Motor Learning and Parkinson Disease: Refinement of Movement Velocity and Endpoint Excursion in a Limits of Stability Balance Task
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Neurorehabil Neural Repair 2006; 20; 459
DOI: 10.1177/1545968306287107

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Objective. To investigate the effects of practice on performance and retention of a balance task in persons with Parkinson disease (PD). Methods. Ten persons with PD and 10 age and gender-matched healthy control subjects were tested on an anticipatory, static base of support, limits of stability (LOS) balance task on a force plate. The motor learning paradigm utilized for all subjects included an acquisition phase and retention tests at 24 h and 1 week after acquisition. A force plate was used for testing and to collect outcome measures including movement velocity (MVL), endpoint excursion (EPE), and directional control. Data were analyzed for differences between groups and change over time. Results. Persons with PD demonstrated performance deficits relative to controls for MVL at all testing periods (P < 0.05), and initially for EPE (P < 0.05), but were able to maintain significant improvements through retention testing relative to baseline (P < 0.05). Conclusions. Persons with PD demonstrated unimpaired capacity for motor learning in a LOS balance task for MVL and EPE, although performance deficits remained for MVL. The results concur with previous motor learning research of upper extremity tasks by suggesting that individuals with mild to moderate PD exhibit a preserved ability to benefit from practice as a means of improving balance task performance.

Key Words: Parkinson disease—Motor learning—Limits of stability—Balance—Practice.

Persons diagnosed with idiopathic Parkinson disease (PD) experience movement disorders affecting balance that can lead to significant disability. Pharmacological management effectively reduces the symptoms experienced and at least partially restores motor control and balance function.\(^1\)\(^2\) Even with optimal medication use, hypokinesia, postural instability, and falls become increasingly problematic as the disease progresses. Up to 60% of persons with PD experience falls, and some of this group may fall more than twice a week. Persons with PD are 5 times more likely than healthy older adults to suffer fall-related injuries.\(^3\)\(^4\)

Balance deficits in individuals with PD, although not well understood, have been attributed in part to neurotransmitter disturbances between the basal ganglia and other motor centers such as the supplementary motor cortex and the portion of the brainstem responsible for maintaining upright stance.\(^5\)\(^6\) Once the primarily automatic and well-learned function of balance is compromised, practice of the impaired task may be employed to compensate for the motor deficiencies that result in balance deficits. Studies examining a practice paradigm that incorporated force platform biofeedback in persons following stroke have demonstrated improvements in limb loading and the control of weight shifting.\(^7\)\(^8\) These findings suggest that some types of focal cerebral injury do not completely limit an individual's ability to re-learn postural motor tasks.

Motor learning is the process due to practice or experience that leads to a relatively permanent change in the capability to achieve a motor task goal.\(^12\) The degree to which motor learning is affected in individuals with PD is uncertain.\(^13\)\(^14\) The cerebellum is traditionally considered the primary structure involved in motor learning\(^9\)\(^15\) although there is growing evidence suggesting the basal ganglia, which are affected by the disease, play a role as well.\(^14\)\(^16\)\(^17\) There is some evidence that the novelty or early phase of motor learning is affected,\(^17\) as well as motor learning in which the subject is required to adapt to changing sensorimotor information.\(^17\)\(^19\)\(^20\)

Despite evidence suggesting impairment of motor learning in persons with PD, many studies have shown that the disease process does not impair motor learning. Performance in upper extremity motor tasks improves and is retained with practice in individuals with PD similarly to the improvement and retention exhibited by healthy elderly individuals.\(^18\)\(^22\)\(^26\)

The utilization of balance practice in rehabilitation programs for individuals with PD is common. No
studies have tested whether the motor learning effects found in upper extremity task paradigms can also be found for balance task paradigms that require the coordinated use of lower extremity and trunk muscles. The purpose of this study was to investigate the effects of practice on performance and retention of a balance task in individuals with PD in comparison to individuals in an age-matched, healthy control group. It was hypothesized that participants with PD would demonstrate similar motor learning effects when compared to their healthy elderly counterparts for all variables, while performance deficits would remain, relative to controls.

