Background and Purpose. Understanding the nature and extent of fluctuations in spatial and temporal variables of gait (e.g., speed, stride length [SL], stride time [ST]) over the course of the levodopa (L-dopa) cycle of individuals with advanced Parkinson disease (PD) is important in order to assess patients and examine the effectiveness of interventions. The purpose of this study was to determine whether gait variables are sufficiently stable to be used as outcome measures in a clinical trial involving patients with advanced PD.

Subjects. Five volunteers (3 male, 2 female; mean age = 67.8 years; Hoehn and Yahr stages 3-4) with idiopathic PD of a mean duration of 15.0 years participated.

Methods. Gait speed, SL, and ST were measured as the subjects walked 7.2 m at self-selected speeds. To evaluate the full “on-off” sequence of the L-dopa response, this analysis was repeated 11 times, at intervals of 10% of the L-dopa cycle. Each subject was analyzed on 3 separate days, with approximately 1 month between tests. Two-way repeated-measures analyses of covariance, with 2 within-subject factors (percentage of L-dopa cycle and day) and 1 covariate (height), were applied, and coefficients of variation were calculated to determine the extent of change in speed, SL, and ST over the L-dopa cycle and over the 3 days.

Results. The subjects' overall mean gait speed was 70.39 cm/s, representing 55.4% of the age-related normative values. There were no effects of percentage of the L-dopa cycle or day or of the interaction of percentage of the L-dopa cycle and day on speed, SL, and ST. The coefficients of variation for speed and SL were consistently higher than the normative values, ranging from 13.5% to 23.8% and from 13.9% to 23.3% at 20% of the L-dopa cycle, respectively.

Conclusion and Discussion. When interpreting spatiotemporal measurements of gait of patients with advanced PD, fluctuations can be extensive and may not follow a predictable pattern.

Key Words: Gait, Levodopa, Motor fluctuations, Parkinson disease.

Marilyn MacKay-Lyons

Parkinson disease (PD) generally becomes manifest with a degeneration of 60% to 80% of the dopaminergic neurons in the substantia nigra or a loss of 90% of striatal dopamine. Because it is not possible to deliver dopamine across the blood-brain barrier and into the central nervous system, levodopa, the precursor of dopamine, is given. The L-dopa cycle is the interval between 2 consecutive times of ingestion of medication. Often, titration of anti-PD medications is difficult, with the therapeutic window being different for each individual and usually narrowing over time.

For the first 3 to 5 years, patients with PD generally have a stable clinical response to L-dopa therapy, with reduction in tremor, rigidity, and bradykinesia. Fluctuations in motor performance, however, become noticeable later. In advanced PD, dose-related dyskinesias during the “on” period and an end-of-dose wearing-off effect (ie, “off” period) can amplify the extent of these fluctuations. These fluctuations include changes in spatial and temporal variables of gait, such as speed, stride length (SL), and stride time (ST), over the L-dopa cycle. An appreciation of the nature and extent of these fluctuations in performance is important in order for clinicians to accurately assess and manage patients and to assess the effectiveness of interventions.

In preparation for a large-scale clinical trial of the effects of neural tissue transplantation involving patients with long-standing PD, it was essential to identify outcome measures that could be used to document the effectiveness of the intervention. Gait characteristics were chosen as potential outcome measures because they are functionally relevant and meaningful to both patients and clinicians and because they can be simple and inexpensive to measure and interpret. No studies have been reported that involved monitoring spatiotemporal variables of gait over the complete L-dopa cycle in people with advanced PD. Therefore, this preliminary study, involving a small number of patients with long-standing PD, was conducted to determine whether gait variables would be sufficiently stable to be used as outcome variables in the proposed study. The objectives of the study were (1) to document spatiotemporal gait variables of people with advanced PD over the L-dopa cycle and (2) to determine whether there is a systematic pattern of fluctuations in gait variables within the L-dopa cycle and over time.

