Research Report

Performance on Clinical Tests of Balance in Parkinson's Disease

Background and Purpose. Due to the high incidence of falls in people with idiopathic Parkinson's disease (PD), the assessment of standing balance is a key component of physical therapist evaluation. This study investigated performance on clinical tests of standing balance in subjects with and without PD. **Subjects.** The subjects were 10 persons with PD who had a history of falls (age range=60–80 years), 10 persons with PD who had no history of falls (age range=63–79 years), and 10 persons with no known neurological impairment (age range=60–78 years) who served as a comparison group. **Methods.** Subjects were tested on their ability to maintain stability in 3 conditions: (1) steady standing (feet apart, feet together, tandem stance, step stance, and single-limb stance), (2) in response to perturbations generated by self-initiated movements (arm raise, functional reach, bend-reach, and step tests), and (3) in response to an external perturbation to upright stance (shoulder tug). Balance was measured at peak dosage in the levodopa medication cycle (in the morning) and 7 days later. **Results.** The mean Hoehn and Yahr Disability Scale score was 3.0 for the fallers with PD and 2.5 for the nonfallers with PD. Performance on the tandem stance, single-limb stance, functional reach, and shoulder tug tests demonstrated differences between the subjects with PD and the comparison group and between the fallers and nonfallers with PD. The results of these tests were highly repeatable over 7 days (ICC=.61–.94). **Conclusion and Discussion.** Although there was a small sample size, performance was highly consistent across 7 days when testing occurred during peak dosage of levodopa. A small battery of tests were sensitive enough to discriminate between people with PD who fall and those with no history of falls. [Smithson F, Morris ME, Iansek R. Performance on clinical tests of balance in Parkinson's disease. *Phys Ther.* 1998;78:577–592.]

Key Words: *Balance, Movement disorders, Parkinson's disease, Postural control.*

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Assessment of balance in standing is a key component of the physical therapist evaluation for people with idiopathic Parkinson's disease (PD). Due to depletion of dopamine-producing neurons in the basal ganglia of the brain, individuals with PD experience deterioration in balance and postural control as well as a progressive reduction in the speed and amplitude of movements (hypokinesia).[1,2] Together, these movement disorders predispose people with PD to slips, trips, and falls.[3,4] Balance assessment enables clinicians to determine the degree to which they need to address fall prevention. In this article, the term "balance" refers to the ability to maintain the body's center of mass over the base of support in order to retain stability.

A large range of clinical tests have been used by physical therapists to assess balance in elderly people and people with neurological disorders. These tests are summarized in Table 1. Five main groups of tests can be identified: (1) tests that measure the ability to maintain steady standing in a variety of foot positions[5–7]; (2) tests that measure the ability to maintain stability in standing while coping with perturbations to balance by self-initiated movements such as arm raises, lifting a foot up and down onto a step, or reaching forward[8–11]; (3) tests of postural responses to an unexpected external perturbation such as a push or pull[12–16]; (4) functional tests of balance during activities such as walking, standing up, and turning[17–21]; and (5) tests of the ability to integrate visual, somatosensory, proprioceptive, and vestibular input in order to maintain stability in standing.[22–24] Many of these tests correlate with frequency of falls in elderly people.[8–14,17–19,25]

Although physical therapists routinely use the tests outlined in Table 1 to assess balance in people with neurological conditions, it remains unclear which tests are most useful for delineating performance in people with PD from performance in people without PD and which tests are most useful for discriminating between people with a history of falls and people with no history of falls. Because the entire battery of tests is too extensive to administer to any single individual, there is a need to identify a small subgroup of tests that fulfill this need.

The motor functions of the basal ganglia provide a helpful guide to the clinical tests that are most likely to be useful in the evaluation of people with PD. The basal ganglia have 2 major roles in motor control. The first role is to maintain the activity of set-related neurons in the motor cortex in a state of readiness for action.[26] This preparation enables postural muscles to be recruited in a feedforward manner so that when movement occurs, the person can maintain his or her center of mass over the base of support. The second role of the basal ganglia is to provide phasic internal cues that activate submovements in long movement sequences with appropriate timing.[26] The disorders of balance and postural control observed in people with PD appear to be mainly related to defective set-related activity, which in turn disrupts anticipatory postural adjustments, allowing postural muscles to be recruited with adequate response amplitude.[27,28] Although the sequencing of activation in lower-limb and trunk muscles in response to unexpected perturbations appears to remain intact, the timing of muscle activation is slower than usual and the size of movement responses is diminished.[29,30] Individuals with PD, however, can enhance set-related activity by deliberately focusing their attention on the task,[31] thereby using frontal cortical regions of the brain to override defective basal ganglia circuitry.[32]

People with PD are likely to have difficulty responding to unexpected perturbations to their body's center of mass. Conversely, they should be able to maintain a range of steady stance postures to the same extent as age-matched individuals without PD because they presum-

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This study was conducted in partial fulfillment of the requirements for Ms Smithson's postgraduate diploma at the School of Physiotherapy, La Trobe University.

This study was approved by the Kingston Centre Ethics Committee.

This study was supported by Grant No. 971268 from the National Health and Medical Research Council (NHMRC) of Australia.

This article was submitted March 7, 1997, and was accepted December 17, 1997.

ably can use attentional processes to override the defective contribution from the basal ganglia. Responses on tests of self-initiated movement should not be different from normal responses, provided that (1) such tests allow people with PD to focus their attention on the task and (2) the tests do not have a timing component that could be influenced by the effects of parkinsonian hypokinesia. In examples such as the step test, in which subjects are scored on the number of times they lift their foot onto a step in 15 seconds, it seems likely that performance would be slower than usual due to hypokinesia.

Previous research provides some support for these predictions. Although investigators have not yet evaluated the ability of people with PD to maintain standing postures, laboratory studies on anticipatory postural adjustments confirm that people with PD usually respond well to self-induced perturbations to their balance, provided they have time to prepare.[33–35] Experiments by Traub et al[36] have shown that anticipatory postural responses induced by an unexpected external perturbation of a hand-held lever system are reduced or absent in people with PD.

In deciding whether a particular balance test is useful for people with PD, therapists should have information on whether the results can be used to discriminate between people with PD who have a history of falls and people with PD who have no history of falls. There have been no systematic attempts to document the results of clinical tests of balance in relation to history of falls in people with PD, even though this knowledge might be useful in early detection of patients at risk of injury. Therapists also need to know whether performance on a test is repeatable over time. Although interobserver and retest reliability of measurements of balance and postural control have been reported for elderly people with no known neurological impairment and for patients with stroke,[7,17,20,37,38] reliability remains undocumented for measurements from persons with PD. Clinicians need this information so that they can make judgments about the relative contributions of measurement error, patient variability, and treatment to changes in performance over time. Recent research on gait disorders has shown that the footstep pattern in people with PD remains stable, provided that they are tested at peak dosage during the medication cycle.[39,40] Whether this finding applies to performance on clinical tests of balance in people with PD remains open to question.

