

## ARTICLES

# The Effects of Balance Training and High-Intensity Resistance Training on Persons With Idiopathic Parkinson's Disease

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**ABSTRACT.** Hirsch MA, Toole T, Maitland CG, Rider RA. The effects of balance training and high-intensity resistance training on persons with idiopathic Parkinson's disease. *Arch Phys Med Rehabil* 2003;84:1109-17.

**Objective:** To assess immediate and near-term effects of 2 exercise training programs for persons with idiopathic Parkinson's disease (IPD).

**Design:** Randomized control trial.

**Setting:** Public health facility and medical center.

**Participants:** Fifteen persons with IPD.

**Intervention:** Combined group (balance and resistance training) and balance group (balance training only) underwent 10 weeks of high-intensity resistance training (knee extensors and flexors, ankle plantarflexion) and/or balance training under altered visual and somatosensory sensory conditions, 3 times a week on nonconsecutive days. Groups were assessed before, immediately after training, and 4 weeks later.

**Main Outcome Measures:** Balance was assessed by computerized dynamic posturography, which determined the subject's response to reduced or altered visual and somatosensory orientation cues (Sensory Orientation Test [SOT]). Muscle strength was assessed by measuring the amount of weight a participant could lift, by using a standardized weight-and-pulley system, during a 4-repetition-maximum test of knee extension, knee flexion, and ankle plantarflexion.

**Results:** Both types of training improved SOT performance. This effect was larger in the combined group. Both groups could balance longer before falling, and this effect persisted for at least 4 weeks. Muscle strength increased marginally in the balance group and substantially in the combined group, and this effect persisted for at least 4 weeks.

**Conclusion:** Muscle strength and balance can be improved in persons with IPD by high-intensity resistance training and balance training.

**Key Words:** Balance; Exercise; Parkinson disease; Rehabilitation.

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**I**DIOPATHIC PARKINSON'S DISEASE (IPD) features impairment of resting muscle tone and voluntary movement, because of loss of striatal dopamine in the nigrostriatal dopa-

mine pathway.<sup>1</sup> Clinical signs of bradykinesia, rhythmic tremor, rigidity, and postural instability follow dopamine depletion.<sup>2</sup> Optimal management of Parkinson's disease (PD) involves both pharmacologic treatment and encouragement of physical activity,<sup>3</sup> yet few well-controlled prospective studies have documented the benefits of physical activity in PD.<sup>4-6</sup> Recent work with animal models of PD, stroke, and spinal cord injury indicates that rehabilitative training can stimulate a number of plasticity-related events in the brain and the spinal cord, including neuronal outgrowth, neurotrophic factor expression, synaptogenesis, and even neurogenesis.<sup>7-16</sup> These use-dependent events, in turn, enhance the range of self-regulated movements that may contribute to a greater plasticity and improved behavioral outcome. Moreover, during slow degeneration of nigrostriatal dopaminergic neurons, coapplication of intense sensorimotor training appears to be neuroprotective.<sup>17</sup>

Our study evaluates the effect of a series of physiotherapeutic exercises selected on the basis of their efficacy in improving balance in frail older adults.<sup>18-22</sup> Strategies for enhancing balance among older adults with PD are needed, because in the absence of regular physical activity, balance and muscle strength deteriorate in persons with PD.<sup>6</sup> Many persons with PD report impaired balance and falls.<sup>23-30</sup> Koller et al<sup>27</sup> found that balance impairment in older adults with longer duration PD usually does not respond to levodopa; 38% of persons with PD experienced falls; 13% fall more than once per week; some report falling repeatedly throughout the day; and persons with PD are 5 times more likely than healthy older adults to suffer falls-related injuries, such as hip fractures.<sup>30</sup>

Recently Olanow and Koller<sup>2</sup> and Glendinning and Enoka<sup>31</sup> identified risk factors for falls in PD including postural instability and muscle weakness. Studies have documented impaired knee and ankle muscle strength in PD<sup>32-36</sup> and dyssynchrony of reciprocally innervated leg muscles during movement initiation.<sup>37,38</sup> Specifically, persons with PD show reduced peak torque production in knee extension, knee flexion, and ankle dorsiflexion in comparison with healthy age-matched adults—muscle weakness is not related to rigidity or tremor, and the unaffected leg in persons with PD is weaker than either leg in subjects without PD.<sup>35,36</sup> Isometric force production, release of isometric force, and rate of force generation are also abnormal in some patients with PD,<sup>37-40</sup> suggesting impairment in force production may be associated with a reduced ability to generate rapid contractions.

We previously showed a strong relationship between lower-body muscle strength and impaired balance in IPD.<sup>41</sup> Eighty-eight percent of the variability on a standardized test of balance (EquiTest<sup>®</sup>) may be attributable to (1) peak torque of knee flexion relative to that of knee extension, (2) peak torque of the inversion of the ankle, and (3) use of an ankle strategy to control balance.<sup>41</sup> During an "ankle strategy," the individual uses the ankle as a fulcrum to control sway, allowing the shoulders and hips to stay aligned with the ankles. Individuals with weak ankle muscle strength were likely to fall on this balance test and subjects swayed excessively when the ratio of hamstring strength to quadriceps strength was less than two thirds.<sup>41</sup> Lower-extremity weakness in persons with PD may

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Table 1: Pretreatment Subject Characteristics

Characteristic	Balance Group (n=9)	Combined Group (n=6)
Age (y)	75.7±1.8	70.8±2.8
Body weight (kg)	69.3±3.2	75.0±3.0
Hoehn and Yahr stage (pretest)	1.9±0.6	1.8±0.3
Covariates		
Age at initial diagnosis (y)	67.3±4.3	65.3±5.1
Disease duration (y)	8.3±9.8	5.5±3.91
EquiTest falls	3.2±1.0	2.8±1.2
Strength to body weight ratio	41.2%±2.1%	45.1%±4.4%
Hamstring to quadriceps ratio	69.7%±7.5%	79.1%±5.6%
Dependent variables		
Latency to fall (s)	15.5±1.5	16.5±1.8
% EquiTest trials resulting in falls	35.9±11.1	28.2±12.0
Summary EquiTest score	52.8±8.2	59.0±8.5
Strength score (kg)	28.6±2.5	33.8±3.7

NOTE. Values are mean ± standard error of the mean.