Method

Subjects

Five individuals with the diagnosis of idiopathic PD were recruited with the assistance of neurologists. To be included in the study, subjects were required to be 55 to 75 years of age; to have had the diagnosis of PD confirmed by a neurologist a minimum of 5 years before the start of the study; and to be classified as being at Hoehn and Yahr stage 3 during the “on” phase of the L-dopa cycle, which meant that the subjects had bilateral involvement of the extremities and impairment of balance but were independent in ambulation. The subjects were also required to be able to walk 12 m without ambulatory aids or manual assistance during both the “on” and “off” phases of the L-dopa cycle and to be able to provide informed consent.

The subjects had a mean age of 67.8 years (range=57.4–74.6) and a mean duration of PD of 15.0 years (range=9.2–21.2). All subjects claimed to be independent in household ambulation, but they required the assistance of another person, a walking aid, or a wheelchair for community ambulation during the “off” phase of the L-dopa cycle. None of the subjects participated in physical rehabilitation during the course of the study. Background characteristics of the 5 subjects are summarized in Table 1.

Instrumentation

The temporal and spatial kinematics of the gait cycle were measured using a computerized resistive walkway, as described by Crouse et al. The walkway consisted of a series of rubber mats into which 2 grids of copper-clad steel welding rods were set. The walkway was 10.4 m long, with the central 7.2 m containing the rods. Dummy mats were placed at the beginning and at the end of the central area of the measurement system to eliminate the effects of accelerations and decelerations that occur at initiation and conclusion of each walking trial. Thus,
Table 1.
Background Characteristics of Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Duration of Parkinson Disease (y)</th>
<th>Hoehn and Yahr Stage</th>
<th>Medication</th>
<th>Daily Dosage (mg)</th>
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<tr>
<td>1</td>
<td>F</td>
<td>61.3</td>
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<td>9.2</td>
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<td>4</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td>Sinemet CR 1,200/300</td>
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<td></td>
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<td>74.2</td>
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<td>16.3</td>
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<td>Sinemet 200/20</td>
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<tr>
<td>3</td>
<td>M</td>
<td>57.4</td>
<td>172</td>
<td>17.8</td>
<td>3</td>
<td>4</td>
<td>Sinemet 700/175</td>
</tr>
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<td>M</td>
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<td>172</td>
<td>10.3</td>
<td>3</td>
<td>4</td>
<td>Sinemet 500/125</td>
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<tr>
<td>5</td>
<td>M</td>
<td>71.8</td>
<td>168</td>
<td>21.2</td>
<td>3</td>
<td>4</td>
<td>Sinemet 1,500/150</td>
</tr>
</tbody>
</table>

there was an attempt to measure trials with subjects walking at a constant speed. A stabilized voltage source drives the walkway. A strip of self-adhesive aluminum tape was attached to the sole of each of the subjects' shoes. These strips of aluminum tape completed, when the feet were in contact with the mat, a current path to the otherwise electrically isolated rods. A linear voltage-position relationship was established in which the voltage was measured at the output of the current source and the position alternated between the most proximal and most distal parts of the foot in contact with the walkway. These signals were processed through a control box, and data were collected and stored in a microcomputer.

**Procedure**

The subjects were requested to arrive at the gait laboratory 30 minutes before taking their morning medications and to bring comfortable walking shoes and clothing. Calibration of the walkway was done prior to each testing session, and aluminum tape was placed on the soles of the subjects' shoes. Walking speed (measured in centimeters per second), SL (the distance between 2 consecutive right heel-strikes, measured in centimeters), and ST (the time between 2 consecutive right heel-strikes, measured in seconds) were recorded as the subjects walked on the walkway at a self-selected speed. A practice trial preceded each test, and standby supervision was provided during all tests as a safety precaution.

Several strategies were used in an attempt to minimize potential sources of variability. Standard instructions were used (eg, "Walk down the walkway at your normal, comfortable walking pace"), and all tests were administered by the same investigator at the same time of the day and in the same environment. The medication schedule for each subject was established by the referring neurologist, depending on the individual's responsiveness to L-dopa. This schedule was stable for 3 to 4 months prior to and over the course of the study, and subjects were requested to maintain their normal schedule on the day of the test. The duration of the L-dopa cycle was determined by the medication schedule of the individual and ranged between 4 and 6 hours. Therefore, in an effort to standardize gait analyses across all subjects, testing was repeated 11 times, at 10% intervals during each cycle. The 0% time test was the test done immediately after ingestion of the morning medication, and the 100% time test was the test done after the subsequent ingestion of medication. At the end of each test, the subjects were asked an open-ended question about how they were feeling, and their responses were documented.