The main purpose of our investigation was to identify clinically useful tests of balance for people with PD by systematically evaluating performance in (1) steady standing, (2) response to self-initiated perturbations to the body's center of mass, and (3) response to unexpected perturbations to the body's center of mass. The results from subjects with PD who had a history of falls, subjects with PD who had no history of falls, and age-matched comparison subjects were compared. Because physical therapists routinely reassess patients at weekly intervals, the repeatability of performance over 7 days was examined to gain some insights into retest reliability of measurements obtained with the tests, coupled with intrasubject variability. Based on the role of the basal ganglia in regulating feedforward postural control, we predicted that tests of unexpected external perturbations would best discriminate among subjects with PD who had a history of falls, subjects with PD who had no history of falls, and comparison subjects. We also predicted that subjects with PD and comparison subjects would show similar performance on tests of steady standing and ability to respond to internal perturbations to the center of mass, provided that these tests allowed subjects to focus their attention on the task and did not have an inherent requirement for the performance of fast, repetitive movement. Finally, we predicted that performance would remain stable over a 7-day period

Table 1.
Clinical Tests of Balance Used by Physical Therapists

Classification	Test
Steady standing	Feet apart[5,7] Feet together[5,7] Stride stance[7,14] Tandem stance[7] Single-limb stance[5,6] Romberg Test[25,a]
Perturbation of standing balance by self-initiated movements	Arm raises[7] Step test[10,a] Functional reach[8,9,11,a]
Response to externally generated perturbations	Sternal push[16] Postural stress[12–14,a] Pastor, Marsden, and Day Test[15]
Ability to maintain balance during functional tasks	Berg Balance Scale[17,a] "Get up and go" test[19,a] Gait[20,21] Tinetti Mobility Index[18,a] Subcomponents of functional assessment scales such as Barthel Index, Functional Independence Measure, and Webster Scale[45,b,c]
Ability to integrate sensory information to maintain stability	Sensory organization[22–24]

[a] Tests shown to correlate with the frequency of falls in elderly people (age range=60–104 years).
[b] Wade DT, Collin C. The Barthel ADL index: a standard measure of physical disability? *International Disability Studies.* 1988;10:64–67.
[c] Granger CV, Hamilton BB, Sherwin FS. *Guide for the Use of the Uniform Data Set for Medical Rehabilitation.* Buffalo, NY: Uniform Data System for Medical Rehabilitation Project Office, Buffalo General Hospital; 1986.

Table 2.
Characteristics of Subjects With Parkinson's Disease (PD) Who Had a History of Falls

Subject No.	Age (y)	Sex	Height (m)	Weight (kg)	Webster Scale[43] Score	Duration of PD (y)	Medication	Dosage (mg/d)
1	65	F	1.54	43.0	10	9	Sinemet Sinemet CR Eldepryl Amantadine	100/25 900/225 10 100
2	66	M	1.65	58.4	8	12	Sinemet Sinemet CR	500/125 100/25
3	69	F	1.52	59.6	17	15	Sinemet Sinemet CR	100/25 800/200
4	75	F	1.52	68.8	13	15	Madopar 200 Sinemet CR Eldepryl	150/37.5 1,000/250 5
5	60	F	1.56	68.4	18	15	Sinemet Sinemet CR Selegiline Motilium	300/75 200/50 10 60
6	73	M	1.73	60.8	6	5	Sinemet	800/200
7	80	M	1.60	59.8	9	15	Sinemet Symmetrel	800/200 200
8	78	M	1.68	83.2	8	3	Sinemet Motilium	800/200 40
9	74	M	1.67	73.4	12	13	Madopar 200 Motilium Sinemet CR	1,250/312.5 60 400/100
10	66	F	1.56	57.0	10	13	Madopar 200	750/187.5

when subjects with PD were tested at the peak dosage during the medication cycle.

Method

Subjects

A total of 30 elderly subjects were recruited for the study. Ten subjects with idiopathic PD and a history of falls and 10 subjects with idiopathic PD without a history of falls were recruited from the Kingston Centre Movement Disorders Clinic (Cheltenham, Victoria, Australia). Ten age-matched subjects were recruited from the Volunteer Services Unit of Kingston Centre to serve as a comparison group. Tables 2 through 4 provide a summary of the characteristics of the subjects. A *fall* was defined as a disturbance to the body's center of mass that resulted in the person involuntarily coming to the ground. A *faller* was defined as a person who had experienced 2 or more falls in the 12-month period immediately prior to the study. A history of falls was obtained by a self-report from each subject with PD and was verified by an interview with his or her caregiver.

To be included in this study, subjects were required to be between 50 and 85 years of age, medically stable, able to walk a 14-m distance at least 3 times without assistive devices or assistance from another person, and able to provide informed consent according to the Declaration of Helsinki (1964). Subjects were excluded if they had neurological conditions other than idiopathic PD as determined by a neurologist, scored greater than 3 on the Hoehn and Yahr Disability Scale,[41] scored less than 20 on the Short Test of Mental Status,[42] or were taking tranquilizers. Subjects were excluded if they scored higher than 20 on the Webster Scale,[43] which measures functional disability in relation to gait, tremor, balance, rigidity, hypokinesia, seborrhea, facial expression, and speech. Subjects were not included if they exhibited postural hypotension, visual disturbance, or vestibular dysfunction affecting balance, as screened by a neurologist (RI); cardiovascular disorders affecting locomotion; or musculoskeletal disorders, including lower-limb fractures or osteoarthritis, limiting locomotion or balance. Subjects with severe lower-limb dyskinesia, as determined by a neurologist (RI), were not included.

All subjects with PD were tested in the mornings during the "on" phase of the medication cycle, which was at least 60 minutes after ingesting medication and when they were moving freely and easily without dystonia, excessive rigidity, or tremor. Subjects with PD with a history of falls were tested an average of 87 minutes after their medica-

Table 3.
Characteristics of Subjects With Parkinson's Disease (PD) Who Did Not Have a History of Falls

Subject No.	Age (y)	Sex	Height (m)	Weight (kg)	Webster Scale[43] Score	Duration of PD (y)	Medication	Dosage (mg/d)
1	72	F	1.64	62.8	4	2	Sinemet	600/150
2	63	M	1.79	89.8	5	10	Sinemet CR Sinemet Disipal	1,100/275 50/12.5 100
3	70	F	1.54	71.4	3	4	Madopar 200	600/150
4	79	F	1.60	60.0	6	2	Kinson 200	1,500/375
5	64	F	1.54	60.8	13	17	Madopar HBS Sinemet 100 Motilium Cogentin	500/125 50/25 10 0.5
6	78	M	1.73	79.6	3	4	Madopar Motilium	800/200 40
7	76	M	1.64	70.4	6	9	Sinemet Madopar HBS Pergolide	800/200 400/100 2
8	65	M	1.74	95.4	6	1	Madopar Q Madopar HBS Eldepryl	400/100 200/50 10
9	70	M	1.71	67.0	5	1	Madopar 200 Madopar HBS	600/150 200/50
10	71	F	1.62	60.4	13	15	Sinemet 100 Motilium Cogentin	450/12.5 30 3

Table 4.
Characteristics of Elderly Subjects With No Known Neurological Impairment (Comparison Group)

Subject No.	Age (y)	Sex	Height (m)	Weight (kg)
1	73	M	1.79	86.0
2	66	M	1.59	67.6
3	78	M	1.69	65.8
4	75	M	1.73	92.8
5	68	F	1.56	67.2
6	76	F	1.46	47.4
7	60	F	1.56	64.2
8	78	M	1.75	76.6
9	67	F	1.60	72.8
10	65	F	1.57	74.4

tion and subjects with PD without a history of falls were tested an average of 103 minutes after their medication. The types and dosages of PD medications are summarized in Tables 2 and 3.

In the sample, the mean age was 70.6 years (SD=6.4, range=60–80) for subjects with PD who had a history of falls, 70.8 years (SD=5.7, range=63–79) for subjects with PD who had no history of falls, and 70.6 years (SD=6.2, range=60–78) for comparison subjects. The mean duration of PD was 11.6 years (SD=4.3, range=3–15) for subjects with PD who had a history of falls and 6.9 years (SD=5.6, range=1–13) for subjects with PD who had no history of falls. The mean Webster Scale[43] scores for subjects with PD who had a history of falls were 11.1 (SD=3.9, range=6–18) for test 1 and 10.1 (SD=2.9, range=6–16) for test 2. For subjects with PD who had no history of falls, the mean Webster Scale scores were 6.4 (SD=3.7, range=3–13) for test 1 and 6.3 (SD=4.0, range=1–14) for test 2. There were no differences in Webster Scale scores from one week to the next. The mean Hoehn and Yahr Disability Scale[41] scores were 3.0 for the fallers with PD and 2.5 for the nonfallers with PD.

