The effects of a balance and strength training program on equilibrium in Parkinsonism: A preliminary study

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The purpose of this study was to determine if a balance and strength training program could improve equilibrium and strength in persons with stage I-III Parkinsonism. Subjects were pre-tested on strength and balance (EquiTest) and randomized into either a treatment or a control group. The treatment subjects participated in 10 weeks of lower limb strength training and balance exercises designed to challenge a stable posture and increase limits of stability. Both groups were then posttested on balance, knee flexion, knee extension, and ankle inversion strength. Subjects who received strength and balance training demonstrated significantly improved equilibrium and modest gains in knee flexion and extension strength, while the control group showed no improvement in conditions of destabilizing balance environments and significant declines in strength. Results indicate that 10 weeks of balance and strength training lead to improved equilibrium by producing positive changes in two different control mechanisms. One, training altered the ability to control the motor system when vestibular cues had to be the primary source of reliable feedback; and two, training helped subjects to override faulty proprioceptive feedback and utilize reliable visual or vestibular cues.

Keywords: Falls, Parkinsonism, rehabilitation

1. Introduction

Postural instability in itself is not a life-threatening problem for persons with Parkinsonism. However, a growing body of evidence \cite{8} points toward a significant increase in falls and fall related injuries in persons with Parkinsonism \cite{20,21} and higher percentages of complications and increased mortality rates following hospitalization for an injury sustained during a fall. Persons with Parkinsonism are incapacitated by a number of motor impairments which compromise the ability to maintain upright stance. Among these are rigidity, bradykinesia, impaired postural reflexes \cite{33} and dysfunctional vestibular, proprioceptive and visual systems \cite{2,3,24,34}. Physical therapy can ameliorate many functional aspects of Parkinsonism by improving motor control and reducing unwanted movements \cite{6,14,18,28,30,45}. Most of these studies, however, have not employed strength and balance exercises to improve function in persons with Parkinsonism, and only recently \cite{15} has the idea surfaced that persons with Parkinsonism could benefit from strength training.

2. Strength and Parkinsonism

Positive relationships have been found between muscular weakness and Parkinsonism. Koller and Kase \cite{22} report significantly lower knee extension and knee flexion torque values in patients with early stage Parkinsonism compared to age-matched healthy controls. Maximal isometric muscle strength was significantly decreased at the wrist, upper extremity and the knee, with no difference in strength reported between
the more affected side and the less affected side in persons with Parkinsonism. “Muscle weakness appears to be an elementary symptom of Parkinson’s disease” [22, p. 133].

These results agree with research conducted by Yanagawa, Shindo and Yanagisawa [46] who found that voluntary evoked dorsiflexion muscle torque was significantly lower in persons with Parkinsonism than in age-matched controls. In contrast, Saltin and Landin [35] found those with Parkinsonism and age-matched controls to have similar isometric knee and ankle strength torque values. Regardless of whether there is a link between Parkinsonism and muscle weakness, strength training may be beneficial to persons with Parkinsonism as it is to normal individuals. However, the role of resistance exercises in the reduction of postural dyscontrol (and the potential for improvement of strength through resistance training in persons with Parkinsonism) has not been thoroughly investigated. One study [31] that employed strength training failed to produce gains in peak torque for knee extension or flexion.

A number of studies [26,43] in older adults free of pathology have found that postural instability and an increased tendency to sway result from decreased ankle, quadriceps and hamstring strength. Recently, others [5,44] have maintained that an approach which combines strength and balance training could be useful for older adults free of pathology. Despite considerable evidence that strength and/or balance training can reduce sway in older adults [9,19,37–39] remarkably few studies examine the effects of strength and/or balance training on the ability to control balance and increase muscular strength in persons with Parkinsonism. Thus, the purpose of this study was to investigate whether a combined strength and balance training program could facilitate strength and promote positive equilibrium changes in persons with Parkinsonism. It was hypothesized that 10 weeks of balance and strength training would improve the use of vestibular, proprioceptive, visual and musculoskeletal systems used for postural control in individuals living with Parkinsonism.