Between tests, subjects were encouraged to rest, read, or watch television in the laboratory while refreshments were provided. Each subject was tested in the same time period on 3 separate occasions, with approximately 1 month between tests. This interval was chosen because the protocol for the clinical trials that are to follow this preliminary study involves conducting physical performance evaluations at monthly intervals.

**Data Analysis**

Descriptive statistics, including means, standard deviations, and ranges, were calculated for each dependent variable. Two-way repeated-measures analyses of covariance (ANCOVAs), with 2 within-subject factors (percentage of L-dopa cycle × day) and 1 non–time-varying covariate (height), were applied to determine the extent of change in speed, SL, and ST during free-speed walking over the L-dopa cycle and over the 3 days. Because of the small sample size and missing data for some tests, the BMDP 5V Unbalanced Repeated-
poses, coefficients of variation were also calculated using published means and standard deviations of speed, SL, and ST for elderly subjects with no known neurologic impairments. The pattern of variability in walking speed was also examined by plotting the standardized residuals obtained in the ANCOVA against the fitted values for speed.

**Results**

All subjects were tested, as scheduled, on 3 separate days. The subjects tolerated the testing protocol well. There were no reports of feeling fatigued during or at the end of each testing session, but some subjects reported higher levels of fatigue on the day after testing. There were a total of 11 missing data points for each dependent variable. Three data points were missing due to technical problems during data collection, and 2 data points were missing due to excusing subjects 1 and 2 from a test to use the washroom. Although all subjects initially met the inclusion criteria for this study, 2 subjects were unable to walk 12 m independently throughout the L-dopa cycle. Subject 3 missed 3 tests because he was unable to walk at 90% and 100% of the L-dopa cycle. Subject 2 also missed 3 tests due to inability to walk at 90% and 100% of the L-dopa cycle. The overall mean walking speed of the 5

* BMDP Statistical Software Inc, 1440 S Sepulveda Blvd, Los Angeles, CA 90025.
Figure 2.
Mean stride length for each subject across the L-dopa cycle, averaged over the 3 test days. Note that the last data point for subject 2 is not included because she was unable to walk during this phase in the cycle. (B) Mean stride length of all subjects across the L-dopa cycle, averaged over the 3 test days, and associated coefficients of variation. Error bars of 1 standard deviation are included.
Figure 3.
(A) Mean stride time for each subject across the L-dopa cycle, averaged over the 3 test days. Note that the last data point for subject 2 is not included because she was unable to walk during this phase in the cycle. (B) Mean stride time of all subjects across the L-dopa cycle, averaged over the 3 test days, and associated coefficients of variation. Error bars of 1 standard deviation are included.
subjects in my study was approximately 55% of the reported mean walking speed for comparison subjects in the same age range. Corresponding values for SL and ST were 65% and 112% of normal, respectively. Thus, on average, decreases in SL contributed more to the below-normal walking speed values than did increases in ST. The relationships between walking speed and SL and between walking speed and ST are depicted in the scatter plots in Figure 4.

The coefficient of variation calculated for the mean walking speeds of all subjects averaged across the L-dopa cycle and over the 3 test days was 22.3%, almost twice the value of 12.6% reported for the subjects in the study by Ostrosky et al. The disparity in the coefficients of variation of the pooled data for SL between the 2 studies was even greater (20.3% versus 9.6%, respectively), whereas the coefficients of variation for ST were comparable (10.1% and 9.7%, respectively).

The results of Wald tests of significance of fixed effects (percentage of the L-dopa cycle, day, and interaction of percentage of the L-dopa cycle and day) and the single covariate (height) for each of the dependent variables are summarized in Table 3. The only statistically significant result was that of the covariate (height) on each of the dependent variables.