METHODS

Participants

Ten persons with mild to moderate severity (Hoehn and Yahr stage II-III) PD and 10 healthy age- and gender-matched persons participated in this study. Both groups had a 6:4 male-to-female ratio and were similar in age. Age, disease duration and severity, and recorded falls in the previous year are listed individually for the PD group participants and by group in Table 1. All participants in the PD group were taking either dopamine agonist or dopamine replacement anti-parkinsonian medications. These medications were kept at consistent dosages and medication times throughout the course of the study. At the time of the study, all PD participants were attending an exercise wellness program at the University of Utah’s Rehabilitation and Wellness Clinic. Matched control group participants were recruited from the local community and represented a nonneurologically impaired, healthy elderly population. Participants were excluded from the study if they had any concomitant medical, neurological, and orthopedic conditions that would prevent them from completing the task. Although individuals who had a history of falls were not excluded from the study, none of the participants had a history of recurrent falls. Prior to participation, all subjects read and signed a University of Utah Institutional Review Board–approved informed consent form.

Apparatus and Task

Testing was performed on a Neurocom Balance Master System (Neurocom International Inc., Clakamas, OR), which consists of a force plate connected to a computer and monitor. The Balance Master system has 4 symmetrically positioned force transducers that measure vertical pressures applied by a standing person to the support surface. These vertical pressure data were used to derive anteroposterior and mediolateral coordinates of the center of pressure, which were subsequently used to calculate the spatial and temporal characteristics of the projected COG movements. The manufacturer’s software was used to provide visual feedback during task performance and for data collection (Figure 1A).

Participants were tested on a visually guided balance task that consisted of moving their center of gravity (COG) to 2 predetermined targets while maintaining a stationary base of support. Center of gravity position on the force platform was visually represented on the computer screen as a stick figure. By shifting their weight in anterior and right or left lateral directions, participants would move the stick figure visual representation of the
participant’s current COG position toward that target. Figure 1B illustrates the target positions relative to the center starting position and the trajectory of the COG movement toward the target for 2 trials of a representative participant. During each trial, the visual feedback provided to participants only reflected their current COG position and not their trajectory.

Outcome measures included movement velocity, endpoint excursion, and directional control. Movement velocity (MVL) is the average speed of COG movement in degrees per second. Endpoint excursion (EPE) is the distance of the 1st movement toward the designated target, expressed as a percentage of maximum limits of stability (LOS) distance. The endpoint was defined as the point at which the initial movement toward the target ceased. Directional control (DC) was the comparison of the amount of movement in the intended direction (toward the target) to the amount of extraneous movement (away from the target).27

Testing was modified from the available LOS balance task to include only 2 of the 8 available targets. The right forward and left forward targets were chosen (Figure 1B) to distribute the potential effects of leg dominance for both groups and the “more affected side” for individuals in the PD group.

Procedure

Testing took place at the same time on each of 3 testing days to ensure that participants with PD were at the same point in their medication cycle. Testing was scheduled to take place approximately 1 to 2 h after the patient had taken his or her medication so that the pharmacological influence would be consistent.

On the 1st day of testing, each participant’s height was used to create a personal profile, which assigned the correct foot placement on the force plate. A blank paper template was secured to the force plate, and the tester then positioned the participant’s feet according to the patient’s profile. To ensure accurate foot placement for the duration of testing, the foot placement was traced onto the template, then used for positioning between trials and between testing days. A 2nd profile was created for each participant in which 5 inches were added to the actual height, thereby extending the distance to the targets located at the theoretical limit of stability. This was done to avoid a task ceiling effect that had been observed in preliminary testing; many pilot subjects were able to meet or exceed the targets, even on the initial movement to target (EPE). Testing was completed using the 2nd profile with the foot template created from the 1st profile.

After proper foot placement, participants were instructed to observe how they could move their COG, utilizing the computer monitor located in front of the force plate. Two minutes were allowed for the participants to become accustomed to moving while watching the stick figure representation on the monitor. Instructions were then given about the target boxes they would be attempting to reach (left forward and right forward).

Each participant was given standardized instructions to start the trial with the stick figure in the center box (representation of theoretical COG in neutral stance) and, upon verbal cuing, to move the stick figure toward the selected target box as quickly, accurately, and far as possible. Participants were told to hold their position once the limit was reached until the 10-s trial was completed. Standardized positive verbal reinforcement was given on all trials. To prevent participants from experiencing a fall during testing, the tester stood beside the participant within arm’s reach. If a loss of balance (defined as any reaching or grabbing for external support or taking a compensatory step) was experienced, the trial was discarded and performed again.
The 1st day of testing was the acquisition phase or initial practice phase. The subject first moved to the right target box and then to the left target box. This sequence did not vary throughout the study. When 1 successful attempt without falling or stepping was made to each of the 2 target boxes, the data were stored as 1 complete trial. After 3 successful trials, the 1st “block” of testing was complete and the subject was given a 2-min seated break to prevent fatigue. The above procedure was repeated 4 more times for a total of 5 blocks of 3 trials each or 15 trials to each target.