3. Method

3.1. Participants

The preliminary testing was conducted with 11 subjects living with Parkinsonism, stage I–IV [17], who were randomly assigned into a treatment (n = 6) and a control group (n = 5). Three subjects (two in Stage IV and one in Stage II) were eliminated from posttesting analyses, due to medical problems (radiation treatment for melanoma, depression, and eye surgery) which arose during the study. A fourth subject was eliminated from posttesting to maintain group-stage consistency (Stage IV subjects were, therefore, all eliminated from the study), see Table 1. Thus, pre-test and posttest analyses are based on data from four persons in the treatment group (2 males, 2 females, M age = 73 years, stages I–III) and three persons in the control group (2 males, 1 female, M age = 71 years, stages I–III). All subjects continued to take their prescribed Parkinsonism medication and the control group continued with their own typical activities for the duration of the study. The study was approved by the Florida State University Internal Review Board.

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender (M/F)</th>
<th>Age (years)</th>
<th>Stage</th>
<th>Medication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>M</td>
<td>55</td>
<td>I</td>
<td>Eldepryl</td>
</tr>
<tr>
<td>Treatment</td>
<td>M</td>
<td>77</td>
<td>III</td>
<td>Sinemet</td>
</tr>
<tr>
<td>Treatment</td>
<td>F</td>
<td>77</td>
<td>III</td>
<td>Premarin</td>
</tr>
<tr>
<td>Control</td>
<td>M</td>
<td>60</td>
<td>I</td>
<td>Eldepryl</td>
</tr>
<tr>
<td>Control</td>
<td>M</td>
<td>74</td>
<td>III</td>
<td>Sinemet</td>
</tr>
</tbody>
</table>

3.2. Assessment of balance and strength

Equilibrium and muscle strength of the lower extremities were measured pre and post using the Equitest computerized dynamic posturography (CDP) [29] and Biodex b-2000 isokinetic dynamometer (Biodex Medical Systems). CDP is a reliable [29] and valid [12] method of assessing balance. The Biodex is a reliable instrument for the measurement of muscle strength [4,
The measurements were done according to the prescribed protocol and safety regulations. For balance assessment, the subject stood, with feet centered and facing the visual surround, on the Equitest forceplate, which measured the anterior to posterior center of gravity displacements in six sensory conditions. Each condition was tested in a 20 sec trial. When a fall occurred, however, subjects were tested on another 20 sec trial until they were able to maintain balance or until three trials were tested on that condition. When subjects lost their balance, they were protected from injury by a safety harness. One support surface condition, support sway-referenced (SSR), and three visual conditions, eyes open (EO), eyes closed (EC), or sway-referenced surround (SRS) were used. During SSR the floor and visual surround were controlled by a servomechanism (Gain = 1.0) to follow movements of the subjects’ center of gravity. Sway-referencing eliminates accurate somatosensory and/or visual information used to orient the body. The instructions were to stand upright and relaxed throughout the test, with knees slightly bent and arms hanging loosely at the sides of the body. Prior to each testing condition subjects were instructed that during testing the forceplate, visual surround, or both would move. For each condition an equilibrium score (0–100 points) was calculated by the Equitest system. The equilibrium score represents how much the subject sways during each trial. Scores closer to 100 indicate very little excursion or sway from vertical while scores closer to 0 indicate that subjects are approaching their limits of stability with increases in anterior/posterior displacement. The equilibrium score compares the subject’s sway during each trial to a theoretical sway stability limit of 12.5 degrees [29]. A total composite score for all three conditions (total of three conditions, 3 trials on each condition divided by 9) was used as an indicator of the subjects overall ability to adapt to altered visual and support environments [29]. The equilibrium score is ecologically valid based on the test of environmental conditions which induce falls. When the cone of stability (theoretical 12.5 degrees) is threatened as in falling, the proprioceptive, vestibular, and visual systems provide feedback to effect musculoskeletal corrections. The Equitest system provides challenges to these systems and measures the bodies biomechanical response.