In Figures 1A, 2A, and 3A, line graphs illustrate the walking speed, SL, and ST of each subject averaged across the L-dopa cycle and over the 3 test days. Line graphs in Figures 1B, 2B, and 3B illustrate the magnitude and pattern of the variability of the means and standard deviations of walking speed, SL, and ST of each subject averaged over the 3 test days. The coefficients of variation for walking speed were consistently higher for the subjects in this study than the reported values for subjects without PD, ranging from 13.5% at 60% of the L-dopa cycle to 23.8% at 20% of the L-dopa cycle. Similarly, the coefficients of variation for SL ranged from 13.9% at 60% of the L-dopa cycle to 23.3% at 20% of the L-dopa cycle, indicating a tight coupling between the variability in walking speed and SL. In contrast, the coefficients of variation for ST for the subjects in this study approximated the normal value of 9.7% calculated from the data reported by Ostrosky et al, ranging from 6.5% at 40% of the L-dopa cycle to 13.4% at 70% of the L-dopa cycle.

The plot of the standardized residuals against the fitted values for walking shown in Figure 5 are grouped into 3 portions of the L-dopa cycle: 0% to 20% and 100% of the L-dopa cycle to approximate the period when plasma levels of L-dopa would be assumed to be lowest, 30% to 60% of the L-dopa cycle to represent the period when plasma levels would typically be at the highest level, and 70% to 90% of the L-dopa cycle to represent the time frame when plasma levels would be expected to decrease toward the lowest level. These groupings were done to determine whether the spread of the residuals changed during these periods, that is, to ascertain whether there were periods in the L-dopa cycle when walking speed was relatively stable. Visual inspection of the plots would suggest that this was not the case.

**Discussion**

Speed of gait and SL have been reported to be useful outcome measures for patients with neurologic impairments because these variables can be measured reliably and are thought to relate to function. Ostrosky et al found high test-retest reliability of measurements of walking speed obtained from 30 individuals without neurologic impairments (15 male, 15 female) with a mean age of 28.2 years (range=20–40) and from 30 individuals without neurologic impairments (15 male, 15 female) with a mean age of 67.4 years (range=60–80) (intraclass correlation coefficients [ICC(2,1)]=.97). Bohannon et al found high test-retest reliability of measurements of walking speed obtained from 156 individuals without neurologic impairments (77 male, 79

### Table 2.

Spatiotemporal Gait Measurements of Individuals and Group Averaged Across the L-dopa Cycle Over the 3 Test Days

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
<th>Subject 5</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (cm/s)</td>
<td>70.61±10.48</td>
<td>56.36±11.53</td>
<td>84.38±9.65</td>
<td>58.62±7.26</td>
<td>83.48±11.58</td>
<td>70.39±15.70</td>
</tr>
<tr>
<td>Percentage of normal values&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55.6</td>
<td>44.4</td>
<td>66.4</td>
<td>46.2</td>
<td>65.7</td>
<td>55.4</td>
</tr>
<tr>
<td>Stride length (cm)</td>
<td>89.68±9.83</td>
<td>68.19±13.88</td>
<td>101.26±13.82</td>
<td>80.89±5.20</td>
<td>106.86±12.80</td>
<td>89.61±18.23</td>
</tr>
<tr>
<td>Percentage of normal values&lt;sup&gt;b&lt;/sup&gt;</td>
<td>63.2</td>
<td>48.0</td>
<td>71.3</td>
<td>57.0</td>
<td>75.3</td>
<td>63.2</td>
</tr>
<tr>
<td>Stride time(s)</td>
<td>1.27±0.12</td>
<td>1.21±0.09</td>
<td>1.20±0.15</td>
<td>1.38±0.11</td>
<td>1.28±0.07</td>
<td>1.27±0.13</td>
</tr>
<tr>
<td>Percentage of normal values&lt;sup&gt;c&lt;/sup&gt;</td>
<td>112.4</td>
<td>107.1</td>
<td>106.2</td>
<td>122.1</td>
<td>113.3</td>
<td>112.4</td>
</tr>
</tbody>
</table>

<sup>a</sup> Normal values=127±16.10

<sup>b</sup> Normal values=142±14.10

<sup>c</sup> Normal values=1.13±0.11.10
Scatter plots of [A] gait speed versus stride length and [B] gait speed versus stride time, using data from all subjects. Pearson product-moment correlation coefficients (r) are shown.

