velocity CG = maximal velocity of the iliac crest marker as an estimation of the maximal antero-posterior velocity of the center of gravity. The area under curve of the horizontal ground reaction force in sagittal plane is calculated between the onset of force change (T1) and the end of the step (T3). Note that the only significant differences between FDS and BDS concern the duration of the stepping phase and the step length, which rely on biomechanical differences in the step performance in the two directions (landing on the tip toes in BDS).]
Healthy Control Subjects

In healthy subjects, the parameters recorded in FDS were very similar to those obtained with BDS. The mean postural phase duration recorded in FDS was 306 ± 90 ms, whereas in BDS the duration was 350 ± 84 ms; no significant difference, based on the results of the ANOVA ($F_{1,48} = 3, p = .07$), were observed in FDS versus BDS (Figure 2, top left).

The mean duration of the stepping phase was slightly longer in FDS (802 ± 101 ms), then in BDS (742 ± 106 ms) and this difference was significant (ANOVA: $F_{1,48} = 4, p = .04$; Figure 2, bottom left).

The length of the first step in FDS (683 ± 101 mm) was slightly longer than in BDS (607 ± 98 mm). The difference was significant (ANOVA: $F_{1,48} = 7.8, p = .009$; Figure 2, top right). It should be noted however that the stepping phase duration and step length were shorter in BDS because of the biomechanical asymmetry of the feet (landing on tip toe).

The horizontal ground reaction forces (sagittal component, $F_x$) during the whole initiation phase (T1 to T3) did not differ significantly between BDS and FDS (Figure 2, right middle). In forward stepping, the absolute value of the $F_x$ component was 77,746 ± 11,761 N · s, whereas in backward stepping, it was 74,622 ± 10,554 N · s. The difference was not significant (ANOVA: $F_{1,48} = 0.9, p = .3$).

The $V_{\text{max}}$ CG (estimated from the maximal velocity of the iliac crest marker) did not differ significantly (ANOVA: $F_{1,48} = 0.8, p = 0.4$) between the two modes of stepping initiation: 0.907 ± 0.134 m/s in FDS and 0.872 ± 0.133 m/s in BDS (Figure 2, bottom right).

Parkinsonian Patients

Generally speaking, the gait initiation parameters were impaired in Parkinsonian patients in comparison to control subjects, both for forward and backward step initiation.

Upon comparing the two groups, Parkinsonians and Controls, a group effect was observed (MANOVA: $F_{1,122} = 48.8, p < .0001$; see Table 2). The main differences between Parkinsonians and Healthy subjects parameters were:

- the significant increase observed in the duration of the postural phase in PD in both FDS (ANOVA: $F_{1,60} = 33.3, p < .0001$) and BDS (ANOVA: $F_{1,61} = 16.7, p = .001$) with respect to controls;
- the marked decrease in the step lengths noted in FDS (ANOVA: $F_{1,60} = 26.5, p < .0001$) and especially in BDS (ANOVA: $F_{1,61} = 64.4, p < .0001$);
- the marked decreased $V_{\text{max}}$ CG observed in FDS (ANOVA: $F_{1,60} = 0.4, p = .7$) and especially in BDS (ANOVA: $F_{1,61} = 25.5, p < .0001$);
- the marked impairment of the horizontal propulsive forces in FDS (ANOVA: $F_{1,60} = 45.74, p < .0001$), and especially in BDS (ANOVA: $F_{1,61} = 161, p < .0001$).