The strength assessment included peak torque during ankle inversion at 120°/s, knee extension and knee flexion at 90°/s and 180°/s and were measured with the Biodex. Peak torque is the maximal rotational tendency of a joint. The ecological validity of peak torque relates to when the body starts to fall. Maximal peak torque produced by lower limb muscles are required to center the body back over the base of support thus preventing loss of balance. Peak torque is measured in foot-pounds of muscular contraction. Ankle inversion instead of dorsiflexion was measured because ankle inversion was highly correlated with balance \(r = 0.69, p < 0.01\) [41]. For both joint actions common muscle groups are utilized. Each participant performed five continuous repetitions of each joint action and the maximal peak torque occurring over those five repetitions was the dependent measure.

Saltin and Landin [35] and Toole et al. [41] found no significant differences in strength between the right and left lower extremities in Parkinsonism. Further, a regression analysis revealed that 90°/s and 180°/s knee extensor and flexor muscle strength, and 60° and 120°/s ankle inversion muscle strength were highly correlated in those with Parkinsonism (knee extensor peak torque at 90°/s and 180°/s \(r = 0.99, p < 0.001\); knee flexor peak torque at 90°/s and 180°/s \(r = 0.95, p < 0.001\); ankle inversion peak torque at 60°/s and 120°/s \(r = 0.98, p < 0.001\)). Therefore, the strength measurements were performed for only the right lower extremity at 120°/s for ankle inversion muscles and at 90°/s for knee extensor and flexor muscles. Additionally, the ratio for strength of the knee flexor muscles relative to that of the knee extensors was calculated.

### 3.3. Training

Every workout was preceded by a 10 minute warm-up consisting of a series of trunk and lower extremity stretches, gentle calisthenics movements, and five minutes on a cycle ergometer. The treatment group exercised three times per week [1] for one hour each, and a total of ten weeks. Four resistance and ten balance exercises were performed. Subjects trained the knee flexor and extensor muscle groups bilaterally, using leg extension and side lying leg flexion machines at 60% of a four repetition maximum force test. The training load for each muscle group was readjusted weekly to keep the training stimulus on 60% of the subjects’ maximum force. In order to promote a high adherence rate and prevent injury, 60% of the subjects’ maximum force was chosen. This training intensity is suitable to promote significant strength gains in lower body musculature for persons with chronic diseases [10], while minimizing the risk of injury. The training load of the ankle inversion muscles (tibialis anterior and posterior,
lasting four seconds.

For balance, an equilibrium composite was created using rubber bands of different elasticity (i.e. Theraband). Subjects had to perform three sets of 10 repetitions for each exercise with a concentric contraction lasting two seconds and an eccentric contraction lasting four seconds.

Balance was trained by systematically altering the subjects visual and support surface environments, see Table 2. Subjects performed the balance exercises under a variety of destabilizing environments, each designed to challenge their individual limits of stability. Retropulsion exercises (posterior pulling, see Table 2) consisted of five strong pulls backward, at the subjects shoulders, while standing on a fixed surface with eyes open, and ten mild to moderate pulls while standing on foam. In addition, subjects underwent a series of randomly induced antero-posterior and lateral forced-displacement exercises, consisting of mild to moderate antero-posterior and lateral pushing with feet together and feet shoulder width apart. Subjects also had to sway toward one of eight fixed targets (Bug exercise, see Table 2), maintaining an upright, fixed position while standing on a non-compliant surface and while standing on foam pads. These training conditions are consistent with those used by others [19,36,38,39].

### 3.4. Data analysis

Pre and posttest raw data were used in several analyses. All analyses utilized the analysis of variance (ANOVA) technique with the statistical package for the social sciences (SPSS). The dependent variables were equilibrium, strength for knee extension, knee flexion, and ankle inversion, and knee extension/flexion ratio. For balance, an equilibrium composite was created using the three difficult balance conditions 4, 5, and 6 (these are the last three conditions on the typical Sensory Organization Test of the Equitest, NeuroCom Inc.). All nine scores (three for each trial) were added and an average was taken. It was decided to use another measure of balance, path sway during voluntary weight shifting (anterior/posterior displacement), as a covariate for the equilibrium composite analysis. It was thought that this other indicator of balance would help to reduce the large variability known to exist in Parkinson’s disease equilibrium scores as measured on the Equitest [41]. The independent variables were group and pre/posttest producing a $2 \times 2$ mixed model ANOVA with repeated measures on the last factor. The factor of pre/post represents “time”, or scores before the intervention and scores after the intervention. For each of the strength analyses, the independent variables were group and pre/posttest which utilized a $2 \times 2$ ANOVA with repeated measures on the last factor. Tukey’s HSD test was used as a follow-up test for all ANOVAs. The level of significance was set at $p < 0.05$.