Missing Data

There was one missing data point in this investigation. Subject 5 of the comparison group was unable to carry out the bend-reach test during test 2 due to subacute back pain.

Apparatus

Tests in steady stance were measured using a commercially available stopwatch (Micronta Sports Timer*), which recorded time in seconds with an accuracy of 2 decimal places. In order to standardize the foot place-

* Tandy Electronics, 91 Kurrajong Ave, Mt Druitt, New South Wales, Australia 2770.

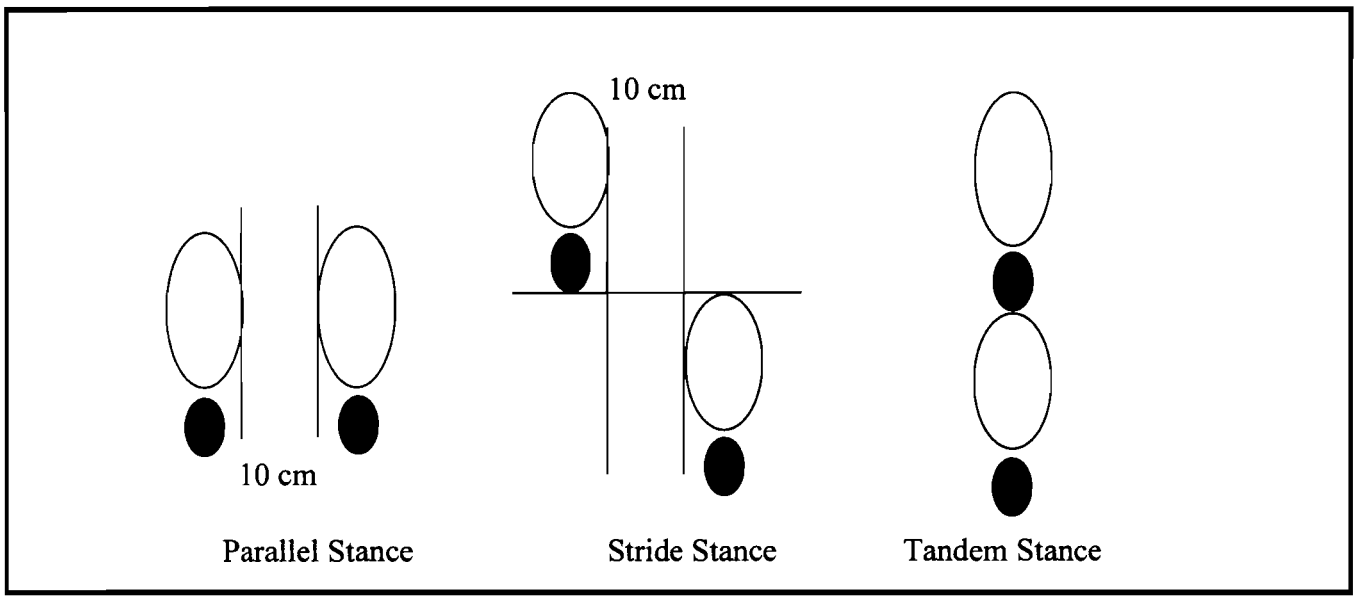

Figure 1.
Alignment of feet for parallel, stride, and tandem stance positions. [Adapted from Goldie et al.[7]]

ment, footprint images for aligning the feet in parallel, step, and tandem stance were marked on the floor using removable colored contact footprint images. The rationale for having subjects assume a standardized foot position was to reduce errors in measurement arising from deviations from the initial stance position. In addition, previous research[44] has shown that foot position, including the foot angle, influences standing balance.

Tests of self-generated perturbations were measured using the stopwatch, a tape measure, and a portable step measuring 150 mm high, 290 mm wide, and 600 mm long. Commercially available plastic pegs, which were set at 5-cm intervals along a line, were used for the bend-reach test. The response to an external perturbation was rated by the examiner (WT) on a 5-point scale according to the protocol for the shoulder tug test described by Pastor et al.[15]

A screened area within a large isolated room (20 × 10 m) was used for all data collection. Testing in this quiet area had the benefit of minimizing background noise, distractions, and interruptions.

Procedure

Prior to testing, the purpose of the study was explained to the subjects, and informed consent, which outlined the rights of the subjects, was obtained. Height and weight were measured, and subjects were scored on the Webster Scale[43] by a trained physical therapist (WT). Each of the balance tests was administered by the same physical therapist, who was blind to the aims and design of the study. To control for series effects, half of the subjects in each group performed the tests first in steady standing, second in response to perturbations generated by self-initiated movements, and finally in response to an external perturbation. The other half of the subjects performed the tests in the reverse order. One week later at the same time of day and at the same point in the levodopa medication cycle, the procedure was repeated.

Balance in Steady Standing

The ability to maintain various stance positions with eyes open and without hand support was recorded for each subject. The stance positions were (1) feet 10 cm apart, as specified in the protocol described by Goldie et al[7]; (2) feet together; (3) stride stance, with the subject's feet placed 10 cm apart and with the heel of the front foot in line with the toes of the rear foot, as described by Goldie et al[7]; (4) tandem stance, in which the subject stood with one foot directly in front of the other foot and with the toes of the rear foot contacting the heel of the front foot; and (5) single-limb stance, in which the subject stood on one foot with the opposite knee held at 45 degrees of flexion and both hips in the anatomical position.

Subjects stood on the footprint templates during feet apart, stride stance, and tandem stance conditions (Fig. 1). Stride stance and tandem stance were tested with each of the feet in the front position. Single-limb stance duration was also recorded for both feet. The tests were concluded if subjects changed their stance position, if the examiner was required to provide external support, or if the subjects maintained the position for the maximum testing period of 30 seconds. In an effort to control for the effect of fatigue and other variables, the best of 3 scores was recorded if all scores were less

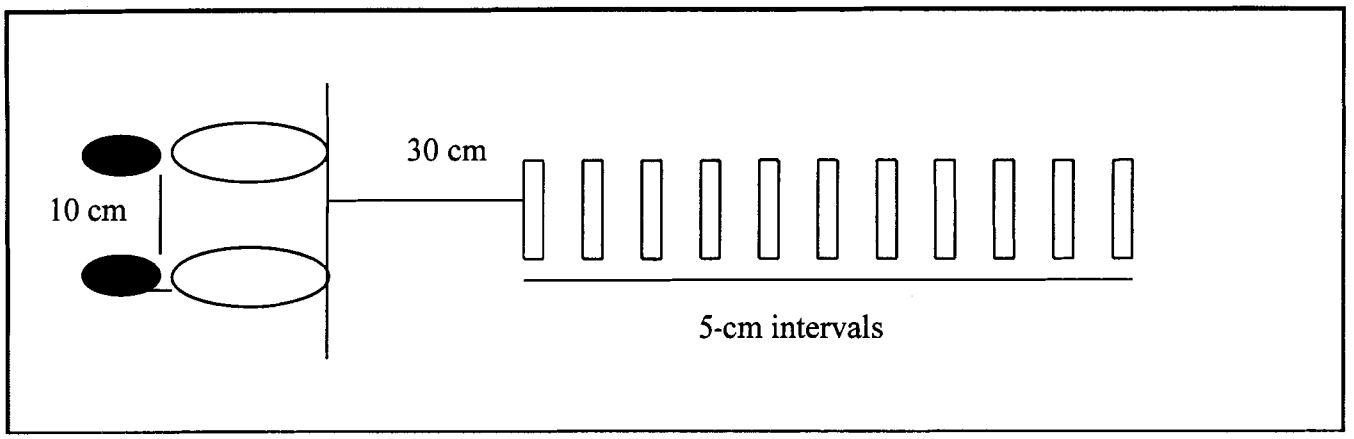

Figure 2.
Position of feet and pegs for bend-reach test.

than 10 seconds. If the score exceeded 10 seconds in any trial, that time was recorded without further trials.