The main differences for Parkinsonian patients in FDS versus BDS stepping are shown in Figure 3

When comparing forward and backward oriented stepping in PD, it was shown that the impairment was more important in BDS than in FDS (see Figure 3, right); this was noticed for the step length, the horizontal ground reaction forces and the
Table 2  Comparison Between the Recorded Parameters in Healthy Control Subjects and Parkinsonian Subjects During Forward and Backward Step Initiation

<table>
<thead>
<tr>
<th></th>
<th>Postural phase T1 - T2 (ms)</th>
<th>Stepping phase T2 - T3 (ms)</th>
<th>Area Fx Sagittal plane T1 - T3 (N.s)</th>
<th>Maximal Velocity CG (m/s)</th>
<th>Step Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FORWARD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEALTHY</td>
<td>306 +/- 90</td>
<td>802 +/- 101</td>
<td>77 746 +/- 11 761</td>
<td>0.907 +/- 0.134</td>
<td>683 +/- 101</td>
</tr>
<tr>
<td></td>
<td>★ ★ ★</td>
<td>★ ★ ★</td>
<td>★ ★ ★</td>
<td>★ ★</td>
<td>★ ★ ★</td>
</tr>
<tr>
<td>PARKINSONIAN</td>
<td>474 +/- 126</td>
<td>706 +/- 98</td>
<td>60 904 +/- 7 872</td>
<td>0.760 +/- 0.077</td>
<td>576 +/- 62</td>
</tr>
<tr>
<td><strong>BACKWARD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEALTHY</td>
<td>350 +/- 84</td>
<td>742 +/- 106</td>
<td>74 622 +/- 10 554</td>
<td>0.872 +/- 0.133</td>
<td>607 +/- 98</td>
</tr>
<tr>
<td></td>
<td>★ ★ ★</td>
<td>★ ★ ★</td>
<td>★ ★ ★</td>
<td>★ ★</td>
<td>★ ★ ★</td>
</tr>
<tr>
<td>PARKINSONIAN</td>
<td>451 +/- 102</td>
<td>736 +/- 212</td>
<td>45 905 +/- 7 407</td>
<td>0.537 +/- 0.144</td>
<td>434 +/- 73</td>
</tr>
</tbody>
</table>

**Note.** FDS = forward step initiation; BDS = backward step initiation; Area Fx = integral of the horizontal ground reaction forces in the sagittal plane in Newton · second (N · s) from the onset of force changes (T1) until the end of the step (T3); Maximal Velocity CG = maximal velocity of the iliac marker, which is an estimation of the center of gravity velocity.
maximal velocity of the hip marker (estimated CG velocity).

The step length in FDS was 576 ± 62 mm, whereas in BDS it was 434 ± 73 mm (ANOVA: $F_{1,73} = 82.2, p = 10^{-5}$; Figure 4, right top). The PD patients also showed a greater reduction of the Fx component of the ground reaction forces in BDS (45,905 ± 7,407 N · s) than in FDS (60,904 ± 7,872 N · s). The difference was highly significant (ANOVA: $F_{1,73} = 72.1, p < .0001$; Figure 4, right middle). The $V_{\text{max}}$ CG was significantly lower in BDS (0.537 ± 0.144 m/s) than in FDS (0.760 ± 0.077 m/s; ANOVA: $F_{1,73} = 37, p < .0001$). The comparable change observed in the step length indicated that the shortest step corresponded to the lowest velocity of the CG (Figure 3, right bottom). The duration of postural phase (ANOVA: $F_{1,73} = 0.7, p = .3$) and the duration of the stepping phase (ANOVA: $F_{1,73} = 0.6, p = .4$), did not differ significantly between the two stepping directions (see Figure 3, left).
Discussion

The results of the present experiments show that backward as well as forward step initiation are impaired in Parkinsonian patients. The main deficit focuses on the propulsive ground reaction forces and on the resulting reduced acceleration of the CG during the postural and stepping phases. As a result, the step length was reduced as well as $V_{\text{max}}$ CG, while the postural phase was conspicuously lengthened. This deficit of propulsive forces has been related to several factors such as a lack of energizing in the command (Hallett, 1990; Hallett & Khoshbin, 1980), a basic problem in initiating coordinated tasks (Gantchev et al., 1996b; Latash et al., 1995) and in impaired handling of antigravity forces (Dietz, 1994).