Abbreviations: Age at initial diagnosis, age at participants initial diagnosis with PD; Disease duration, time lapse from initial diagnosis to beginning of study; EquiTest falls, average number of falls on pretest EquiTest conditions 4–6; Latency to fall, number of seconds elapsed before an EquiTest fall occurred; % EquiTest trials resulting in falls, total number of trials (conditions 4–6, as defined in table 2) divided by number of trials resulting in falls; Summary EquiTest score, averaged score from the 3 trials of EquiTest conditions 4–6; Strength score, averaged score from the 3 muscle strength tests; Strength to body weight ratio, strength divided by body weight; Hamstring to quadriceps ratio, hamstring strength score divided by quadriceps strength score.

impair the ability to mount postural responses of an appropriate magnitude when balance is challenged.<sup>41</sup>

Other authors<sup>2,6,29,31</sup> have suggested that balance impairment in PD and normal age-related physical changes, such as declines in muscle strength which occur in adults<sup>19,22</sup> (healthy and pathologic populations) who do not exercise to strengthen muscle, may respond favorably to muscle-strengthening and balance rehabilitation. Physical interventions related to enhancing balance and muscle strength and potentially reducing falls are relatively inexpensive interventions that help prevent dysfunction and dependence in the elderly and would appear to be a logical avenue for addressing balance impairment in persons with PD.

The aim of this study was to determine how a specific group rehabilitation program would influence muscle strength and balance in patients with IPD. We hypothesized that the beneficial effects would include enhanced balance scores and muscle strength on 2 standardized tests. If so, this work would suggest that outpatient rehabilitation involving resistance training and/or balance training may be a useful adjunct to current medical therapy in PD. To test this hypothesis, a 2-group experimental design was used. We compared the results from a group with balance training alone to the results from a group with a combination of resistance training and balance training. Patients were tested before and at the end of the intervention as well as 4 weeks after cessation of training.

## METHODS

### Participants

Participants' characteristics are listed in table 1. Participants were recruited from the members of the Big Bend Parkinson's Disease Support Group, Tallahassee, FL. Eligible participants

were volunteers who had been diagnosed with IPD by their neurologist and who had not participated in any organized balance or muscle strengthening activities before being pretested. All participants were ambulatory, were not acutely ill, were able to follow simple commands, and were not suffering from unstable cardiovascular disease or other uncontrolled chronic conditions that would interfere with the safety and conduct of the training and testing protocol. A total of 15 patients qualified for the study. Because Tallahassee is a relative small city (≈200,000 people), it is very difficult to recruit larger numbers of patients who qualify and who also will invest the time for testing and intervention. The protocol was approved by the Human Subjects Committee of Florida State University and reviewed by the participants' primary care physicians, who also gave their written consent. All participants gave informed consent for the procedures used.

During the study, participants were taking Parkinson's medications, that is, levodopa and carbidopa (Sinemet) (n=11), selegiline (Eldepryl) (n=12), pergolide (Permax) (n=1), bromocriptine (Parlodel) (n=3), and amantadine (n=2). Participants followed their normal schedule of medications throughout the course of the study and we tested them 2 hours after they had ingested their morning dose and within the same relative temporal period of their drug cycle (between 9:00 AM and 12:00 PM). Parkinson's medications were not changed during the study.

All participants were first pretested for balance and then pretested for muscle strength on separate days. After assessment, participants were randomly assigned to 1 of 2 training groups. To prevent an unequal distribution of nonfallers and to ensure that each group contained a similar number of subjects who fell during the EquiTest, 4 subjects who had not fallen on any trial of the EquiTest were paired (2 men, 2 women) and randomly assigned to the 2 groups. Then subjects who did fall during the EquiTest were randomly assigned to the 2 groups. Both groups received identical balance training exercises, but the combined group also engaged in resistance training. All physiologic measurements were obtained at baseline (pretreatment) and repeated within 5 days of completion of training (posttreatment). Additionally, measurements were repeated 4 weeks after training ceased (follow-up treatment). Participants did not train during this 4-week period. Exercise sessions for both groups were conducted at different times of the day.