Perturbation of Standing Balance by Self-Initiated Movements

Functional reach test. The maximal distance each subject was able to reach while maintaining a fixed base of support in standing was measured following the procedure described by Duncan et al.[9] The subjects were required to stand with their right side close to, but not touching, a wall and with their feet set 10 cm apart. The subjects were asked to raise their right arm to 90 degrees with the hand outstretched, and the position of the third digit was recorded on the wall with removable adhesive tape (position 1). The subjects then reached as far forward as they could without moving their feet, and the position of the third digit was recorded with another strip of tape (position 2). The difference between positions 1 and 2 was then recorded using a tape measure. To minimize fatigue and the duration of testing, only one trial of the functional reach test was performed.

Bend-reach test. This new test, which has not been validated previously, was included because of our observations that patients with PD had difficulty retrieving objects from the floor, apparently due to balance disorders. The examiner measured the maximal distance that each subject could bend and reach to pick up an object from the floor. Target objects (plastic pegs) were placed at 5-cm intervals in a straight line from the footprint templates described earlier (Fig. 2). The maximum distance that the subject could successfully reach to retrieve a peg without touching down on the floor with the hands, requiring external support from the examiner to steady the subject, or changing foot position was recorded for one trial.

Arm raise test. The arm raise test was performed as described by Goldie et al.[7] Subjects were required to stand with their feet placed 10 cm apart and were instructed to "lift your arm up and down to shoulder height as many times as you can in 15 seconds when I say go." The tester passively moved each subject's arm up to 90 degrees of flexion and down again twice in order to demonstrate the desired action. Performances for one trial of the right and left arms were then recorded.

Step test. The step test was administered following the procedure described by Hill et al.[10] Subjects stood with their feet 10 cm apart, with a 15-cm-high step positioned 5 cm in front of their toes. The tester delivered the following instructions: "When I say go, step your foot onto then off the step as many times as you can until I say stop. Make sure that all of your foot contacts the step each time." The number of times the subjects successfully placed the foot onto the step in 15 seconds was then recorded. This procedure was completed for both feet.

Balance in Response to an Externally Generated Perturbation

The external perturbation test (shoulder tug) was administered according to the protocol described by Pastor et al.[15] Subjects were positioned in steady stance with their feet 10 cm apart. The examiner stood directly behind each subject and delivered the instructions: "I am going to tap you off balance, and I won't let you fall." Information about the direction and timing of the perturbation was not provided. The examiner then delivered a brief and quick tug to the subject's shoulders in a posterior direction with sufficient force to destabilize the subject. The destabilizing force was determined by the examiner, who was blind to the subject's group, based on the mass of each subject.

Postural reactions in response to the external perturbation were scored by the examiner using the 5-point clinical rating scale described by Pastor et al[15]:

1. Subject stays upright without taking a step.
2. Subject takes one step backward but remains steady.
3. Subject takes more than one step backward but remains steady.
4. Subject takes one or more steps backward, followed by the need to be caught.
5. Subject falls backward without attempting to step.

Data Analysis

Intraclass correlation coefficients (ICC[2,1]) were used to analyze the repeatability of the measurements from one week to the next.[45] Correlation coefficients for the external perturbation test, which was measured on a 5-point ordinal scale, were calculated using Spearman's rho.[46] Systematic trends in the data were examined by calculating the mean change ($\bar{D}$) over the 2 tests for each of the variables. Paired t tests were used to determine whether systematic change occurred. Variable change was estimated by obtaining the standard deviation of the change scores (SD_{diff}) and the 95% confidence interval (CI) for individual change scores using the following equation:

$$95\%CI = \bar{D} \pm Z_{\alpha} \times SD_{diff}$$

where $Z_{\alpha} = 1.96$.

To determine whether differences existed among the 3 groups on tests of balance over the 2 measurement sessions, 2-factor (group, test) repeated-measures analyses of variance (ANOVAs) were used.[46] To control for the accumulation of error due to multiple statistical tests, the probability values were adjusted according to the procedure recommended by Bonferroni.[46] The Scheffé F test was then used to determine whether differences from test 1 to test 2 existed between fallers and nonfallers with PD, between fallers with PD and comparison subjects, and between nonfallers with PD and comparison subjects. The external perturbation test was analyzed using a Kruskal-Wallis H test,[47] which is a nonparametric statistical procedure used to compare 3 or more independent groups. The H test is analogous to the ANOVA used for parametric data.[47]

Results

Repeatability of Performance Over a 7-Day Period

Tables 5 through 7 show the means and standard deviations for the 3 groups for the 2 testing occasions.

Table 5.
Means and Standard Deviations for Test 1 and Test 2 Scores for Subjects With Parkinson's Disease Who Had a History of Falls (n=10)

	Test 1		Test 2	
Condition	$\bar{X}$	**SD**	$\bar{X}$	**SD**
Steady standing (s)				
Feet apart	29.47	1.69	30.00	0.00
Feet together	29.18	2.59	29.74	0.84
Stride stance (R)	28.31	5.34	29.02	2.68
Stride stance (L)	28.17	5.78	29.43	1.80
Tandem stance (R)	15.64	13.90	11.45	9.96
Tandem stance (L)	12.27	12.63	8.22	9.52
Single-limb stance (R)	9.53	10.06	7.75	9.68
Single-limb stance (L)	9.26	10.07	8.59	9.53
Internal perturbation				
Functional reach (cm)	24.45	5.93	24.10	6.41
Bend-reach (cm)	64.00	8.76	65.00	9.13
Arm raises (R)[a]	11.00	2.21	12.60	2.17
Arm raises (L)[a]	10.60	1.90	12.50	1.72
Step (R)[a]	9.20	3.55	10.60	3.84
Step (L)[a]	9.70	3.53	9.80	3.80
External perturbation	3.00	1.16	3.10	1.20

[a] Frequency over 15 seconds.

Table 6.
Means and Standard Deviations for Test 1 and Test 2 Scores for Subjects With Parkinson's Disease Who Did Not Have a History of Falls (n=10)

	Test 1		Test 2	
Condition	$\bar{X}$	**SD**	$\bar{X}$	**SD**
Steady standing (s)				
Feet apart	30.00	0.00	30.00	0.00
Feet together	30.00	0.00	30.00	0.00
Stride stance (R)	30.00	0.00	30.00	0.00
Stride stance (L)	30.00	0.00	30.00	0.00
Tandem stance (R)	21.50	8.11	25.01	7.02
Tandem stance (L)	22.12	7.76	23.04	8.85
Single-limb stance (R)	17.56	8.92	15.35	7.19
Single-limb stance (L)	14.53	8.18	15.57	8.21
Internal perturbation				
Functional reach (cm)	29.95	3.82	31.95	5.64
Bend-reach (cm)	65.00	3.33	64.00	3.94
Arm raises (R)[a]	13.00	2.54	13.30	2.58
Arm raises (L)[a]	12.80	2.53	13.40	2.41
Step (R)[a]	12.10	2.60	13.50	3.17
Step (L)[a]	12.20	2.86	12.50	2.55
External perturbation	2.00	1.41	2.10	1.45

[a] Frequency over 15 seconds.