Interestingly, in PD patients these deficits were greater with BDS than with FDS initiation, whereas in the control subjects, the propulsive forces responsible for the CG acceleration were found to be similar in both FDS and BDS initiation. In the healthy control group, the comparison between forward and backward step initiation did not show any major difference, although the step duration tended to be slightly shorter in BDS, where there was a slight shortening in step length. This step length shortening was only due to the biomechanical characteristics of the foot, then causing a landing on tip-toe in BDS with a shorter step duration than in FDS where there was a heel strike; this interpretation was confirmed by the unchanged $V_{\text{max}}$ of the foot in both FDS and BDS. Why BDS is more affected in PD patients than in FDS will be the main focus of the discussion. Three main hypotheses were formulated.

1. Biomechanical Hypothesis

This hypothesis claiming that the asymmetry of the deficit in PD between BDS and FDS is related to an asymmetry in the biomechanical constraints associated with forward and backward stepping seems not validated. On the whole, the inverted pendulum-like behavior of the body around the ankle joint (Brenière et al., 1981) and the direct pendulum-like properties of the stepping leg around the hip joint during gait initiation might provide the biomechanical basis for both forward and backward step initiation. The present data are in agreement with the previous findings based on recordings of the center of foot pressure beneath each leg during FDS and BDS initiation. In a previous study (Gantchev et al., 1996a), the recorded traces were symmetrical for both directions. The slightly shorter step duration and step length observed in the present experiments in the case of BDS initiation might be due to the asymmetry of the hip joint movement, the mode of foot lifting, and the mode of ground contact. In the FDS the step initiation starts with heel elevation, the tip toe remains longer on the ground, whereas in BDS the heel elevation coincides with the whole foot elevation (Duysens et al., 1996). At landing, the foot contact starts with the heel in FDS, while in BDS the very first contact is with the toes. It is worth noting that the total force needed in the sagittal direction ($F_x$) to produce the stepping movement remained unchanged in both the stepping directions. The maximal velocity of the iliac crest marker, which gives approximately the maximal velocity of the center of gravity, was also unchanged between FDS and BDS.

In normal subjects, the lack of any marked difference between forward and backward stepping has also been observed by several authors, who reported that the movement trajectories of the leg in forward and backward walking practically...
mirrored each other (Thorstensson, 1986). It has also been established on the basis of EMG recordings that backward walking can be described as temporal reversal of forward directed walking—in other words, the concentric muscle activity occurring in the forward direction becoming eccentric in the backward direction (Winter et al., 1989).

As BDS and FDS are performed in a symmetrical way in control subjects, it excludes the difference in BDS versus FDS characteristics seen in PD results from differences in biomechanical constraints.

2. Visual Hypothesis

A second hypothesis that could explain the lower performance for BDS versus FDS in PD patients is that, in Parkinson’s disease, the lack of visual feedback about the direction of the step might aggravate the postural adjustments impairment during the backward step initiation as compared with forward stepping. The role of visual feedback in compensating for PD deficit has been emphasized by several authors. It has been established that a visually displayed arm position improved the performance of arm movement in both Parkinsonian patients (Cooke & Brown, 1979) and monkeys during cooling of the globus pallidus (Hore et al., 1977). The importance of external cues in posturo-kinetic coordination during gait processes has been demonstrated by Forssberg et al. (1984) and has been recently confirmed in locomotion of Parkinsonian patients (Morris et al., 1994a, 1994b; Azulay et al., 1996, 1999) and especially during backward stepping (Beuter et al., 1992). This is in agreement with the data from the present study on backward step initiation.