### Testing and Intervention

**Muscle strength testing.** Muscle strength of the knee extensors, knee flexors, and ankle plantarflexors was measured at baseline, after 10 weeks of training, and 4 weeks after training had ceased by using standardized weight-and-pulley systems.<sup>b</sup> The 4-repetition maximum was defined as the highest weight the seated participant could lift 4 times only from 90° of knee flexion to full knee extension, from 170° of knee extension to 90° of knee flexion, and from 90° of ankle flexion (neutral) to maximal ankle plantarflexion.<sup>42</sup>

After a 5-minute warm-up on a cycle ergometer, and familiarization with the equipment, both legs were tested concurrently. Participants practiced 4 warm-up movements and then performed 4 maximum movements for each joint movement. Weights were added in small increments (1.1–2.3kg), and participants rested 30 seconds between sets. The test ended when the participant could no longer perform 4 maximum movements of full range of motion exercise. Reliability of the measurements was tested; the test-retest correlation coefficient was .93 for knee extension, .98 for knee flexion, and .99 for

**Table 2: Summary of Experiment Protocol for the Sensory Organization Test (SOT)**

EquiTest SOT Condition	Sensory Conflict	Sensory Information Accurate	Sensory Information Inaccurate
1	No	Vestibular, vision, prop	None
2	No	Vestibular, prop	None
3	Yes	Vestibular, prop	Vision
4	Yes	Vestibular, vision	Prop
5	Yes	Vestibular	Prop
6	Yes	Vestibular	Vision, prop

Abbreviations: Vestibular, vestibular apparatus; Prop, proprioception; Condition 1, eyes open and fixed support; Condition 2, eyes closed and fixed support; Condition 3, eyes sway-referenced and support sway-referenced; Condition 4, eyes open and support sway-referenced; Condition 5, eyes closed and support sway-referenced; Condition 6, eyes sway-referenced and support sway-referenced.

ankle plantarflexion, showing high reliability of the strength testing measurement.

**Resistive intervention.** The resistance training exercises, were performed on Nautilus equipment<sup>b</sup> at a local health facility. Participants assigned to resistance training underwent a regimen of high-intensity progressive resistance training of the ankle plantarflexors and knee extensors and flexors. These muscle groups were chosen because of their presumed importance in balance in persons with PD.<sup>6,35</sup> Resistance exercise sessions lasted 15 minutes and were held 3 times weekly on nonconsecutive days. Each participant was trained and supervised by an exercise leader who also recorded exercises completed in a log. The 10-week resistance training protocol used an adaptation of standard rehabilitation principles of progressive-resistance training by using concentric and eccentric muscle contraction.<sup>43</sup> The initial 4-repetition maximum was used to set the load for the first 2 weeks at 60% of the 4-repetition maximum for each muscle group. Participants performed 1 set of 12 repetitions, moving both legs simultaneously at 6 to 9 seconds per repetition, with no rest between repetitions, and with a 2-minute rest between exercises. Emphasis was on performing the exercise with good form and minimal substitution of other muscle groups. At the end of the second week, the load was increased to 80% of the 4-repetition maximum. The 4-repetition maximum was measured in all study participants every 2 weeks; for those in the combined group, the training stimulus was adjusted to keep the load at 80% of the new 4-repetition maximum.

**Balance testing.** Body sway was assessed quantitatively by using a computerized test for isolating individual sensory and motor components of balance in standing humans.<sup>a</sup> The EquiTest is a reliable method for following changes in balance after balance rehabilitation programs.<sup>6,41,44-51</sup> The different sensory test conditions—1 through 6—have been described table 2.<sup>41</sup> The EquiTest device consists of a moveable platform on which a subject stands, which can rotate about an axis close to that of the ankle joint; and a surrounding screen enclosure that can rotate about an axis close to that of the ankle joint. Two forceplates in the platform, 1 for each foot, are equipped with strain gauges that measure the  $x$  axis (anteroposterior [AP]) center of vertical force position.

We used a standardized EquiTest assessment protocol—Sensory Organization Test (SOT)—to measure how well participants maintained balance under progressively more difficult test conditions, which either disrupted or removed visual and proprioceptive feedback. Visual and proprioceptive environ-

ments were altered systematically for fixed support and sway-referenced support and surround conditions, and under normal (eyes open), absent (eyes closed), and sway-referenced vision (eyes sway-referenced). Under sway-referenced conditions, the platform on which subjects stood and/or the visual surround also moved proportionally to their AP sway. Sway-referenced visual conditions show the participant's ability to suppress conflicting (inaccurate) visual inputs and to rely on alternative systems for maintaining equilibrium.<sup>41</sup>

An equilibrium score was determined for each balance condition based on peak-to-peak sway amplitude in the AP axis. This score expresses the participant's sway relative to the theoretical limits of stability; scores near 100 indicate minimal sway, whereas those near zero indicate more extreme sway. When a participant took a step, touched the surround panels, or needed assistance from the technician, that trial was marked as a fall and the participant received an equilibrium score of zero for that trial.

Participants were carefully positioned on the platform by aligning the lateral malleoli (ankle joint) with the axis of rotation of the platform and visual surround. Before each trial, participants were instructed to stand still and erect with arms by their side. Three 20-second trials were administered for each of the 6 test conditions.

Scores for conditions 1 through 3 did not change throughout the training period, so they were not included in the analysis. Because the raw scores for conditions 4 through 6 were highly correlated, these data were combined to give a single summary balance score. This summary balance score reflects performance under the most difficult test conditions when the support surface is sway-referenced and visual cues are misleading or absent. Two other summary variables for conditions 4 through 6, the mean latency to a fall (average number of seconds participants swayed before stepping or falling, touching the surrounding panels with hands, or needing assistance from the technician to keep from sitting in the harness) and the proportion of falls (number of trials resulting in falls), were used as additional measures of the subject's ability to maintain postural stability under the most difficult conditions.

