Acceleration Patterns of the Head and Pelvis During Gait in Older People With Parkinson’s Disease: A Comparison of Fallers and Nonfallers

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Background. Falls are common in older people with Parkinson’s disease (PD) and are likely to be related to gait disturbances associated with the condition. Although several studies have evaluated differences in basic gait parameters in people with PD, none have directly evaluated the stability of the upper body during gait.

Methods. Temporospatial gait parameters and acceleration patterns at the head and pelvis were measured in three groups of older people: 33 controls without PD (mean age 67 ± 4 years), 33 older people with PD and no history of falls (mean age 63 ± 4 years), and 33 older people with PD and a history of falls (mean age 67 ± 2 years). Harmonic ratios of head and pelvis accelerations in each plane were calculated to provide an indicator of upper body stability.

Results. Compared with the control group, older people with PD exhibited significantly reduced walking speed and step length and increased step timing variability. Acceleration patterns were also significantly less rhythmic at the head and pelvis in all three planes. After adjusting for differences in walking speed and step timing variability, PD fallers exhibited significantly less rhythmic accelerations at the pelvis in the vertical and anteroposterior planes than PD nonfallers.

Conclusions. Acceleration patterns during gait differ between older people with and without PD and between older people with PD who do and do not fall. These findings suggest that an inability to control displacements of the torso when walking may predispose older people with PD to falls.

Key Words: Parkinson’s disease—Gait—Balance—Accidental falls.

Parkinson’s disease (PD) is a common neurodegenerative disorder characterized by impaired postural control and gait disturbances (1). Community-based studies indicate that PD is a strong independent risk factor for falls (2–4), and studies specifically focusing on PD populations have demonstrated fall rates of between 38% and 50% over a 6-month period (5–7). Advancing age, duration of disease, and disease severity appear to be the strongest predictors of falls among people with PD (5,8). However, it has also been suggested that the gait pattern associated with PD, characterized by reduced walking speed, shortened step length, and increased double support time (9–12), may also contribute to an increased risk of falling (13).

The mechanism responsible for the relationship between gait patterns and falls in PD has not been fully explored. In particular, it is not clear why the adoption of a reduced walking speed and shortened step length would increase the risk of falling, as previous studies in people without PD have indicated that adopting this “cautious” gait pattern may be an attempt to improve stability by reducing the magnitude of upper body accelerations (14). However, in a recent study of 100 older people with varying degrees of falls risk, we found that high-risk fallers demonstrated less rhythmic head and pelvis accelerations, despite walking at a reduced speed (15). This finding suggested that older people at risk of falling have difficulty controlling the motion of the upper body during gait, which may predispose to falls by interfering with the normal processing of visual, vestibular, and somatosensory information regarding body position (16,17).

A similar mechanism may be responsible for the high rate of falls observed in people with PD. Therefore, the aim of this study was to compare gait patterns in three groups of older people: non-PD controls, older people with PD who do not fall, and older people with PD who do fall. In doing so, we hoped to ascertain whether PD is associated with impaired upper body stability during gait and whether older people with PD who fall demonstrate greater difficulty controlling their upper body than those who do not fall.

Methods

Participants

Healthy controls, PD patients without a history of falls, and PD patients with one or more falls in the previous year (median 1, interquartile range 1–3) were matched on a 1:1:1 basis for age, male-to-female ratio, height, and weight (Table 1). Each group contained 33 participants (15 male...
and 18 female). PD participants were recruited from community-based PD support groups and healthy controls from a database of volunteers. PD participants were eligible if they had a diagnosis of PD according to the United Kingdom Parkinson’s Disease Brain Bank criteria (18), lived in the community, were able to walk unassisted with or without a walking aid, and could perform activities of daily living (such as housework, grooming, and dressing) independently (Hoehn and Yahr Stages I–III) (19). No participant had evidence on history, examination, and review of the medical records of psychosis, neuroleptic use, vertigo, epilepsy, stroke, transient ischemic attacks, syncope, uncompensated heart failure, or moderate or severe valvular heart disease. In addition, all participants had normal vestibular ocular reflexes and a negative Unterberger’s sign on clinical examination. To optimize subject comfort and compliance, PD participants were instructed to take their usual doses of levodopa and other antiparkinsonian medications, and gait tests were performed between 10 and 11 AM during a typical “on” phase (when their response to antiparkinsonian medications was as good as usual). At the time of gait measurement, no participant had dystonia, hyperkinesias, gait freezing, or start hesitation detectable on clinical examination.