Test-retest reliability of measurements of walking speed also has been reported to be high in studies of people with hemiparesis (n=37, age range=21–40 years) and multiple sclerosis (n=24, age range=21–60 years) (r=.97). Some authors, however, have noted that the gait profile of patients with PD becomes increasingly unpredictable over the L-dopa cycle as the disease progresses, with variability in the same patient from hour to hour and between patients at similar stages of PD. These
Table 3.
Wald Tests of Significance

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<th>Test</th>
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<th>$p$</th>
<th>$\chi^2$</th>
<th>$p$</th>
<th>$\chi^2$</th>
<th>$p$</th>
</tr>
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<tbody>
<tr>
<td>Day</td>
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<td>1.68</td>
<td>.433</td>
<td>0.02</td>
<td>.992</td>
<td>4.75</td>
<td>.093</td>
</tr>
<tr>
<td>Percentage of L-dopa cycle</td>
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<td>5.02</td>
<td>.890</td>
<td>4.33</td>
<td>.931</td>
<td>7.45</td>
<td>.682</td>
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<tr>
<td>Day x percentage of L-dopa cycle</td>
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<td>7.99</td>
<td>.992</td>
<td>5.17</td>
<td>1.000</td>
<td>18.97</td>
<td>.524</td>
</tr>
<tr>
<td>Height</td>
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<td>25.64</td>
<td>.000</td>
<td>45.92</td>
<td>.000</td>
<td>8.13</td>
<td>.004</td>
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</tbody>
</table>

* Statistically significant, $p < .05$.

Figure 5.
Plot of standardized residuals against fitted values of gait speed, using the unstructured model for the covariance structure. Residuals are coded in 3 groups representing different portions of the L-dopa cycle.

Fluctuations in motor performance affect most patients who have been exposed to L-dopa therapy for longer than 5 years. Blin et al.\textsuperscript{15} reported greater variability in SL of 21 subjects with PD (mean age=69.6 years, disease duration=1–17 years, Hoehn and Yahr stages 1–4) compared with an age-matched group of 58 subjects without PD. In my study, involving patients ranging from 9 to 21 years postdiagnosis, ST varied randomly over the L-dopa cycle but within the range reported for individuals without PD. In contrast, the variability in walking speed and SL over the course of the L-dopa cycle was extensive, exceeding the reported coefficients of variation for subjects without PD by 2 times or more, thus precluding a clear pattern of systematic variation. Nevertheless, the lowest variability in walking speed and SL, albeit excessive, coincided with the portion of the L-dopa cycle (ie, 60%) when the plasma levels of L-dopa purportedly are highest.\textsuperscript{12} These results are consistent with the findings of Blin et al.,\textsuperscript{16} who performed gait assessments on 20 patients with PD before and 1 hour after ingestion of L-dopa. Walking speed and SL were found to be “dopa-sensitive,” whereas temporal variables such as ST and swing duration were characterized as “dopa-resistant.”\textsuperscript{10}

Although no researchers have reported investigating gait characteristics over the entire L-dopa cycle, there have been reports of changes over part of the cycle.\textsuperscript{15–19} Boudreau et al measured spatiotemporal gait characteristics of 11 patients with PD (mean age=65.7 years) every 5 minutes beginning 30 minutes before medication and ending 40 minutes after medication (unpublished research). They found variability in all of the variables measured. Recently, Schenkman et al.\textsuperscript{17} investigated the stability of several impairment and physical performance measures in 15 individuals in Hoehn and Yahr stages 2 to 3 of PD (mean age=74.5 years, mean of 6.2 years since diagnosis). Measurements were taken at a single, consis-

tent point in the L-dopa cycle on 2 consecutive days, and they were repeated on 2 days a week later. Their findings suggested that many of the measures, including one distance measure and one speed measure of gait, are relatively stable in the early to middle stages of the disease. They identified a need for investigations of measurement stability with patients in the later stages of PD.