**Balance intervention.** Both groups received the same type of balance training. Balance exercise sessions lasted 30 minutes and were performed on 3 nonconsecutive days per week. The 10-week balance training program used an adaptation of standard balance rehabilitation exercises that have been shown to improve balance in frail older adults,<sup>18-21</sup> persons with PD,<sup>6</sup> and in older adults with vestibular pathology.<sup>49-51</sup> Training was in 2 areas: (1) standing with feet shoulder-width apart on foam by using commercially available medium density foam pads<sup>c</sup> 4 to 6 in thick and (2) standing without foam. Training without foam included standing with feet shoulder-width apart and flat on the ground with eyes open, eyes closed, and neck neutral or neck extended for 20 seconds. This sequence was repeated 5 times. Foam training involved balancing on a single 4-in thick piece of foam and then progressing to several pieces of foam throughout the training period, with eyes open, eyes closed, and neck neutral or neck extended for 20 seconds. This sequence was also repeated 5 times. By the end of the sixth week of training, all participants were using 3 foam pads. Balancing on foam reduces the usefulness of somatosensory inputs of the ankles for controlling balance, thereby challenging visual and vestibular inputs for balance control. Head extension was used to provide unreliable vestibular feedback and, during this task, each participant extended their head as far as was comfortable.

During a second set of exercises the therapist gently perturbed the participant—pulling hard enough to challenge, yet gently enough not to overshoot the participant's limit of sta-

bility. Perturbation exercises were designed to enhance the participant's limit of stability. The focus was on maintaining equilibrium through counterbalancing motions by using the lower extremities. Sternal and dorsal perturbations were directed at the participant's shoulders, with the therapist standing either behind the participant or in front. These exercises were performed standing on the ground with eyes open or closed (20 times) and standing on foam with eyes open or closed (20 times). Weight-shifting exercises were then performed with eyes open on the ground and on foam; each weight shift was held at the limit of stability (achieved with the ankle as fulcrum) for 5 seconds. During weight shifting, participants gently swayed to their limit of stability, leaning as far as they could without falling and keeping the ankle, hip, and shoulders in a line. Participants swayed toward 1 of 4 imaginary targets (forward, backward, left, right), and each position was held for 5 seconds.

**Compliance.** Participants in the balance group attended 91.8% of all training sessions, and those in the combined group attended 89.4% of all sessions. During the training period, 1 participant in the combined group developed an acute urinary tract infection, requiring lengthy hospitalization. This occurred after 7 weeks of training. Another combined group participant was rediagnosed as not having IPD by his neurologist. This occurred after 5 weeks of training. Data for these 2 participants were eliminated from all statistical analyses. A third participant in the combined group reported a minor inguinal hernia after 3 days—presumably as a result of strength testing during baseline evaluation—and chose not to perform resistance training or strength testing. This participant continued with balance training and completed all balance testing in a timely manner. Data from this participant were included in balance group data analyses for latency to fall and balance analysis, but not in strength analyses. Data indicate that the protest scores of these 3 individuals were comparable to those of the other subjects. One participant in the balance group had minor outpatient surgery in 1 eye after 9 weeks of training. This participant chose not to complete any post or follow-up muscle strength measures but was able to complete all post and follow-up balance testing in a timely manner.

### Data Analysis

All data were analyzed with SPSS.<sup>d</sup> We used 4 primary analyses, 1 each for balance scores, latency to fall scores, proportion of falls scores, and muscle strength scores.

**Balance analyses.** The analysis for the balance (EquiTest) scores used the analysis of covariance (ANCOVA) model for repeated measures. Table 1 lists and defines the covariates and the dependent variable and provides summary statistics. ANCOVA was deemed important to use based on prior analyses<sup>6,41</sup> that showed high levels of variability in persons with IPD on balance and strength measures. Covariates believed to be important in the current analysis include the age at onset of PD, the duration of PD, the number of falls in preexperiment balance tests, and subject's initial muscle strength levels. We selected these variables because empirical evidence shows: (1) rapid deterioration of balance in patients who are older at onset of PD,<sup>52</sup> (2) frequent falls on EquiTest conditions 4 through 6 in patients with limited lower-extremity muscle strength,<sup>41</sup> and (3) longer duration of PD associated with falling.<sup>22,29</sup> The covariates correlated highly, from  $-.93$  to  $.56$ , with the dependent variable for pre, post, and follow-up balance scores and there were no significant differences between the means of the covariates for the balance and combined groups.

For the analysis of SOT summary balance scores, there were 2 groups (balance, combined) and 3 sets of measurements

(pretreatment, posttreatment, follow-up treatment) taken at different times, so the design for the balance scores was a  $2 \times 3$  (group by time of pre, post, follow-up) mixed model with repeated measures on the last factor.

**Latency to fall and proportion of falls analyses.** There were 2 groups (balance, combined) and 3 sets of measurements (pretreatment, posttreatment, follow-up treatment) taken at different times; the design for the latency to falls scores was a  $2 \times 3$  (group by time) mixed model with repeated measures on the last factor. The proportion of falls scores were also analyzed with a  $2 \times 3$  (group by time) mixed model with repeated measures on the last factor.

**Muscle strength analyses.** To be consistent with the balance analyses, an attempt was made to use the same covariates in the analyses of muscle strength. A regression was performed on the 5 covariates of age of diagnosis with PD, duration of disease, ratio of pretreatment muscle strength to body weight, ratio of hamstring muscle strength to quadriceps muscle strength, and pretreatment number of falls on EquiTest conditions 4 through 6. The coefficients for each of these variables with the dependent variables of knee extension, knee flexion, and ankle plantarflexion muscle strength for pretreatment, posttreatment, and follow-up treatment tests were low, however, ranging from  $-.38$  to  $.35$  with most near zero. Thus, the analysis of muscle strength was repeated without covariates. Therefore, the design for the analysis of variance (ANOVA) for muscle strength was a  $2 \times 3 \times 3$  mixed model (groups by time of pre, post, follow-up by muscles of quadriceps, hamstrings, gastrocnemius). For this design there were 2 repeated-measures factors: time and muscles.