Tables 8 through 10 present the means and standard deviations for the change scores from test 1 to test 2, the 95% CI around the change scores, t values, and correlation coefficients. On the whole, the results showed consistency of performance over the 7-day testing period. Inspection of the means, standard deviations, and raw scores for the tests of feet apart, feet together,

Table 7.
Means and Standard Deviations for Test 1 and Test 2 Scores for Elderly Subjects With No Known Neurological Impairment (Comparison Group) (n=10)

Condition	Test 1		Test 2	
	$\bar{X}$	SD	$\bar{X}$	SD
Steady standing (s)				
Feet apart	30.00	0.00	30.00	0.00
Feet together	30.00	0.00	30.00	0.00
Stride stance (R)	30.00	0.00	30.00	0.00
Stride stance (L)	30.00	0.00	30.00	0.00
Tandem stance (R)	28.67	4.22	30.00	0.00
Tandem stance (L)	26.53	7.33	28.74	3.98
Single-limb stance (R)	20.45	10.36	22.28	10.96
Single-limb stance (L)	21.27	11.85	21.60	10.35
Internal perturbation				
Functional reach (cm)	34.20	4.12	35.05	3.60
Bend-reach (cm)	66.00	8.76	67.79	7.55
Arm raises (R)[a]	13.90	3.73	14.70	2.50
Arm raises (L)[a]	13.90	3.45	14.90	2.56
Step (R)[a]	13.90	4.12	15.20	3.88
Step (L)[a]	13.50	4.22	15.30	4.45
External perturbation	1.50	0.71	1.30	0.48

[a] Frequency over 15 seconds.

and stride stance for each group and for the test of tandem stance on the right lower extremity for the control group, however, indicated attenuation of the data due to ceiling effects. That is, the majority of the subjects were able to maintain steady stance during the tests for the maximum testing period of 30 seconds. We therefore considered it inappropriate to calculate further correlation statistics for these particular results due to the lack of variability within and between subjects.[46]

Repeatability of performance in subjects with PD who had a history of falls. The results for the subjects with PD who had a history of falls indicated strong temporal stability for repeated measurements for the tandem stance, single-limb stance, functional reach, bend-reach, step, and external perturbation tests, with ICCs ranging from .71 to .93. The correlation for the external perturbation test was also strong (r=.99). There was poor to moderate repeatability for the arm raise test (ICC=.07–.51).

For the majority of the tests, there were no differences between repeated measurements from one week to the next. The exceptions were the step test on the right lower extremity (t_9=−2.585, P=.030), the right arm raise test (t_9=−2.667, P=.026), and the left arm raise test (t_9=−2.487, P=.035). As shown in Table 8, the standard deviations for the change scores were large for some conditions, notably the bend-reach, tandem stance, stride stance, and single-limb stance tests.

Repeatability of performance in subjects with PD who had no history of falls. The results for the subjects with PD who had no history of falls indicated strong temporal stability for the arm raise, step, and external perturbation tests, with ICCs ranging from .73 to .86. The product-moment correlation for the external perturbation test was also high (r=.97). There was moderate temporal stability for the right tandem stance, right and left single-limb stance, and right arm raise tests, with ICCs ranging from .50 to .66. For the left tandem stance, functional reach, and bend-reach tests, the ICCs ranged from .40 to .43. Paired t tests showed no statistically significant differences from one week to the next for any of these variables, except for the right step test (t_9=−2.409, P=.039).

Repeatability of performance in comparison subjects. The results for the comparison subjects showed strong temporal stability for the single-limb, bend-reach, step, and right arm raise tests (Tab. 10). Intraclass correlation coefficients for these variables ranged from .77 to .89. There were moderate correlations between test 1 and test 2 scores for the remaining tests, with ICCs ranging from .51 to .65. The correlation between test 1 and test 2 for the external perturbation test was high (r=.96). For the comparison group, there were no differences between repeated measurements for any of the variables.

Between-Group Differences in Test Performance

Steady standing tests. The results indicated little difference among groups for many of the steady standing tests. All of the comparison subjects and subjects with PD who had no history of falls were able to maintain the steady stance position with feet apart, with feet together, and in stride stance for the maximum testing period of 30 seconds. The majority of the subjects with PD who had a history of falls could also maintain steady standing in these positions for periods close to the maximum testing time. In contrast, the results for the tandem stance and single limb stance tests revealed differences among groups. Two-factor repeated-measures ANOVAs showed significant main effects for right tandem stance (F=10.2; df=2,27; P=.0005), left tandem stance (F=13.14; df=2,27; P=.0001), right single-limb stance (F=4.84; df=2,27; P=.016), and left single-limb stance (F=4.61; df=2,27; P=.02). These results were attributable to superior performance in the comparison subjects compared with the subjects with PD who had a history of falls, as indicated by Scheffé F tests during test 1 for right tandem stance (F=4.36; df=2,27; P<.05), left tandem stance (F=5.58; df=2,27; P<.05), and left single-limb stance (F=3.5; df=2,27; P<.05) and during test 2 for right single-limb stance (F=4.6; df=2,27; P<.05). There were no differences between the comparison subjects and the subjects with

Table 8.
Means and Standard Deviations of Change Scores ($\bar{D}$) (in Seconds), 95% Confidence Intervals (CI), *t* Values, and Correlation Coefficients for Repeated Measurements Taken at 1-Week Intervals for Subjects With Parkinson's Disease Who Had a History of Falls (n=10)

Condition	$\bar{D}$	SD_{diff}	Lower 95% CI	Upper 95% CI	*t*	Product-Moment Correlation (Test 1-Test 2)	ICC (2,1) (Test 1-Test 2)
Steady standing (s)							
Feet apart	0.53	1.69	−2.78	3.84	. . .[b]	. . .	. . .
Feet together	0.55	2.81	−4.95	6.10	. . .	. . .	. . .
Stride stance (R)	0.71	6.28	−11.60	13.02	. . .	. . .	. . .
Stride stance (L)	1.26	6.25	−10.99	13.51	. . .	. . .	. . .
Tandem stance (R)	−4.19	7.30	−18.50	10.13	1.81	.86	.76
Tandem stance (L)	−4.05	8.10	−19.92	11.83	1.58	.77	.71
Single-limb stance (R)	−1.78	3.15	−7.95	4.40	1.78	.95	.94
Single-limb stance (L)	−0.67	5.51	−11.47	10.13	0.39	.84	.85
Internal perturbation							
Functional reach (cm)	−0.35	2.45	−5.15	4.45	0.45	.92	.93
Bend-reach (cm)	1.00	5.16	−9.12	11.12	−0.61	.83	.84
Arm raises (R)[a]	1.60	1.90	−2.12	5.32	−2.67[c]	.63	.51
Arm raises (L)[a]	1.90	2.42	−2.85	6.65	−2.48[c]	.10	.07
Step (R)[a]	1.40	1.71	−1.96	4.76	−2.59[c]	.90	.84
Step (L)[a]	0.10	2.18	−4.18	4.38	−0.15	.83	.83
External perturbation	0.10	0.32	−0.52	0.72	−1.00[d]	.99[e]	

[a] Frequency over 15 seconds.
[b] Ellipsis denotes an indeterminate value.
[c] $P<.05$.
[d] Wilcoxon signed rank, $P=.3173$.
[e] Spearman's rho.

PD who had no history of falls, even though the subjects with PD who had no history of falls consistently scored lower for these variables (Fig. 3).

Perturbation of standing balance by self-initiated movements. Tables 5 through 7 show the means and standard deviations for the self-initiated perturbation tests. The means and standard deviations for test 1 are illustrated in Figures 4 and 5. These results indicate considerable difference among groups for the functional reach and step tests, little difference among groups for the bend-reach test, and equivocal results for the arm raise test.

For the functional reach test, a 2-factor repeated-measures ANOVA revealed a significant main effect ($F=12.65$; $df=2,27$; $P=.0001$), with *post hoc* Scheffé F tests for test 1 showing differences between the subjects with PD who had a history of falls and the subjects with PD who had no history of falls ($F=3.4$; $df=2,27$; $P<.05$) and between the subjects with PD who had a history of falls and the comparison subjects ($F=10.69$; $df=2,27$; $P<.05$). For test 2, there were differences between the subjects with PD who had a history of falls and the subjects with PD who had no history of falls ($F=5.38$; $df=2,27$; $P<.05$) and between the subjects with PD who had a history of falls and the comparison subjects ($F=10.47$; $df=2,27$; $P<.05$). These results indicate that the functional reach test discriminated well among all groups.