Gait Analysis

Linear accelerations of the body were measured along three orthogonal axes (vertical, anteroposterior, and mediolateral) using two tri-axial piezo-resistant accelerometers: one enclosed in a helmet placed on the head and the other firmly strapped onto the participant with a belt at the level of the sacrum (Figure 1). Participants were requested to walk at their preferred self-selected speed along a 20-m level corridor with the instruction “Please walk straight ahead at your usual comfortable pace.” Only the middle 10 m of each walking trial (corresponding to approximately eight stride cycles) were recorded and analyzed. Two trials were recorded.

Full descriptions of the data processing protocol, the derivation of acceleration variables, and test–retest reliability have been described previously (20). The following variables were calculated from the acceleration signals:

1. Step length (cm): walking distance (10 m) divided by the number of steps.
2. Cadence (steps/min); number of vertical pelvis acceleration peaks divided by the duration of the walking trial.
3. Walking speed (m/s); walking distance (10 m) divided by the total time taken to complete the distance.
4. Step timing variability (SD s between successive heel contacts over an entire walking trial).
5. Acceleration root mean square (RMS).
6. Harmonic ratio (HR) of acceleration signals.

The HR provides an indicator of the degree of rhythm of the acceleration signal. The basic underlying premise of this technique is that the unit of measurement from a continuous walking trial is a stride (two steps). A stable, rhythmic gait pattern should therefore consist of acceleration patterns that repeat in multiples of two within any given stride, as these patterns are therefore “completed” prior to taking subsequent strides. Acceleration patterns that do not repeat in multiples of two are problematic, as they produce out-of-phase accelerations that are not completed within each stride and therefore manifest as irregular accelerations during a walking trial. Briefly, the technique involves

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Controls (N = 33)</th>
<th>PD Nonfallers (N = 33)</th>
<th>PD Fallers (N = 33)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>67 ± 4</td>
<td>63 ± 4</td>
<td>67 ± 2</td>
</tr>
<tr>
<td>Male:female ratio</td>
<td>5:6</td>
<td>5:6</td>
<td>5:6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168 ± 3</td>
<td>170 ± 3</td>
<td>169 ± 3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70 ± 4</td>
<td>73 ± 5</td>
<td>68 ± 5</td>
</tr>
<tr>
<td>Duration of PD (y)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Since onset of symptoms</td>
<td>8 ± 2</td>
<td>10 ± 2</td>
<td></td>
</tr>
<tr>
<td>Since diagnosis</td>
<td>7 ± 2</td>
<td>9 ± 2</td>
<td></td>
</tr>
<tr>
<td>UPDRS total score</td>
<td>25 ± 4</td>
<td>42 ± 5*</td>
<td></td>
</tr>
<tr>
<td>UPDRS motor score</td>
<td>12 ± 3</td>
<td>21 ± 3*</td>
<td></td>
</tr>
<tr>
<td>Hoehn and Yahr Stage</td>
<td>(1–1)</td>
<td>3 (3–4)*</td>
<td></td>
</tr>
<tr>
<td>Schwab and England Scale</td>
<td>100 (90–100)</td>
<td>80 (60–90)*</td>
<td></td>
</tr>
<tr>
<td>Medications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-acting levodopa (mg/d)</td>
<td>666 ± 133</td>
<td>958 ± 241†</td>
<td></td>
</tr>
<tr>
<td>Long-acting levodopa (mg)</td>
<td>6</td>
<td>12†</td>
<td></td>
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<tr>
<td>Dopamine agonists (mg)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Anticholinergics (mg)</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>COMT inhibitors (mg)</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Results presented as mean ± 95% confidence interval, median (interquartile range), or number of participants (n). PD = Parkinson’s disease; UPDRS = Unified Parkinson’s Disease Rating Scale.