When the F ratios were significant, post hoc comparisons of the means were analyzed with the Tukey honestly significant difference (HSD) multiple-comparison test. Relations among the covariates were analyzed pairwise with the Pearson correlation coefficient. Additionally, we compared baseline characteristics by using 1-way ANOVA. All results are presented as means and standard errors of the mean (SEMs). A 2-sided  $P$  value of .05 or less was considered statistically significant.

## RESULTS

### Baseline

Baseline characteristics of the subjects in the combined and balance groups did not differ significantly (table 1). The variances of these variables also did not differ significantly for the groups. In addition, before training started, the dependent variables did not differ significantly for the 2 groups, and the variances also did not differ significantly.

### Effect of Training on Summary Balance Score

Analysis of balance scores for 9 participants from the balance group and 6 participants from the combined group provides evidence of the effects of training on the summed, averaged scores of EquiTest conditions 4 through 6. There was a main effect for group ( $F_{1,8} = 14.16$ ,  $P = .006$ ; effect size = .64; observed power = .91 [91% power is large]). Thus, when the balance scores were collapsed over time (pretreatment, posttreatment, follow-up treatment), the combined group had a significantly higher mean on the EquiTest (mean  $\pm$  SEM,  $69.28 \pm 4.7$ ) than did the balance group (mean,  $55.9 \pm 4.3$ ). The combination of balance and resistance training improved balance scores of persons with PD significantly more than did balance training alone.

The time effect for the training was not statistically significant; however, the pooled data from both groups showed a trend ( $P = .063$ ) for change in balance scores over time, with a

**Table 3: Covariate Coefficients for EquiTest ANCOVA**

Covariate	B	$\beta$	t	P
Age at initial diagnosis	.34	.34	1.10	.30
Disease duration	.05	.04	.14	.89
Strength to body weight ratio	6.86	-.05	.40	.70
EquiTest falls	-3.52	-.87	-6.71	.00
Hamstring to quadriceps ratio	14.96	.24	1.49	.17

small effect size of .18. For both groups, the means of the summed, averaged, balance scores for EquiTest conditions 4 through 6 increased after training (balance pretreatment mean,  $52.8 \pm 8.2$ ; balance posttreatment mean,  $60.1 \pm 3.4$ ; combined pretreatment mean,  $59.0 \pm 8.5$ ; combined posttreatment mean,  $75.1 \pm 3.1$ ). Four weeks after the training ended, the mean for the balance group declined to near pretreatment levels (mean,  $54.8 \pm 5.2$ ), whereas scores for the combined group declined moderately (mean,  $73.9 \pm 3.6$ ).

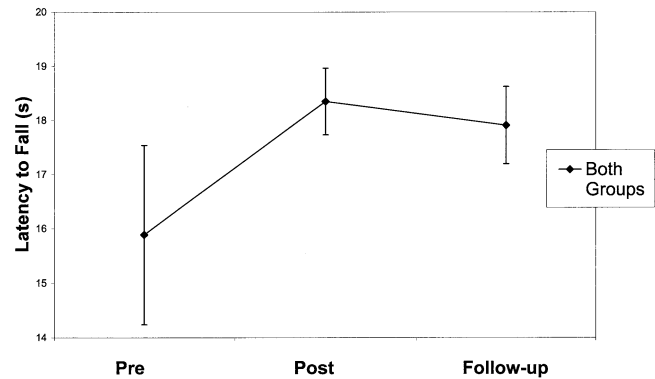
Table 3 reports the ANCOVA results, showing a statistically significant relationship between the covariates and the dependent variable (summary EquiTest score) ( $F_{5,8} = 14.47$ ,  $P = .000$ ), indicating that the covariates were significantly related to the summary EquiTest score. The relationship between the pretreatment number of falls for the participants was significantly related to the EquiTest summary balance scores ( $P < .001$ ). The other covariates were not statistically significant and thus there was statistical evidence that they were not strongly related to the summary EquiTest scores in these participants. However, because they all correlated moderately to highly with the EquiTest balance score, all were used as covariates.

### Effect of Training on Latency to Fall and Proportion of Trials Resulting in Falls

The data provide evidence that training affects the average number of seconds a participant could balance and the percentage of trials resulting in falls. Nine participants from the balance group and 6 participants from the combined group were included in these analyses. For latency to fall, there was a significant time effect ( $F_{2,26} = 4.25$ ,  $P = .025$ ; effect size = .25; observed power = 69%; see fig 1, table 4), showing a significant (15%) change in the latency to fall data from pretreatment to posttreatment testing (Tukey HSD = 2.214) for both groups. Latency to fall was significantly longer after the treatment than before in both groups (seconds to fall pretreatment, mean,  $15.89 \pm 1.10$ ; posttreatment mean,  $18.35 \pm 0.25$ ). At follow-up testing, participants in both groups showed a modest, but not significant, decline in latency to fall (mean change, .44s). For the proportion of trials resulting in falls, there was a significant time effect ( $F_{2,26} = 4.67$ ,  $P = .018$ ; effect size = .26; observed power = 74%), showing a reduction in the percentage of trials resulting in falls from pretreatment (mean,  $32.86 \pm 8.04$ ) to posttreatment (mean,  $12.77 \pm 4.07$ ). There were no other significant effects.