### 4. Results

In order to explore the possibility that group means for strength and balance scores were not equal prior to the beginning of the intervention, we used one-way ANOVAs to determine whether the treatment and control groups differed significantly from each other. Despite differences in the number of falls sustained during the balance pre-test, the groups were not statistically different on either strength or balance measures on the pre-test.

#### 4.1. Strength

The analysis of knee flexion strength produced a significant group by pre/posttest interaction, $(F(1.5) = 13.94$, $p = 0.014$, see Fig. 1). Tukey’s HSD post hoc procedure $(HSD = 9.01)$ did not produce any pairwise significant differences, see Table 3 and Fig. 1. Thus, the statistical interaction occurred due to declines in knee flexor strength in the control group from pre to posttest and general improvements, although not significant, in knee flexor strength in the treatment group over the duration of strength training. However, the fact that there was a significant interaction of group with time (see Fig. 1) shows that modest improvements due to training in combination with declines due to no training produced a significant interaction result.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Equitest</th>
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<tbody>
<tr>
<td>Posterior pulling (Foam)</td>
<td>EO*</td>
</tr>
<tr>
<td>Posterior pulling (Foam)</td>
<td>EC</td>
</tr>
<tr>
<td>Anterior and posterior (Foam)</td>
<td>EO</td>
</tr>
<tr>
<td>Retropulsion (Foam)</td>
<td>EC</td>
</tr>
<tr>
<td>Retropulsion (Foam)</td>
<td>EO</td>
</tr>
<tr>
<td>Bug (Foam)</td>
<td>EO</td>
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</tbody>
</table>

EO = eyes open; EC = eyes closed; Bug = subject had to sway toward one of eight fixed targets (finger of experimenter placed at waist height approximately one foot from participant’s waist in eight positions, octagon shaped, around the participant).

*Note: All conditions are support surface sway referenced on the Equitest.

**Table 2** Balance training conditions as they relate to the specific balance exercises
For the analysis of knee extension, there was a significant group by pre/post interaction ($F(1, 5) = 0.32$, $p = 0.02$), see Fig. 2. Tukey’s HSD (5.64) again, did not produce any pairwise significant differences. There were declines over time for the control group and improvements in knee extensors for the trained group and these two changes produced the significant interaction. For the analysis of right ankle inversion and the ratio of hamstring to quadriceps group, there were no significant effects.

4.2. Equilibrium

Table 3 also presents means and standard errors of the mean for equilibrium. Using the equilibrium composite score with the covariate of path sway on a voluntary task, the group by pre/posttest interaction was significant, $F(1, 4) = 326.2$, $p < .001$. The strength and balance training group improved significantly from pre to posttest (Tukey HSD = 2.28), while the control group did not produce significant change, see Fig. 3. In addition, on the posttest, the strength and balance group was significantly better than the control group. Furthermore, this interaction accounted for a very large 98% of the variability (eta squared = 0.988) and power was 1.00.

The number of times the subjects in the control and strength and balance training group lost balance during posttesting decreased from pre tests. During the pre test there were eight falls on condition 5 (eyes closed and floor sway referenced) or condition 6 (surround sway referenced and floor sway referenced) for the exercise group (44% of trials resulted in falls for persons in the exercise group; 11.1% of trials resulted in falls for persons in the control group). There were no falls for experimental or control subjects during any portion of the balance posttest. This phenomenon probably reflects a learning effect, in part, but the larger reduction in falls observed from the treatment group subjects (44% of pretest trials and 0% posttest trials) would seem to largely reflect a training effect.