The most comprehensive investigation of the stability of spatiotemporal gait variables in PD has been conducted by Morris et al. A series of 4 substudies were done involving a total of 45 individuals with PD. In one of these studies, gait was measured over a distance of 12 m at 15-minute intervals for 165 minutes beginning 30 minutes after peak dose (ie, the “on” phase of the L-dopa cycle). The sample consisted of 16 patients with PD (mean age = 72.8 years, mean disease duration of 7.8 years), all of whom were capable of independent community ambulation. In addition, patients with severe lower-extremity dyskinesia or dystonia were excluded because these abnormal movements interfered with data collection using footswitches. In contrast to the results of my study, they found little change in performance for any of the variables during the “on” phase of medication. The disease of the patients in that study, however, appeared to be less advanced than that of the subjects in my study, making comparability of results questionable. Another substudy by the same investigators compared the test-retest reliability of gait measurements obtained at peak dose (ie, “on” phase) and at end of dose (ie, “off” phase) in 12 patients with a mean age of 70.1 years and a mean disease duration of 8.8 years. Morris and colleagues found a low degree of repeatability for all measures between the “on” and “off” phases (ICCs [2,1] of −.54 to −.07), and they hypothesized that the greater variability seen in the “off” phase is related to L-dopa concentrations in the plasma and brain.

In discussing the findings of the 4 substudies, Morris et al. concluded that the parkinsonian gait pattern is reproducible across either 30-minute or 24-hour intervals during the “on” phase but that there is marked variability during the “off” phase. My study showed extensive variability throughout the entire L-dopa cycle. The most obvious explanation for the difference in results is the contrast in disease severity (mild in the study by Morris et al. versus moderate in my study), average disease chronicity (8.3 years versus 15.0 years, respectively), and functional limitations (independent community ambulators versus household ambulators, respectively) of the subjects under study. Sage and Mark reported that the extent of variability in motor responses increases with length and severity of the disease, but they did not provide supporting evidence for this observation.

Poewe categorized fluctuations in motor performance in persons with advanced PD as being either predictable (ie, predictable “wearing-off” response) or random (ie, unpredictable “on-off” effects). No data were presented to support this impression. According to Poewe, approximately 15% of patients treated with L-dopa eventually develop random fluctuations in motor performance. He stated, “Without apparent relation to the timing of their individual L-dopa doses, these patients experience abrupt and frequent oscillations between mobile and dyskinetic states on the one hand and severe immobility on the other.” Unpredictable “freezing” also may occur. In my study, 4 of the 5 subjects demonstrated fluctuations in gait that I describe as random. For example, the minimum and maximum walking speeds of subject 1 were at 0% and 70% of the L-dopa cycle, respectively, on day 1 and at 70% and 20% of the L-dopa cycle, respectively, on day 2. Subject 3 demonstrated an abrupt change in walking status, from independent ambulation at 90% of the L-dopa cycle to complete immobility at 100% of the L-dopa cycle. Twenty minutes later, he was able to walk independently again. In contrast, subject 4 showed little variability over the course of the L-dopa cycle.

Findings similar to those of Morris et al. were reported by Bowes et al. who investigated spatiotemporal variables of gait in a group of 14 people without PD and without overt fluctuations in motor performance, comparing the sensitivity and specificity of these variables for the L-dopa treatment effect. After omission of a morning dose of L-dopa, baseline measurements of free-speed gait over a 6-m distance, mobility (ie, time taken to rise from a chair, walk an individually set distance, return, and sit), and manual dexterity (ie, a buttoning task) were taken. Assessments were then repeated 2, 4, and 6 hours after administration of L-dopa or a placebo. The tests of mobility and dexterity were not affected by the treatment effect (ie, a lack of sensitivity), but walking speed, SL, and double-limb support time during free-speed walking were affected. The extent of the treatment effect (eg, improvement in walking speed with L-dopa versus placebo) was inversely related to the concentration of L-dopa in the plasma. The authors postulated that this seemingly paradoxical loss of sensitivity may reflect reduced uptake of L-dopa from the plasma into the brain or an adverse effect of the drug or a metabolite.
3 were taking a controlled-release preparation (Sinemet CR), which is used to reduce motor fluctuations by providing a more stable and constant L-dopa plasma level. Koller and Pahwa noted that such preparations are more efficacious in patients who manifest mild to moderate disease with predictable "wearing-off" phenomena. The time of day was kept constant among subjects and test days. The degree of fatigue was monitored qualitatively but not quantitatively. The subjects did not report increased fatigue at the end of the testing sessions, and, in 4 of the 5 subjects, the walking speed at 100% of the L-dopa cycle was equal to or greater than their walking speed at 0% of the L-dopa cycle (even subject 2, who could not walk at 100% of the cycle, did not identify fatigue as the limiting factor). Physical and emotional stress and diet were not tracked over the course of the study. Dyskinesias were noted during the gait trials of subjects 1, 2, and 5.