### Effect of Training on Muscle Strength

Seven participants from the balance group and 6 participants from the combined group were included in this analysis. There were 3 significant main effects for the strength analysis; the main effect for group was significant ( $F_{1,11} = 7.22$ ,  $P = .021$ ; effect size = .40; observed power = 69%). Over the combined



**Fig 1. Latency to fall effect over the pretreatment, posttreatment, and follow-up tests for both groups. Values refer to average latency to fall for summary balance conditions (SOT conditions 4–6 averaged). Error bars indicate SEM.**

testing periods, the combined group was significantly higher in strength (mean,  $43.8 \pm 4.2$ kg) than the balance group (mean,  $30.4 \pm 2.9$ kg). There was also a significant main effect for time ( $F_{2,22} = 151.22$ ,  $P < .001$ ; effect size = .93 [a very large effect size]; observed power = 100%). Posttreatment strength was significantly higher (mean,  $40.4 \pm 3.7$ kg) than pretreatment strength (mean,  $31.0 \pm 2.3$ kg) and follow-up treatment strength (mean,  $38.3 \pm 3.4$ kg). The last significant main effect was muscle group ( $F_{2,22} = 22.67$ ,  $P < .001$ ; effect size = .67; observed power = 100%). The quadriceps was significantly stronger (mean,  $42.8 \pm 3.4$ kg) than the hamstrings (mean,  $31.5 \pm 2.6$ kg) and the gastrocnemius (mean,  $35.4 \pm 3.5$ kg), whereas the hamstrings and gastrocnemius did not differ significantly from one another.

The group by time interaction was significant ( $F_{2,22} = 78.99$ ,  $P = .001$ ; effect size = .88 [a very large effect]; observed power = 100%; fig 2, table 5). The combined group was significantly higher in average strength of the 3 muscle groups than the balance group at posttreatment and follow-up testing. The balance group had a modest and statistically significant improvement (9%) in muscle strength from pretreatment to follow-up treatment testing (Tukey HSD = 6.068 for all comparisons). By using the strength score, there was a 52% improvement from pre- to posttreatment for the combined group. The combined group lost 10% of its posttreatment strength score (mean, 50.8kg posttreatment vs 45.9kg follow-up treatment), which was a statistically significant decline, but its

**Table 4: Latency to Fall and Percentage of Trials Resulting in Falls**

	Pretreatment	Posttreatment	Follow-Up
Latency to Fall			
Balance group (n=9)	15.5 ± 1.5	18.0 ± 0.7	17.1 ± 0.9
Combined group (n=6)	16.5 ± 1.8	18.8 ± 0.6	19.1 ± 0.6
Percentage of trials resulting in falls			
Balance group (n=9)	36.0 ± 11.1	16.0 ± 6.1	29.6 ± 8.6
Combined group (n=6)	28.2 ± 12.0	7.9 ± 4.0	7.4 ± 5.4

NOTE. Values are mean ± SEM.

Abbreviations: Latency to fall, average time to fall (in seconds) on SOT conditions 4–6; Percentage of trials resulting in falls, total number of trials (conditions 4–6) divided by number of trials resulting in falls.

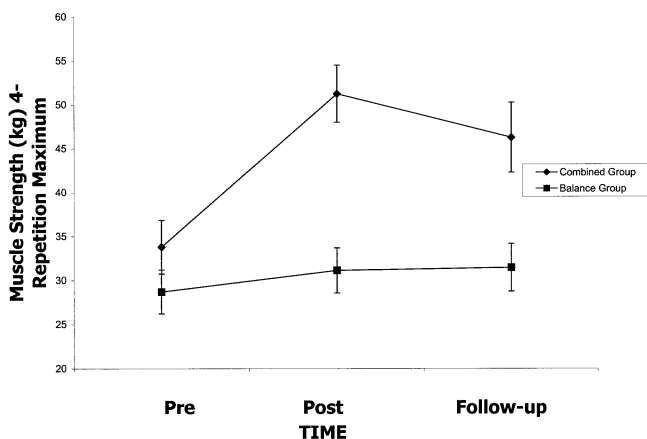


Fig 2. The group and time interaction for strength. Values refer to muscle strength (kg) on 4-repetition maximum test for 3 muscle groups combined for the combined and balance groups. Error bars indicate SEM.

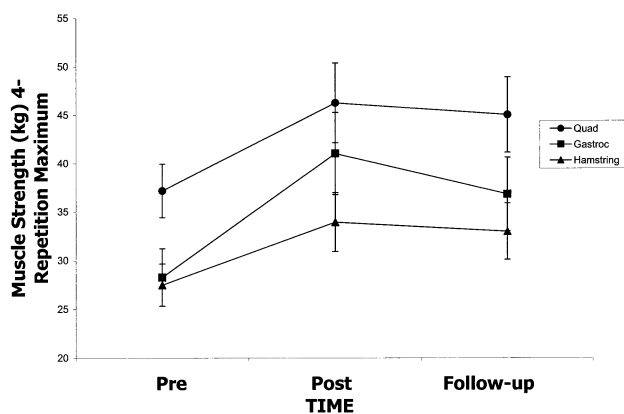


Fig 3. The time by muscle group interaction for strength. Values refer to changes in muscle strength (kg) on 4-repetition maximum test for knee extension (quadriceps), knee flexion (hamstring), and ankle plantarflexion (gastrocnemius/soleus). Error bars indicate SEM.

follow-up treatment strength score was still significantly higher than pretreatment.