*Significant difference between groups, p < .05.
†Significant difference between groups, p < .001.
‡Catechol-O-methyltransferase.
decomposing the acceleration signal into individual harmonics using a finite Fourier transform. The summed amplitudes of the even-numbered harmonics are then divided by the summed amplitudes of the odd-numbered harmonics, providing a HR. Higher ratios represent a more stable walking pattern, as a greater proportion of the acceleration signal is “in phase” with the participant’s stride frequency (20).

The HR for mediolateral acceleration patterns is calculated differently to HRs for vertical and anteroposterior patterns. This is because heel strike by any foot causes head and pelvic accelerations to the contralateral side, creating acceleration patterns that are monophasic in every stride. Acceleration patterns in the lateral plane that occur an even number of times in any stride produce accelerations that are not resolved within that stride. The HR for the lateral plane is therefore calculated as the summed amplitudes of the odd-numbered harmonics divided by the summed amplitudes of the even-numbered harmonics (20).

Statistical Analysis

The data were analyzed using SPSS Version 12 for Windows (SPSS, Inc., Chicago, IL). Measures of gait were examined for normality using stem-and-leaf plots and the Kolmogorov–Smirnov test statistic. Step length, cadence, walking speed, step timing variability, RMS, and HR were normally distributed in this sample. Differences between the three groups (controls, PD nonfallers, and PD fallers) were examined using univariate analysis of variance (ANOVA), with Bonferroni-adjusted post hoc tests. As HR has been shown to be influenced by walking speed and step timing variability (21), it was necessary to adjust for these variables using multivariate ANOVA when testing for differences in HR between participant groups and estimating marginal means.

RESULTS

Participant Characteristics

Demographic characteristics of the sample and PD severity and medication use for the two PD groups are shown in Table 1. PD fallers had significantly worse Unified Parkinson’s Disease Rating Scale total and motor subscale scores, higher Schwab and England scores, and more advanced Hoehn and Yahr stage than PD nonfallers.

Differences in Temporospatial Gait Parameters

Differences in temporospatial gait parameters between the three groups are shown in Figure 2. Compared with the controls, PD nonfallers exhibited significantly reduced step length and walking speed and increased step timing variability. Among participants with PD, fallers exhibited significantly reduced walking speed and increased step timing variability compared with nonfallers. There were no differences in cadence between the three groups.

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Figure 2. Differences in temporospatial gait parameters (*p < .05; **p < .01; ***p < .001).
Differences in Acceleration Patterns

Typical acceleration patterns obtained from the accelerometry system are shown in Figure 3. Acceleration RMS values are shown in Figure 4. Compared with the controls, PD nonfallers exhibited reduced acceleration RMS in all three planes at the pelvis and head. Among participants with PD, fallers exhibited reduced acceleration RMS in all three planes at the pelvis and reduced acceleration RMS in the vertical and mediolateral planes at the head compared with nonfallers.

Acceleration HRs are shown in Figure 5. Compared with the controls, PD nonfallers exhibited reduced HRs in all three planes at the pelvis and head, with the exception of the mediolateral HR at the head. Among participants with PD, fallers exhibited reduced HRs in all three planes at the pelvis and head. After adjusting for walking speed and step timing variability, the control group had significantly higher HRs at the head in all three planes and at the pelvis in the vertical and mediolateral planes (Table 2). In the participants with PD, differences between fallers and nonfallers remained significant at the pelvis in the vertical and anteroposterior planes even after adjusting for walking speed and step timing variability.

Discussion

The objective of this study was to determine whether PD is associated with impaired upper body stability during gait and whether older people with PD who fall demonstrate greater difficulty controlling their upper body than those who do not fall. Our findings clearly indicate that PD is not only associated with decreased walking speed, step length shortening, and increased step timing variability, but also with a disruption of head and pelvis accelerations. Few previous studies have evaluated the effect of PD on head and trunk stability. This is a major limitation as effective head stabilization while walking is fundamental for processing visual, vestibular, and somatosensory information; motor programming; and maintaining postural stability (22,23). The few studies that have investigated head or torso motion in PD gait have observed abnormal strategies of head stabilization, leading to en bloc movement of the head and upper body.
In our study, PD nonfallers demonstrated significantly lower acceleration HRs in the vertical and anteroposterior planes compared with controls, indicating a significantly less rhythmic upper body movement pattern. Furthermore, in the PD group, fallers had significantly lower vertical and anteroposterior HRs than nonfallers. The differences between controls and PD nonfallers and between fallers and nonfallers in the PD group persisted in linear regression models after adjusting for walking speed and step timing variability. In our previous study of older people without PD (15), we reported similar findings; however, it is interesting to note that the HR values of PD fallers in the current study were considerably lower than those of older fallers without PD, suggesting a more pronounced deficit in postural control. These results are consistent with previous findings of increased spatial (26) and temporal (27) variability in footstep patterns in people with PD.