The direct relationship between walking speed and SL and the inverse relationship between walking speed and ST observed in individuals without PD were also seen in subjects with PD. This finding supports a previous report that the relationships between kinematic variables of gait remain unchanged in persons with PD. Compared with data from a comparison group, a substantially slower walking speed (55% of normal), a shorter SL (63% of normal), and a somewhat longer ST (112% of normal) were observed for the subjects with PD. The observation that decreases in SL contributed substantially more to the below-normal walking speeds than did increases in ST is consistent with the finding that, in people without neurologic impairments, walking speed and SL decrease with age but ST does not change. The finding of an effect of height on walking speed and SL during free-speed gait has been reported for elderly individuals without neurologic impairments. The averages for gait measures in my study corroborate the findings of the studies by Blin et al and Morris et al. Although percentages of normal values for walking speed, SL, and ST were similar in the 3 studies, the absolute values for the same variables in the study by Blin et al were considerably different than those in my study and in the study by Morris et al. For example, the mean walking speed (averaged over all patients with PD) in the study by Blin et al was 44 cm/s, whereas the mean walking speed was 70.39 cm/s in my study and 79.79 cm/s in the study by Morris et al. The subjects in the study by Blin et al were comparable to the subjects in my study in terms of age and height, but they differed in terms of disease severity in that 7 subjects (33%) were in Hoehn and Yahr stage 4 of PD during the "on" cycle. This difference, together with the methodological difference (data from chart recorder traces measured by hand versus computerized resistive walkway) could well have contributed to the differences in the results.

Evans and colleagues investigated systematic and random error in spatiotemporal gait measurements taken on 3 consecutive days for 31 individuals with stroke (mean age of 69 years, mean of 46 days poststroke). They attributed variability in walking speed to variations in performance rather than to measurement error, and they contended that, although this error was small relative to individual differences in the subjects, it was large relative to the extent of change reported over the course of stroke rehabilitation. They recommended that the clinical relevance of potentially unstable measurements could be enhanced by conducting serial evaluations in order to examine variations within the trends of change over a longer time interval.

Limitations
The small sample size used in my study limits the generalizability of the findings. The study was designed to be exploratory in nature, prior to initiating a large-scale clinical trial. Direct comparison of the results with those of other investigations is hindered not only by the sample size but also by analytical differences. Another limitation is the potentially confounding effect of different interpretations to the verbal instruction "Walk down the walkway at your normal, comfortable walking speed." In an attempt to control for this effect, the investigator and the instructions remained constant throughout the study. Finally, it was not feasible, within the confines of this study, to control for all of the multiple factors mentioned (eg, emotional stress, dyskinesia, diet, changes in responsiveness to L-dopa) that can influence the extent of fluctuations in motor performance.

Conclusions
Lindsey contended that "a [PD] patient's response during a 10:00 AM therapy session may be very different than at a 2:00 PM treatment time." The findings of my study suggest that this observation could be extended to include "and the patient's gait profile on a given Tuesday may be very different from that on a Tuesday a month later." Fluctuations in spatiotemporal variables of patients with advanced PD may be extensive and may not follow a predictable pattern. Thus, caution must be exercised when interpreting the results of gait kinematic data from patients with PD, particularly if the disease is in an advanced stage. The conventional method of assessing gait as part of an overall 1-hour neurologic assessment is unlikely to yield data that are representative of the patient's performance over the course of the L-dopa cycle. To obtain a more valid representation and to ascertain the extent of variability in the gait profile, periodic assessment over the full L-dopa cycle is recommended, especially if the patient has long-standing PD and if these data are to be used to assess the effectiveness of intervention. The use of spatiotemporal gait charac-
teristics as robust outcome measures for the subgroup of
diseases. Appreciation is extended to the patients for their eager
behavioral, however, may also be subject to erratic fluctuations
over the course of the L-dopa cycle. Further research on this issue is warranted.

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References