5. Discussion

The purpose of this study was to determine if a balance and strength training program could improve equi-
librium and strength in persons with stage I–III Parkinsonism. It was hypothesized that 10 weeks of balance and strength training would improve the use of vestibular, proprioceptive, visual and musculoskeletal systems used for postural control in those who have Parkinsonism. The results provide evidence that people living with Parkinsonism can increase balance performance and promote modest gains in strength (significant interaction in knee flexion and knee extension peak torque between groups and before and after the intervention), as a result of 10 weeks of balance and strength training. Subjects in the treatment group showed an increased ability to adapt to rapidly changing environmental conditions and a reduced tendency to fall. The results indicate that persons with pathology such as Parkinsonism have the potential to improve balance and demonstrate modest gains in strength in spite of the degenerative nature of their illness.

Standing balance is a complex process controlled by the integration and weighing of afferent sensory information from multiple systems within the central nervous system. Marsden [27] hypothesized that motor planning is severely affected in persons with Parkinsonism. He also states that motor plans are learned through practice. Our approach was to view postural dyscontrol in Parkinsonism as a multifactorial problem. Factors contributing to postural dyscontrol have been identified as dysfunctional visual, vestibular and proprioceptive information flow [2, 3, 24, 27, 34], disorders of righting and protective reactions [33], increased rigidity, bradykinesia [23], and lack of muscular strength [43]. The contribution of each of these individual factors to the overall clinical picture of an unstable, frequently falling parkinsonian, is unknown. Postural instability resulting from this plethora of factors results in an increased risk of falling in persons with Parkinsonism [21]. Koller et al. [21] noted that frequent fallers
did not improve their frequency of falling by changing the dose of their levodopa, but proposed that their patients were able to demonstrate improved equilibrium after having been exposed to physical therapy exercises. Our study lends support to the statement that people with Parkinsonism can benefit from balance training because they may involve practice of motor plans which are used in the planning and execution of movements required to keep the body in a state of equilibrium. There are other explanations, however.

Exercises in the present training program were designed to challenge the vertical position of the body and increase the limits of stability in order to improve equilibrium when the body was destabilized. Trained subjects were able to significantly improve their equilibrium (as evidenced by the composite score change on conditions 4, 5, and 6) under all three visual conditions when the floor was sway-referenced. That is, after balance training, a destabilizing surface was not as formidable when eyes were open or closed, or when visual cues were faulty. Balance training, in addition to lower limb strength training, facilitated the use of proprioceptive, visual, and vestibular cues in order to stabilize the body, increase equilibrium scores, and prevent falls.

Several balance mechanisms could have benefited from the exercise program and, in turn, improved equilibrium. Trained subjects were able to divorce themselves from absent or misleading visual information. Instead, the significant interaction suggests that they probably utilized improved proprioceptive feedback, including joint angle and muscle stretch responses or they were better able to use proprioceptive feedback to exert control over the body. Additionally, they may have improved their use of vestibular sensory sway feedback cues and relied on an improved musculoskeletal system to apply stronger force levels to counteract sway during moments of threatened stability.

We also sought to positively affect lower limb strength. The significant interactions for knee flexion peak torque and knee extension peak torque demonstrated declines in the control group and gains, although modest, for the treatment group. This combination of decline and gain produced the significant interaction. These interactions suggest that subjects used increased muscular strength in the hamstrings group and in the quadriceps group to benefit equilibrium.

Along with greater stability through increased muscular strength, trained subjects may have altered the sensory threshold for sway detection. By responding appropriately during sway conditions where vision was absent and proprioception was misleading or inaccurate (that is, the improvement in equilibrium on conditions 4, 5, and 6 for the treatment group), subjects had to rely more on their vestibular apparatus for motion detection and compensation. One purpose of vestibular therapy is to encourage patients to increase their sway detection sensitivity through active weight shift exercises on non-compliant surfaces (with eyes open and closed, forcing them to rely on vestibular cues during balance retraining). Vestibular rehabilitation exercises are used to treat a variety of balance disorders [38,39] in persons for whom surgical or pharmacological interventions are either untenable or unsuccessful. These exercises are particularly beneficial for persons who fall on the sensory organization portion of dynamic posturography [39,40] and have also been used to improve balance sensitivity in persons with Parkinsonism [36]. It is conceivable that because subjects trained without emphasis on how to use visual cues in balancing, they relied more on the vestibular system and therefore trained this system more. Other studies [3,42] have found that persons with Parkinsonism demonstrate an increased dependence on visual feedback in order to prevent dysequilibrium and falling. The results from the present study indicate that it is possible to decrease this dependence in favor of using vestibular cues for balancing. A larger improvement of equilibrium could be expected when balance training emphasizes the use of visual cues.