Participants returned for retention testing 24 h after the initial acquisition phase and 1 week later. Both of these testing periods followed the same protocol as the acquisition phase testing with the exception that retention testing consisted of only 2 blocks (6 trials to each target). Also, during retention testing, participants were not given the 2-min warm-up period.

ANALYSIS

The independent variables of interest were group (PD group, control group) and time (acquisition, 24-h retention, 1-week retention). The dependent variables examined in this study were movement velocity (MVL), endpoint excursion (EPE), and directional control (DC). All data were collected for both the right-forward and left-forward targets and were combined together for each variable prior to data analysis. This was done because review of descriptive statistics revealed no differences between right and left target directions at each testing period for all variables, demonstrating that the effects of leg dominance and “more affected side” were distributed evenly between targets.

The 1st block of the acquisition phase was considered baseline performance for each variable. The last block of the acquisition phase was considered end of acquisition. Because of our interest in the best performance by participants during the retention testing, block 2 of the retention testing at 24 h and 1 week was used for statistical analysis. Changes in the dependent measures over the course of the acquisition period were considered acute performance changes, whereas motor learning was operationally defined as the preservation of improvements from baseline acquisition to the 24-h and 1-week retention periods.12

To control for the effects of sample size and normality of data, nonparametric tests were chosen for statistical analysis. Friedman tests were used to determine within-group differences over time. When within-group differences over time were identified, separate Wilcoxon signed ranks tests were used to determine the location of these differences. Mann-Whitney U tests were used to identify differences between groups at each testing period. A 1-tailed α level of $P = 0.05$ was used to identify statistically significant results.

In addition, to gain insight into the practical significance of between- and within-group differences, an estimate of the magnitude of differences that used post hoc effect sizes was calculated (ES = Mean_group1 – Mean_group2/ SDpooled1). The ES is a value that reflects the impact of a treatment within a sample of interest and is interpreted according to established criteria as small (<0.41), medium (0.41–0.70), or large (>0.70).28-30

RESULTS

Movement Velocity

Comparison of MVL between the PD group and the control group revealed differences in MVL between the groups at all testing periods including baseline ($P = 0.02$), end of practice ($P = 0.001$), 24-h retention ($P = 0.001$), and at the 1-week retention test ($P = 0.01$). Individuals with PD demonstrated significantly slower movement velocities than controls at all testing periods in the study (Figure 2A, Table 2).

Improvements in MVL in both the PD group ($P = 0.001$) and the control group ($P < 0.001$) were found over the 4 testing periods from baseline through
1 week retention testing. Post hoc analyses indicated increases in MVL relative to baseline for each testing period (both groups for all tests, \( P < 0.01 \)), meaning that all subjects were able to maintain improvements made during the acquisition phase. From baseline, the PD group improved an average of 24% during acquisition, compared to 26% by the control group. By 1 week, the PD group had improved to 36% above baseline, whereas the control group remained 22% improved from baseline (Figure 3). Both groups exhibited motor learning for MVL, with the PD group demonstrating a larger margin of improvement than the control group (Figure 3).

DISCUSSION

The aim of the present study was to explore the ability of persons with PD to demonstrate motor learning in a visually guided, LOS balance task. Individuals with PD in this study were able to improve their movement velocity and endpoint excursion and maintain those improvements for at least 1 week. These results suggest that motor learning did occur in these individuals. When compared to age- and gender-matched control participants, PD group participants performed at lower levels as expected. However, they improved at similar rates, suggesting that motor learning capability in this balance task was not impaired.

End Point Excursion

The PD group consistently performed at lower levels than the control group relative to EPE, but only significantly at baseline and at the end of acquisition (\( P = 0.03; P = 0.04 \)). There was no difference between groups at 24-h retention testing (\( P = 0.13 \)) or at 1 week (\( P = 0.14 \)).