In older persons, it has been hypothesized that walking slowly with shortened step lengths and increased double support time, the so-called “cautious” gait pattern, may be exacerbated by fear of falling and may be a strategy to decrease destabilizing forces by limiting perturbation to the center of gravity at push-off (14). Our study demonstrates
that these gait changes also occur in people with PD but may be counterproductive and exacerbate destabilizing movements of the head and pelvis. It is likely that the acceleration patterns observed here result from intrinsic abnormalities associated with the disease, such as axial rigidity (28) and deficient sensorimotor integration (29), rather than being an adaptation to reduce the risk of falling.

Somewhat surprisingly, PD was not associated with reductions in measures of mediolateral stability, which is inconsistent with previous findings involving standing balance tests (30–32). It is possible that people with PD attempt to maintain mediolateral stability by increasing step width (24) and that this may account for the lack of difference in HRs between PD cases and controls. Most previous studies, however, have not observed any differences between controls and PD cases in step width or have detected them only in participants with PD with more advanced disease (12,33). Although mediolateral instability may have been identified if we had recruited people with more severe PD or measured step width variability, this finding is consistent with our previous study of older people without PD (15), which suggests that vertical and anteroposterior measures of upper body movement are more closely related to gait stability than measures in the mediolateral plane.

The relationship between low HRs and falls requires further exploration. Even in normal gait, self-generated forces arise that perturb posture and disrupt gaze (34,35). In the presence of these perturbations, compensatory mechanisms, such as the cervicocollic, vestibulocular, and vestibulocollic reflexes, are required to maintain stability (36,37). Irregular perturbations could therefore affect the head’s ability to act as a postural reference point (15). This disruption of vestibular and visual inputs would exacerbate postural control in participants with PD, who have been shown to be more dependent upon visual inputs than healthy individuals (38). Therefore, it is possible that the inability to regulate self-generated perturbations of the upper body during gait in PD may interfere with gaze stability, thereby increasing the risk of tripping and decreasing the efficacy of postural responses to changes in terrain.

A limitation of this study is that falls were documented retrospectively, and although we obtained corroborative information from participants’ partners or carers, we acknowledge that some participants may have had difficulty recalling falls in the previous 12 months. Therefore, future studies should use prospective falls ascertainment methods to confirm these findings. Future studies will also need to address head and pelvis stability in the performance of routine activities. Falls occur in many circumstances in PD (6) and may result more commonly from abnormal turning, rushing, or freezing than from walking in a straight line at a constant self-selected speed. Furthermore, additional research is required to determine which particular parkinsonian deficits (i.e., impaired sensorimotor integration or difficulty changing postural set) or signs (i.e., rigidity, subclinical dyskinesia, or shuffling gait) lead to the observed differences between healthy controls, PD nonfallers, and PD fallers. Finally, the accelerometric methods described in this study could be used to determine how head and pelvis stability respond to visual, auditory, or somatosensory cues; antiparkinsonian medication; deep brain stimulation; or pallidotomy, and whether improvements in head and pelvis control reduce the risk of falling.

CONCLUSIONS

This study complements clinical assessments of mobility and provides evidence that gait abnormalities in PD extend beyond traditional temporospatial parameters and footstep parameters. Acceleration patterns of the upper body during gait were found to differ between older people with and without PD and between older people with PD who do and do not fall. These findings suggest that an inability to control displacements of the torso when walking may predispose to falls in older people with PD. Further research is required to evaluate whether these gait parameters are predictive of future falls and whether these patterns are amenable to intervention.

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