A linear regression analysis [41] indicated a predicted increase in equilibrium composite score with increases in strength of ankle inversion and percent strength for the hamstring muscle group relative to that of the quadriceps group. These results suggested that posture control of subjects in the present study could be improved by strengthening inversion of the ankle joint, and strengthening flexion at the knee relative to that of extension. Therefore, the strength and balance training program was designed to facilitate these behaviors. Because the treatment group did not significantly improve their ankle inversion or the ratio of knee flexion to knee extension, it would seem that a higher training stimulus is required to see benefits in these muscle groups. The intensity of the training stimulus has a significant effect on strength gains achieved. High intensity strength training for older adults has promoted strength increments between 57% and 174% for the knee extensors [7,9,10,13,32].

However, studies [10] using lower intensities to promote strength gains, similar to ours, have also produced increases in strength in frail institutionalized
older adults. Deconditioned individuals may benefit from lower intensity strength training. Greater intensities may have improved strength gains even further.

The strength training program utilized in the present study produced positive changes in knee flexion peak torque and knee extension peak torque while the control group experienced declines. Unlike other research [31] which showed no change in peak torque for knee extension after strength training, the present subjects produced modest gains in the quadriceps muscle group. Therefore, improved hamstring and quadriceps strength may have contributed to increased steadiness of the knee, resulting in higher balance scores on the most difficult portion of the balance posttest. Fisher et al. [10] who used a similar training intensity with an institutional population found a 15% increase in knee extension after six weeks of strength training. Although the improvements of our subjects were modest compared to other studies [7,9,13,32], small, albeit significant changes in strength, may bring about meaningful functional outcomes.

A limitation of our study is the sample size. Since this was our first intervention study using a population at risk during exercise protocols, we were extremely careful to prevent accidents. This care required extra attention to safety and biomechanical technique during exercise from many trained assistants, which prevented us from utilizing a large study sample. The extent to which balance behaviors can be altered through longitudinal strengthening and balance programs is unclear due to the small sample size, and warrants further investigation utilizing larger sample sizes, and more homogeneous groups (utilizing all at the same stage). The general concept that age-related loss of muscular strength and decreased ability to control body sway can be treated with exercise intervention has been supported by many studies. This evidence has led others to suggest that strength training could “complement more traditional treatment approaches in Parkinson’s disease” [15, p. 68] in order to decrease the risk of falling in persons so afflicted. We hypothesize that strength and balance training can be useful for people with Parkinsonism who fall during dynamic posturography, although further study will be necessary to establish the relationship between improvements in strength and control of equilibrium. Improvements in strength and balance may be attributed, in part, to the brain’s remarkable plasticity. Our findings imply that an organism’s capacity to adapt and create new organization and order is not necessarily limited by disease. The authors are currently designing experiments to test whether balance training alone is superior to a combination of strength and balance training and the effect of such training on activities of daily living in persons with Parkinsonism.

6. Conclusions

This study has examined the combined effect of strength and balance training on balance in persons with stages I–III Parkinsonism. Improvements were noted in strength and equilibrium, particularly in the hamstring and quadriceps groups muscle strength and balance on conditions where proprioceptive cues were unreliable and vision was present, absent, or faulty. Results indicate that 10 weeks of balance and strength training lead to improved equilibrium by producing positive changes in two different control mechanisms. One, training altered the ability to control the motor system when vestibular cues had to be the primary source of reliable feedback; and two, training helped subjects to override faulty proprioceptive feedback and utilize reliable visual or vestibular cues.

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