The PD group improved over the course of testing (\( P = 0.03 \)). Post hoc analyses revealed significant improvements relative to baseline at all testing periods (for all tests, \( P < 0.05 \)), indicating improvement after acquisition and maintenance of those improvements through retention testing. The control group also improved in EPE performance, although not to statistical significance (\( P = 0.06 \)) (Figure 2B, Table 2).

The PD group improved 8.5% during initial practice and remained 11.3% improved relative to baseline at 1-week retention testing. These findings indicate the presence of motor learning for EPE in the PD group. For the control group, the improvements made relative to baseline during acquisition (7.3%) were maintained at 24-h retention testing (6.1%) but declined to near baseline levels at 1-week testing (1.2% relative to baseline; \( P = 0.31 \)) (Figure 3).

Directional Control

Participants in the PD group performed with more accuracy than control group participants at multiple testing periods including baseline (\( P = 0.01 \)), end of acquisition (\( P = 0.03 \)), and 1-week retention testing (\( P = 0.05 \)). No differences were found between groups at 24 h (\( P = 0.19 \)). Neither group improved in DC over time (PD group: \( P = 0.14 \); control group: \( P = 0.39 \)), suggesting that motor learning for DC did not occur for either group (Figure 2C and 3, Table 2).

Methodologies

Several studies have examined motor learning in PD using tightly constrained upper extremity tasks.\(^{22-26}\) This is also a common research paradigm in the motor learning literature for other neurological disorders such as stroke.\(^{16,31}\) This approach allows for greater control of environmental factors and confounding variables to maintain high internal validity. In this study, a motor learning paradigm utilizing a visually guided, LOS balance task was chosen to improve the external validity of motor learning research in PD. The balance task was chosen because the maintenance of balance is an extremely relevant task for the safety of persons with PD, compared to the laboratory-based upper extremity tasks previously described in the literature. To our knowledge, this type of motor learning paradigm has never been examined in an anticipatory control balance task in PD.

An LOS balance task was chosen because deficits have been described in the ability of persons with PD to voluntarily move their COG over their base of support\(^{22}\) and particularly in those with a history of falls.\(^{33}\) Reactive control has also been shown to be impaired in individuals with PD. Specifically, the ability to integrate and react to proprioceptive sensory information is thought to be impaired.\(^{19,20,34}\) The effect of practice on improving reactive control was examined in a recent report by Jobges et al.,\(^{35}\) who found that individuals with mild to moderate PD were able to improve their ability to respond to perturbations, then maintained their improvements for at least 2 months. In this study, practice was performed for 10 days, twice a day for 20 min each session, resulting in 3600 to 4600 trials. The training effects, then, may have resulted from both motor learning and physiological changes at the muscular level. Also, the absence of a control group prevents comparison to unimpaired subjects in relative ability for motor learning to occur in persons with PD.
One of the challenges for the methodology of this study was balancing the need for an adequate amount of practice with the confounding variable of muscle fatigue induced by repetitive practice of the balance task. Pilot testing revealed that increasing the number of trials beyond 15 to each target resulted in muscle fatigue and cramping, particularly in the intrinsic muscles of Jessop and others.

Table 3. Effect Sizes Given for between- and within-Group Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>End of Acquisition</th>
<th>1 Week</th>
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<tbody>
<tr>
<td><strong>MVL</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Group</td>
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<tr>
<td>Time</td>
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</tr>
<tr>
<td>PG</td>
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<td>0.81</td>
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<tr>
<td>CG</td>
<td>—</td>
<td>0.66</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>EPE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>0.66</td>
<td>0.72</td>
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</tr>
<tr>
<td>Time</td>
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</tr>
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<td>PG</td>
<td>—</td>
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<tr>
<td>CG</td>
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<td>0.38</td>
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</tr>
<tr>
<td><strong>DC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
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<td>0.73</td>
<td>0.58</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG</td>
<td>—</td>
<td>0.29</td>
<td>0.20</td>
</tr>
<tr>
<td>CG</td>
<td>—</td>
<td>0.14</td>
<td>0.23</td>
</tr>
</tbody>
</table>

PG = PD group; CG = control group. Baseline boxes are empty because comparisons were to baseline. Relative size of Cohen $d$: small (<0.41), medium (0.41-0.70), or large (>0.70).27-29

Figure 2. A, Movement velocity. B, Endpoint excursion. C, Directional control. A single asterisk (*) indicates a significant difference between groups ($P < 0.05$). Two asterisks together (dark** or light** color coded by group) indicates a significant change over time relative to baseline ($P < 0.05$). Data from all practice blocks are included to show improvement trends, but testing only occurred on acquisition blocks 1 and 5, and block 2 of the 24-h and 1-week retention tests. LOS = limits of stability.