The bend-reach test failed to show differences among groups for any of the statistical tests.

For the right arm raise test, there were no differences among groups for any of the statistical analyses. For the left arm raise test, however, a 2-factor repeated-measures ANOVA showed a significant main effect ($F=4.2$; $df=2,27$; $P=.03$), with a Scheffé F test indicating that test 1 performance was superior in the comparison subjects, who had a mean score of 13.9 (SD=3.5) arm raises in 15 seconds, compared with a mean score of 10.6 (SD=1.9) arm raises for the subjects with PD who had a history of falls ($F=3.73$; $df=2,27$; $P<.05$).

For the step test, a 2-factor repeated-measures ANOVA showed significant main effects for both the right side ($F=4.74$; $df=2,27$; $P=.017$) and the left side ($F=4.68$; $df=2,27$; $P=.018$). These findings were due to higher scores for the comparison subjects compared with the subjects with PD who had a history of falls during test 1 for the right side ($F=4.55$; $df=2,27$; $P<.05$) and during test 2 for both the right side ($F=3.98$; $df=2,27$; $P<.05$) and the left side ($F=5.88$; $df=2,27$; $P<.05$). There were

Table 9.
Means and Standard Deviations of Change Scores ($\bar{D}$) (in Seconds), 95% Confidence Intervals (CI), *t* Values, and Correlation Coefficients for Repeated Measurements Taken at 1-Week Intervals for Subjects With Parkinson's Disease Who Did Not Have a History of Falls (n=10)

Condition	$\bar{D}$	SD_{diff}	Lower 95% CI	Upper 95% CI	*t*	Product-Moment Correlation (Test 1-Test 2)	ICC (2,1) (Test 1-Test 2)
Steady standing (s)							
Feet apart	0	0	0	0	. . .[b]	. . .	. . .
Feet together	0	0	0	0	. . .	. . .	. . .
Stride stance (R)	0	0	0	0	. . .	. . .	. . .
Stride stance (L)	0	0	0	0	. . .	. . .	. . .
Tandem stance (R)	3.51	5.77	−7.80	14.82	−1.92	.72	.66
Tandem stance (L)	0.92	9.29	−17.29	19.13	−0.31	.38	.40
Single-limb stance (R)	−2.21	6.67	−15.28	10.86	1.05	.68	.66
Single-limb stance (L)	1.04	8.35	−15.33	17.41	−0.40	.48	.50
Internal perturbation							
Functional reach (cm)	2.00	5.13	−8.06	12.06	−1.23	.47	.42
Bend-reach (cm)	−1.00	3.94	−8.73	6.73	0.80	.42	.43
Arm raises (R)[a]	0.30	2.31	−4.23	4.83	−0.41	.59	.61
Arm raises (L)[a]	0.60	1.65	−2.63	3.83	−1.15	.78	.77
Step (R)[a]	1.40	1.84	−2.20	5.00	−2.41[c]	.82	.73
Step (L)[a]	0.30	1.49	−2.63	3.23	−0.64	.85	.86
External perturbation	0.10	0.74	−1.35	1.55	−0.45[d]	0.97[e]	

[a] Frequency over 15 seconds.
[b] Ellipsis denotes an indeterminate value.
[c] $P<.05$.
[d] Wilcoxon signed rank, $P=.6547$.
[e] Spearman's rho.

no differences in performance on the step test between the subjects with PD who had no history of falls and the comparison subjects.

Response to externally induced perturbations. Tables 5 through 7 and Figure 6 indicate that the external perturbation test discriminated among groups on both testing occasions. Kruskal-Wallis tests (corrected for ties) showed differences among groups for test 1 (H (2)=7.5, $P=.024$) and for test 2 (H (2)=9.47, $P=.009$).

Discussion

Repeatability of Test Performance

Our investigation represents the first systematic evaluation of performance on clinical tests of balance in people with idiopathic PD with and without a history of falls. Numerous findings emerged that are relevant to clinical practice. The most notable finding was that most tests demonstrated high repeatability over a 7-day period. The exceptions were the right arm raise test for the subjects with PD with and without a history of falls, the left arm test for the comparison subjects, and the left tandem stance, left single limb stance, bend-reach, and functional reach tests for the subjects with PD who had no history of falls.

The arm raise test was the only test that demonstrated low to moderate repeatability in all 3 groups. Potential sources of error in clinical administration of the arm raise test could have arisen from variability in the examiner's instructions and observations, distractions in the testing environment, and subject-related factors such as soft tissue changes at the shoulder, adherence, attention, fatigue, and alterations in levodopa status. Some of the subjects reported difficulty estimating and reproducing the 90-degree shoulder flexion angle. Reliability could have been enhanced by placing a mark on the wall indicating the criterion shoulder height or by taking the mean of 3 trials of the arm raise test. Despite these potential sources of error, however, the mean change scores represented less than 2 arm raises in 15 seconds, which, in clinical terms, was a negligible change in performance. Thus, the moderate degree of repeatability appears to be within clinically acceptable limits. Attempts were made to control for confounding factors by using standard instructions, objective measures, regular rest periods, and testing in a quiet, isolated area to minimize distraction and background noise. In addition, the medication status of subjects with PD remained constant over the 1-week period.

The strong temporal stability of performance on the majority of balance tests in this investigation is consistent with previous research on the repeatability of gait mea-

Table 10.
Means and Standard Deviations of Change Scores ($\bar{D}$) (in Seconds), 95% Confidence Intervals (CI), *t* Values, and Correlation Coefficients for Repeated Measurements Taken at 1-Week Intervals for Elderly Subjects With No Known Neurological Impairment (Comparison Group) (n=10)

Condition	*D*	SD_{diff}	Lower 95% CI	Upper 95% CI		Product-Moment Correlation (Test 1-Test 2)	ICC (2,1) (Test 1-Test 2)
Steady standing (s)							
Feet apart	0	0	0	0	. . .[b]	. . .	. . .
Feet together	0	0	0	0	. . .	. . .	. . .
Stride stance (R)	0	0	0	0	. . .	. . .	. . .
Stride stance (L)	0	0	0	0	. . .	. . .	. . .
Tandem stance (R)	1.34	4.22	−6.93	9.61	. . .	. . .	. . .
Tandem stance (L)	2.21	5.80	−9.16	13.58	−1.21	.62	.51
Single-limb stance (R)	1.84	5.65	−9.23	12.91	−1.03	.86	.86
Single-limb stance (L)	0.33	5.48	−10.41	11.07	−0.19	.89	.89
Internal perturbation							
Functional reach (cm)	0.85	3.42	−5.85	7.55	−0.79	.61	.62
Bend-reach (cm)	0.56	4.64	−8.53	9.65	−0.36	.83	.84
Arm raises (R)[a]	0.80	2.10	−3.32	4.92	−1.21	.85	.77
Arm raises (L)[a]	1.00	2.75	−4.39	6.39	−1.15	.62	.58
Step (R)[a]	1.30	2.54	−3.68	6.28	−1.62	.80	.77
Step (L)[a]	1.80	3.46	−4.98	8.58	−1.65	.68	.65
External perturbation	−0.20	0.79	−1.75	1.35	−0.82[c]	.96[d]	

[a] Frequency over 15 seconds.
[b] Ellipsis denotes an indeterminate value.
[c] Wilcoxon signed rank, P=.4152.
[d] Spearman's rho.