There was a time by muscle group interaction ( $F_{4,44}=6.96, P=.001$ ; fig 3). One can observe the main finding from this interaction by noticing that the pattern of results was similar for the quadriceps (knee extension) and hamstring (knee flexion) muscle groups. Both of these muscle groups improved significantly from pre- to posttesting and remained the same for follow-up tests (no significant change, Tukey HSD=6.69 for all comparisons). For the gastrocnemius, a steeper change and significant improvement came about from pre- to posttests, with significant decline in muscle strength after 4 weeks of detraining. The interaction occurs with time and muscle group because the pattern of changes over time for the gastrocnemius is different from the other 2 muscle groups.

There was a triple interaction among the 3 factors of group, time, and muscle groups ( $F_{4,44}=6.68, P = .001$ ). This interaction is a combination of the last 2 interactions explained above, and a third pattern of results among the 2 factors of group and muscles. Post hoc analyses (Tukey HSD=17.83) showed that both groups had significantly less strength in their knee flexor muscles than in their knee extensors and strength in ankle plantarflexion was not significantly higher than knee flexion.

DISCUSSION

We examined the effect of balance training and high-intensity resistance training on balance in 15 persons with IPD.

Table 5: Strength

Time	Knee Extension	Knee Flexion	Ankle Extension
Balance group (n=7)			
Pretreatment	35.0±4.9	23.8±1.861	26.9±2.3
Posttreatment	36.6±4.4	26.6±1.7	30.1±3.0
Follow-up treatment	37.3±4.4	27.6±2.0	29.5±3.4
Combined group (n=6)			
Pretreatment	39.7±2.1	31.8±3.5	29.9±5.9
Posttreatment	57.5±3.7	42.6±4.0	53.7±4.5
Follow-up treatment	54.1±4.5	39.4±4.7	45.4±5.6

NOTE. Values are mean ± SEM, are in kilograms, and were recorded as the 4-repetition maximum.

There were 4 main findings: (1) balance training improved performance on the summary balance measure and this effect was enhanced by concurrent resistance training, (2) training increased latency to falling and reduced the percentage of trials resulting in falls, and this effect persisted for at least 4 weeks, (3) muscle strength was increased and this change also persisted for at least 4 weeks, and (4) in comparison to our earlier work,<sup>6</sup> we have extended our findings to show that balance and resistance-training benefits persist for 4 weeks even if participants do not maintain their level of training.

Effect of Training on Muscle Strength

High-intensity resistance training increased lower-extremity muscle strength by 52% with combined training and 9% with balance-only training. Our findings extend observations by Fisher et al<sup>53</sup> who reported similar increases in lower-extremity muscle strength among 18 nursing home residents—2 of whom had PD. The effect of resistance training has rarely been studied in persons with PD and the results of 1 study<sup>54</sup> using rubber bands to improve muscle strength showed no improvement in knee extension strength. This lack of improvement may be due to inappropriate exercise design, high variability between repeated measures, or low exercise intensity. Higher-intensity resistance training has generally improved muscle strength in older adults,<sup>18-20</sup> so this failure may be attributed to the very low training intensity.

Muscle strength also increased significantly in the balance group. Muscle strength is rarely tested in balance training studies. Judge et al<sup>55</sup> compared changes in muscle strength between balance training and combined resistance and balance training in healthy older adults, using foam-based balance training and periodic 4-repetition-maximum strength tests similar to ours; they reported no change in muscle strength from balance training alone. That study, unlike ours, did not test muscle strength every 2 weeks to ensure that training intensity was maintained at 80% of a 4-repetition maximum.<sup>55</sup> Because muscle strength was tested in both groups every 2 weeks, a learning effect may account for the small (9%) but statistically significant increase in muscle strength in the balance trained group. It is also possible that the balance exercises themselves contributed to increases in muscle strength, greater resistance to fatigue, or greater tolerance to muscle discomfort during muscle strength testing.

The effect of detraining on muscle strength is rarely reported in resistance-training studies of healthy or pathologic populations. In young healthy individuals trained using concentric and eccentric high-intensity resistance exercises for the quadriceps and hamstring muscle groups for 16 to 24 weeks, detraining causes substantial decreases in maximum force production after 8 to 12 weeks of inactivity.<sup>56</sup> In our study, the combined group lost 10% of its average muscle strength, with the majority of the loss in the gastrocnemius; however, muscle strength did not decrease to pretreatment levels after 1 month of detraining. In the gastrocnemius, there was greater improvement in strength and greater loss compared with the quadriceps and hamstring muscles (fig 3). Our results suggest that periods of inactivity lasting approximately 1 month did not result in substantial loss of training effect for knee flexors and extensors in persons with PD. In another study,<sup>53</sup> chronically ill persons living in a nursing home (among them, 1 subject with PD) maintained lower-body muscle strength gains for up to 4 months after 10 weeks of high-intensity resistance training for the knee extensors. This is important because older adults with PD may be prone to interruptions in their exercise programs because of frequent travel, chronic illness, hospital admissions, and changes in medication. As long as these interruptions are not too extensive, they are unlikely to completely reverse the effects of resistance training.

Although we did not assess the mechanisms responsible for increased muscle strength, gains in muscle strength in our participants may be because of improved neural activation, a generalized effect of resistive training or to changes in the intrinsic contractile characteristics of muscle.<sup>57</sup> Quadriceps, hamstring, and gastrocnemius muscle strength differed significantly from pretreatment values after 4 weeks of detraining, indicating persistence of nonhypertrophic-related adaptations to high-intensity resistance training among those in the combined group. It is possible that the participants were able to maintain muscle strength by engaging in more complex and extended movements in their everyday repertoires, self-regulated by improvements in balance and reduced fear of falling.