Bradykinesia and/or hypokinesia may be associated with an increase in the variability of movement control (Sheridan & Flowers, 1990). According to this explanation, the use of compensatory sensory feedback, especially visual feedback during movement, may reduce the risk of control errors, while slowing down its performance or reducing the amplitude of the ongoing movement (Viallet et al., 1987). In contrast with forward stepping, the optic flow related to backward stepping does not inform on the subject’s own movement. In addition the retinal images of surrounding objects are decreasing in BDS, whereas they are increasing in FDS. These differences may explain why it is more difficult for Parkinsonian patients to perform backward movements. Another explanation might be that the backward step initiation task is less usual in daily life and therefore more variable and less automated. As a result the impairments affecting PD patients may be increased when they have to move in backward direction.

3. Gastrocnemius Activation Reduced “Gain”

Our previous study suggested that main impairment in PD step initiation is related with deficit in coordinating two tasks in the same motor act (Gantchev et al., 1996b; Viallet et al., 1996b). In PD patients, similar impairments to those described in the case of FDS were observed in that of BDS initiation. The reduced propulsive forces might not be primarily due to bradykinesia but might reflect an adaptation to a deficit affecting the coordinated processes associated with the initiation of the motor act, as suggested by Latash et al. (1995). Here, forward or backward CG propulsion needs to be coordinated with lateral CG propulsion and leg lifting. The difficulty of coordinating these three processes might be overcome by the slowing of the initiation process as previously suggested (Gantchev et al., 1996b).
To initiate the step directed backward, the gastrocnemius (GM) of the leading leg is responsible for producing the backward CG acceleration and can be considered as prime mover for this task in the same way as, in the initiation of the step forward, the tibialis (TA) produces the CG forward acceleration. In fact, both TA activation and activation of GM-SOL in BDS, are a major part of the motor program responsible for step initiation respectively in FDS and in BDS. In the load sensitivity hypothesis (Dietz, 1993), there would exist in PD a deficit in load receptors sensitivity, which accounts for the impaired evaluation of the antigravity forces exerted by the extensor muscles. This would account for a reduced gain of the muscle command related to the development of ground reaction force in step initiation (Gantchev et al., 1996b).

As GM became a prime mover in BDS initiation and as the load receptors sensitivity impairment mainly concerns the extensor muscles (Dietz, 1993), it is more likely that the gain in GM control will be more affected than that of TA, and it is to be expected that BDS will be more impaired than FDS. More precisely, it has been shown a reduced sensitivity of poly-synaptic reflexes in leg extensor muscles (for review see Dietz, 1993): The impaired function of extensor load receptors has been suggested to be involved in the inappropriate activation of Gastrocnemius during walking (Dietz et al., 1995) and then the decrease sensitivity of extensor load reflex mechanisms contributed to impaired gait in PD (Dietz & Collombo, 1998). Thus, the impaired sensitivity of GM muscle leading to an inappropriate activation could also explain why the step initiation deficit was greater with BDS than with FDS initiation.

In conclusion, the present data provide further evidence that the main deficit occurring during step initiation by Parkinsonian patients is due to their impaired postural control, regardless of the direction of the step initiation, and can be more specifically attributed to the decrease in the acceleration of the CG, which takes place during the postural and stepping phases.

The fact that a greater deficit occurs in BDS than in FDS cannot be explained by biomechanical factors. It might be due to the lack of visual feedback when stepping is initiated in a backward direction and to a greater influence of the load receptors’ impaired sensitivity when using extensor muscles to initiate the step. Further investigations are therefore required to provide an evaluation of the respective contribution of the reduction of visual information versus the impairment of load sensitivity during the step initiation process.

References


Acknowledgments

Dr. Nikolai Gantchev was supported by a grant from EEC Tread program and the French Ministry of Research and Technology (Contract 500509, Grant PECO). The study is supported by grant COPERNICUS No. 930099, and by a grant from Conseil de Communauté Marseille Provence Metropole, and by a PHRC of Assistance Publique of Marseille, 1996. The authors would like to express their sincere gratitude to Prof. Marco Schieppati for critically reading the preliminary text of the paper and to Diana Miteva for English editing.

Manuscript submitted: April 4, 2000
Accepted for publication: June 30, 2000