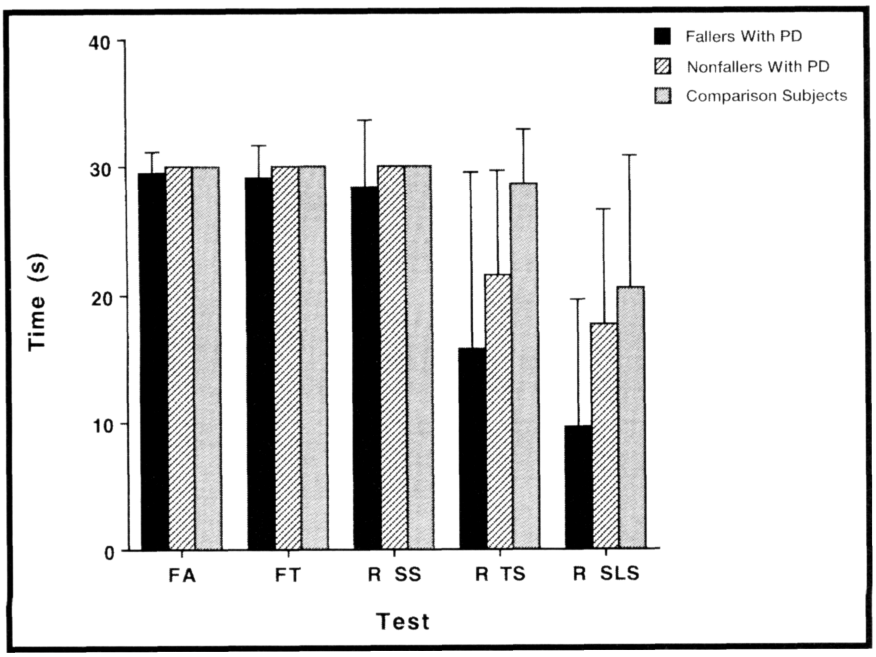

Figure 3.
Test 1 means and standard deviations for the steady stance conditions for all 3 groups. (PD=Parkinson's disease, FA=feet apart, FT=feet together, R SS=right stride stance, R TS=right tandem stance, R SLS=right single-limb stance.)

surements in people with PD. Morris et al[39] reported a high degree of consistency on tests of walking speed, stride length, cadence, and double-limb support duration when subjects with PD and control subjects were retested within a session and from one day to the next. Urquhart[40] found that repeatability of measurements for the temporal and spatial variables of gait was high over a 7-day period. For both of these studies and for our investigation, performance was measured at the peak dosage during the medication cycle. In a recent study by Morris et al,[39] when subjects with PD were tested half an hour before the next dose of levodopa was due (when they were "off" medication), gait performance was much more variable and the standard error of measurement was high. Further research is needed to determine whether performance on balance tests shows similar variability according to levodopa status. In view of the findings on the temporal stability of gait in persons with PD,[39] we

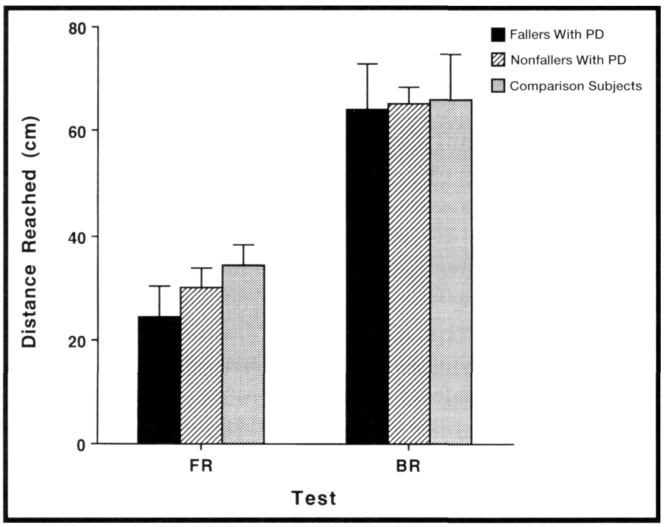

Figure 4.
Test 1 means and standard deviations for the functional reach and bend-reach tests for all 3 groups. (PD=Parkinson's disease, FR=functional reach, BR=bend-reach.)

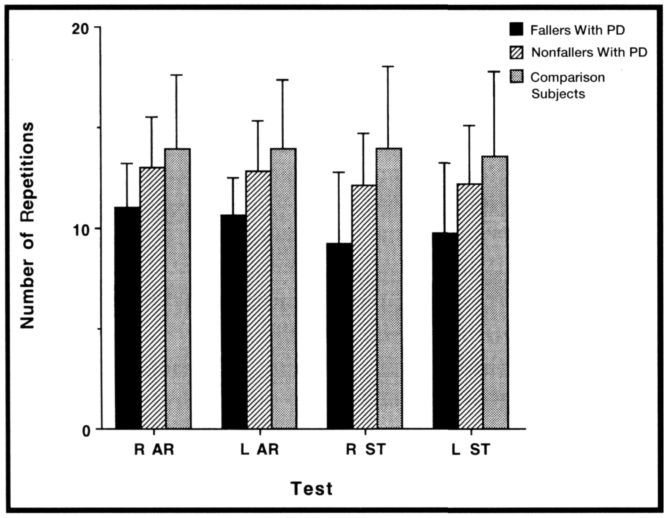

Figure 5.
Test 1 means and standard deviations for the step and arm raise tests for all 3 groups. (PD=Parkinson's disease, R AR=right arm raise, L AR=left arm raise, R ST=right step test, L ST=left step test.)

would predict that within-subject and between-subject variability in balance would be increased in the 30-minute period prior to the next dose of levodopa. We also believe that research is needed to investigate the repeatability of performance on balance tests among people with PD over longer periods of time, such as 1 month, 6 months, and 1 year. Parkinson's disease is a chronic, progressive condition, and it would be expected that people with PD would show deterioration in performance over these longer time periods, leading to lower intersession correlations and larger change scores.

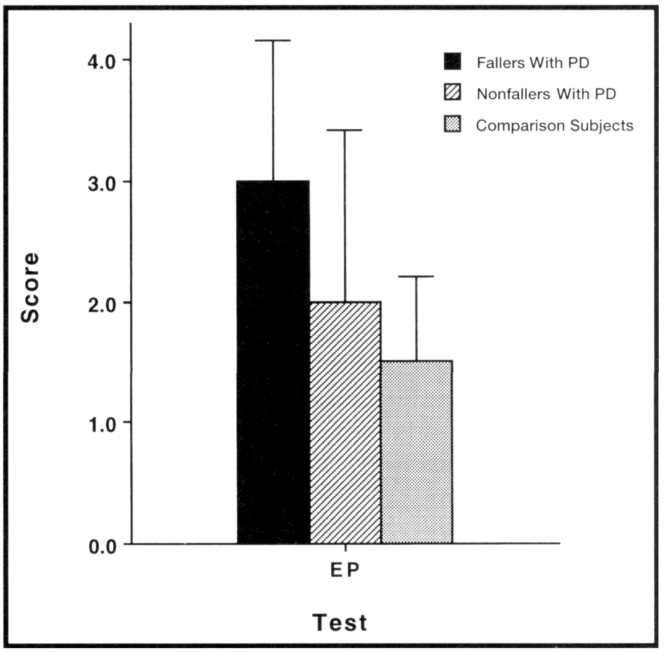

Figure 6.
Test 1 means and standard deviations for the external perturbation test for all 3 groups. (PD=Parkinson's disease, EP=external perturbation.)