### Effect of Training on Balance

Training had 3 effects on balance: (1) training increased the latency to fall by 15% and the effect of detraining was minimal (2%); (2) training reduced the percentage of trials resulting in falls by 20% from pretreatment to posttreatment and this effect remained unchanged for 4 weeks; and (3) participation in the combined group improved the ability to maintain equilibrium, (ie, sway less) during destabilizing conditions.

Our study indicates that a generalized effect of balance and/or resistance training is reduction of latency to fall in persons with PD. Our results are consistent with those of Cass et al,<sup>44</sup> who reported increased latency to fall in 90% of patients on the 2 most difficult test conditions (EquiTest conditions 5 and 6) in response to resistance and balance training, and those of Horak et al,<sup>50</sup> who reported increased single-leg stance time on those conditions.

On the summary balance score measure, the combined group performed significantly better than the balance group. Training had a greater effect on the combined group, and this is reflected in a higher summary balance score and less sway on the 3 most difficult balance conditions among participants in the combined group. Szturm et al<sup>51</sup> used foam-based balance exercises in persons with chronic peripheral vestibular function. They reported balance training reduced sway and falls on EquiTest conditions 4 through 6. Presumably reductions in falls would reduce latency to fall but this was not reported.<sup>51</sup>

In persons with PD, muscle strength at the ankle and knee appears to affect performance on the SOT,<sup>6,22,41</sup> which may partly explain why those in the combined group were able to stand with less sway than those in the balance group. Increased steadiness of the knee may have resulted in higher summary balance scores.<sup>41</sup> Apparently, greater muscle strength has no differential effect on latency to fall or the percentage of trials resulting in falls; however, our results indicate higher levels of ankle strength, knee extension, and knee flexion strength may result in less sway. These effects on balance performance indicate the benefit of training in our participants.

The effect of detraining on balance performance is rarely reported in the literature. For persons in our study, the effect of detraining appears to be negligible for up to 4 weeks. A retrospective study<sup>49</sup> reported sustained improvements in equilibrium associated with balance training in 85% of patients with chronic vestibular dysfunction. Future research should focus more heavily on the effect of detraining on balance and muscle strength and on the possibility that improved function permits self-generated practice during activities of daily living.

The evidence presented here is preliminary and does not address the mechanisms involved in balance control in persons with PD, nor do the data permit any conclusive statements regarding how change in function can result from high-intensity resistance and/or balance training. We combined EquiTest conditions 4 through 6 into a summary score because data for these conditions were highly correlated and we cannot make any conclusive statements regarding changes in individual test conditions; however, excessive sway and falls of PD patients during EquiTest conditions 5 and 6 have consistently been reported.<sup>6,41</sup> This shows that when somatosensory information is reduced by placing patients on foam or standing on a sway-referenced support surface, persons with PD are less able to compensate by using visual or vestibular feedback. Perhaps the reason they cannot apply corrective torque about the ankle and knee during these conditions is because of lack of muscle strength, which can be corrected, in part, by a resistance or balance training program. Another reason why people with PD might sway more with reduced or misleading somatosensory ankle joint feedback during EquiTest conditions 4 through 6 is because of an impaired transmission of motor programming from the basal ganglia to brainstem and spinal cord, as suggested by Garcia-Rill.<sup>58</sup> It is unclear how balance and/or resistance training might serve to ameliorate this. However, it may be that balance training serves to increase frequency and intensity of neuromotor pathways in balance control facilitating neuronal transmission and muscle contraction. Thus, motor programs used for balance adaptation can be better tuned or preset so to enhance transmission and execution.

We want to emphasize that the SOT portion of the EquiTest quantifies only limited aspects of a person's balance control. We used the EquiTest in this study because of its objectivity and its potential to assess responses to balance training among persons with PD.<sup>6,41</sup> The results might have differed and a more complete picture of change over time might have been documented if we had used more functional balance tests.<sup>59</sup>

Maximizing adherence and minimizing injury is an obvious concern. The injury and adherence rates in our study were similar to those in other studies with healthy older adults. We used a conservative test of muscle strength because of the high incidence of musculoskeletal injury (20%) reported in previous studies utilizing a 1-repetition-maximum strength testing protocol.<sup>55</sup> The greater incidence of dropouts in the combined group suggests careful attention to exercise and form are important during resistance training and strength testing in persons with PD, as it is in all adults. Drop-out rates in the

combined group may have been due to the initial high intensity; lower intensities with a more gradual progression to higher intensity training or beginning training with balance training only and then gradually adding resistance training might have prevented the injury in the combined group.

A limitation of our study is lack of a control group. Although balance generally does not improve spontaneously and muscle strength declines over time in persons with PD,<sup>6</sup> the present data suggest it is important to include untreated patients as a control group to further study the effects of resistance and balance training and detraining. Another limitation is sample size and short training period. Group training requires extra attention to safety and biomechanical technique during exercise from many trained assistants, which prevented us from using a larger sample size. The extent to which balance can be altered through longitudinal resistance and balance programs is unclear because of the small sample size and warrants further investigation with larger study samples.

### CONCLUSION

Maintaining functional ability and preventing falls in old age are determined, in part, by maintaining some optimal level of body strength. Although further study is necessary to establish the relationship between muscle strength and balance in PD, we hypothesize that a resistance and balance training program, conducted under proper supervision, is enjoyable, effective, and a relatively safe way to improve muscle strength and balance in persons with PD who fall during dynamic posturography and may reduce the likelihood of falls during balance assessment. We further postulate that a resistance and balance training program may reduce fall risk at home and in the community with enhanced likelihood of long-term independent living.

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