As with previous investigations on temporal stability of performance in persons with PD[40] and stroke,[7,48] CIs were quite wide for the change scores over 7 days for some of the variables. The wide CIs may be related to the small numbers of subjects in the 3 groups and to individual variations in performance over time, although error from the tester and instrument may have contributed. The upper and lower limits for 95% CIs of change scores provide clinicians with metric estimates of the amount of change that they need to observe to conclude that differences in individual performance are likely due to physical therapy rather than measurement error. Table 8, for example, shows that a subject with PD with a history of falls would need to improve by more than 3.8 seconds over a 1-week period on the steady standing test with feet apart to show change exceeding that due to measurement error. Similarly, a subject with PD with a history of falls would have to decrease his or her score by more that 2.8 seconds over a 1-week period to show true deterioration. Hill et al[48] suggested that, in addition to ensuring that all possible strategies are used to reduce error attributable to the measurement device or to tester- and subject-related factors, the use of less rigorous CIs may be warranted in clinical studies such as this. We did not adopt the strategy of using less rigorous CIs because our sample size was relatively small and the probability of incurring a Type I error would have increased to what we would consider an unacceptably high level. Nevertheless, the issue of clinically acceptable CIs needs to be given more consideration by physical therapists and researchers in the future.

In addition to the wide CIs for some variables, trends toward practice effects were present for some tests, as indicated by the positive change scores shown in Tables 8 through 10. These systematic improvements have been found for similar tasks in another investigation[7] and can be expected for unpracticed novel tasks. Despite these trends, the CIs provide the clinician with estimates of these practice effects, which is helpful in determining whether a change is associated with physical therapy.

Differences in Performance Among Groups

Similar to the comparison subjects, the subjects with PD had no difficulty maintaining steady standing with their arms by their side and their feet apart, together, or in the stride stance position. Most subjects could maintain these postures for the maximum testing time of 30 seconds. In contrast, there was considerable difference in performance between the subjects with PD and the comparison subjects on tests that perturbed balance by self-initiated movements. The functional reach and step tests differentiated not only between the subjects with PD and the comparison subjects but also between the subjects with PD with and without a history of falls. Performance on the external perturbation test also showed clear differences among the 3 groups.

Tests of steady standing in the feet apart, feet together, and stride stance positions showed a lack of sensitivity due to ceiling effects. This result was consistent with previous findings for patients with stroke and elderly subjects with a history of falls.[5,7,22,24] Because these tests fail to discriminate between people with and without PD or between people with PD with and without a history of falls, they appear to be of limited use in the physical therapy assessment of people with PD. Increasing the test duration from 30 seconds to 60 or 90 seconds might enhance the discriminative properties of these tests. Our observations together with consideration of the movement disorder literature, however, suggest that this is not the case. In steady standing positions where there are no competing attentional demands, people with PD appear to be able to override the defective basal ganglia input to the maintenance of postural set by consciously attending to maintaining equilibrium.[28]

An unexpected finding was that performance on tandem stance and single-limb stance tests yielded marked differences between the subjects with PD who had a history of falls and the comparison subjects, although there was no difference between the subjects with PD who had no history of falls and the comparison subjects. Our prediction was that all 3 groups would show similar ability on these tests. The finding that the subjects with PD who had a history of falls could maintain these positions only for approximately two thirds of the time achieved by the comparison subjects when there were no competing attentional demands raises the possibility that a central deficit in postural control exists in people with PD that may be only partially compensated for by cognitive processes. The differential findings also suggest that tandem stance and single-limb stance are useful tests in allowing physical therapists to screen for balance disorders that may place people at increased risk of falling.

The results for the functional reach test showed differences among the 3 groups. Previous studies on elderly people[8] and patients with stroke[49] are in agreement with this finding and suggest that the functional reach test is a useful clinical tool in assessing balance in people with neurological disorders and in detecting differences between people with and without a history of falls. In contrast, the bend-reach test showed poor discrimination among groups and does not appear to be a useful clinical tool for assessing balance in people with PD. The difference in discriminative properties between these 2 self-initiated tests could arise from the inherent nature of the 2 tasks. The bend-reach test provides a visual cue that the subject can use to guide performance, whereas the functional reach test has no visual target and appears to require internal guided movement control, which is impaired in people with PD. Performance on both of these tests is also dependent on the person's height and the flexibility of the musculoskeletal system, although the requirement for flexibility is probably accentuated in the bend-reach test.

Although the step and left arm raise tests discriminated well among groups, clinicians should be cautious when interpreting findings from these tests because of the potential for hypokinesia and akinesia to confound scores. People with hypokinesia experience slowness in performing repetitive sequential movements, whereas people with akinesia take longer than usual to initiate movement sequences. Whether differences among groups on the step and arm raise tests were due to postural instability, hypokinesia, akinesia, or a combination of these movement disorders remains unclear. One consideration is that step test scores for the subjects with PD who had a history of falls in our investigation were slightly higher than previous results for elderly people who had no history of PD yet had a history of stroke and falls.[10] This finding argues against the predominant involvement of hypokinesia in the step test results.

The external perturbation test yielded marked differences in performance. On clinical observation, it was apparent that the majority of subjects with PD who had a history of falls failed to display effective stepping strategies because their response was underscaled in size or excessively slow. Six of these subjects needed to be caught by the examiner after the perturbation. The subjects with PD who had no history of falls showed

slower stepping responses yet were able to regain stability after taking one or more steps backward. The comparison subjects were able to maintain their balance by effectively using a stepping strategy.

Clinical Implications

The results of our study provide clinicians with a battery of tests that appear to be sensitive enough to discriminate between people with PD who have a history of falls and people with PD who have no history of falls. The test battery also appears to be useful in discriminating between people with PD and people with no known neurological impairment. This information might assist physical therapists in predicting which people with PD are at risk of falls. Due to the simplicity and applicability of the tests within the clinical setting, minimal training is required for the physical therapist to administer the tests. Furthermore, the tests are highly portable, relatively quick, require very little equipment, and are cost-effective.

The results showed strong repeatability of the test battery over a 7-day period, which is encouraging for clinicians who commonly examine patients weekly or more frequently. Weekly screening assessments of balance may be valuable in detecting any decline in balance and could provide a signal for required intervention. Similarly, improvements may be noted with physical therapy input. The tests that demonstrated the best discrimination and repeatability were the tandem stance and single-limb stance test, the functional reach test, and the external perturbation test.

A number of limitations of our study need to be acknowledged. The relatively small number of subjects in each group may have influenced the probability of sampling error as well as the risk of increasing Type II errors.[46] In addition, the exclusion of subjects with PD who had severe dyskinesia limits the generalizability of findings to people without that movement disorder. We did not evaluate performance on the sensory organization test because vestibular, proprioceptive, and visual functions remain intact in people with PD.[3] We also did not evaluate performance on what are often considered functional tests of balance such as the "timed up and go" test[19] or the "PLM" test[50] because we believed that concurrent movement disorders such as hypokinesia and akinesia would make it difficult to ascertain the contribution of balance disorders to these test results. There is, however, a need for future research to address the impact of balance disturbance in people with PD on performance of functional tasks such as walking, turning, and standing from a sitting position. Finally, the most notable limitation of our investigation was that subjects were tested at peak dosage during the medication cycle. It is likely that there would be more variability within and between subjects if tests were administered at the end of dose or if medication were withheld. The tests, therefore, may be less likely to discriminate between people with PD who fall and those who do not fall.

Conclusion

Performance on the tandem stance, single-limb stance, functional reach, and external perturbation tests showed differences in balance between subjects with PD and comparison subjects and between subjects with PD with and without a history of falls. In addition, performance on these tests was highly consistent from one week to the next, provided that the subjects were measured at peak dosage during the levodopa cycle. This battery of 4 tests, therefore, appears to be useful for assessing balance in people with PD in the clinical setting and may assist in the prediction of falls in this population. Although the step test discriminated among groups and yielded consistent scores over time, the possibility that hypokinesia contributed to the results could not be excluded. Further research is needed to examine the extent to which these tests predict falls in larger samples of subjects with PD.

Acknowledgments

We thank the Geriatric Research Unit at Kingston Centre for their support, the participants of this study for their time and commitment, Ms Winnie Tang, PT, for her valued work as research assistant and examiner, the physical therapists at Kingston Centre for their support and comments on the manuscript, and Dr Thomas Matyas for his statistical advice.

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