Figure 3. Percentage change relative to baseline for the outcome measures. PG = PD group; CG = control group; MVL = movement velocity; EPE = endpoint excursion; DC = directional control.
the feet, resulting in decreased task performance. When examining the motor learning literature in PD with upper extremity task paradigms, practice trials ranged from 18 to 400. Retention testing used to determine presence of motor learning ranged from immediate to 48 h. In the current study, there were fewer practice trials and more delayed retention testing, out to 1 week following task acquisition. Therefore, we feel significant and persistent changes reflect true motor learning, rather than temporary practice effects.

Effects of Training on Bradykinesia

The practice effects on bradykinesia are arguably the strongest results of this study. MVL was the only variable in which hypothesized differences between groups existed at all testing periods and changes over time were significant for both groups. The significant decreases found in the MVL of the PD group relative to the age-matched control group for all testing periods are reflective of the effects of bradykinesia in persons with PD. Our results relative to speed of movement concur with those found by previous researchers. All of these studies found deficits in movement velocity in subjects with PD relative to control subjects throughout testing. In addition, in all of these studies, individuals with PD demonstrated motor learning with improvements and retention of movement speed. The fact that the margin of improvement continued to increase for the PD group after acquisition and not the control group suggests that individuals with PD may have a greater likelihood than healthy elderly patients of continued improvement with increased amounts of practice.

Slowness of movement, whether caused by PD or the natural aging process, can significantly affect performance of daily activities that include balance. Data from the current study in concert with previous literature support the use of practice as a tool to increase speed of movement in a static base of support balance task in medicated persons with mild to moderate PD as well as healthy elders.

Pushing the Limits of Stability

Although evidence suggests that the ability to move the COG over the base of support is impaired in people with PD, no data are currently available in the literature describing the response to repetitive training of moving one’s COG to the limit of stability. Current findings that subjects with PD demonstrated less excursion than control subjects support previous literature describing deficits and may be the result of several factors. Impaired strength has been observed in persons with PD and tends to be more pronounced in extensor muscles, which are the muscles that would be expected to be most active in a balance task. Endpoint excursion reflects the 1st smooth movement to the target, so deficits may also be associated with impaired electromyographic activation patterns. Abnormal modulation and scaling of agonist and antagonist muscle bursts have been described in single-joint upper extremity tasks. Finally, deficits may have been due to a decreased perceived limit of stability in persons with PD. Fear of falling has been correlated to increased postural sway in subjects with PD relative to healthy controls during various balance tasks.

No tests of these potential factors were performed, so we cannot determine the factors responsible for the observed deficits relative to controls or which factors were responsible for the observed improvements in performance. However, because of the relatively brief period of practice and testing, performance improvements probably did not result from increased strength but rather from a combination of other factors. It is possible that improved muscle activation patterns contributed to observed improvements. Support comes from Flament et al. who reported that EMG patterns improved with practice but remained fractionated relative to controls. Also, participants were possibly able to increase their perceived limits of stability as they became accustomed to the task and confident in their ability to effectively "push" their limits of stability.

Control group participants were able to improve EPE during task acquisition, demonstrating the initial practice effects. However, they were unable to maintain improvements compared to PD group participants in our study, meaning by our operational definition that motor learning did not occur for EPE. Our best explanation for the subsequent drop-off in performance after initial acquisition arises from observations that many of the control subjects seemed to lose motivation to perform maximally, especially at 1-week retention testing. Despite increasing the target distance, a ceiling effect may have kept individuals in the control group from attaining significant improvements. This is unlikely, however, because instructions were to move as far as possible, even if it meant moving past the target. Furthermore, a task ceiling effect does not explain the performance drop-off after initial acquisition.

Directional Control

Improvements in accuracy by practice in persons with PD have been demonstrated in upper extremity aiming movements. Gains did not occur for either...
group in this study, which may reflect the complexity of the task for coordinated muscle activation, the relatively modest amount of practice, and the small sample size. Interestingly, PD group participants performed with more accuracy than control group participants. This finding may be due to a type II statistical error, but if the results truly do reflect a difference between groups, it is possible that having been given identical instructions, the PD group chose to focus on the “accurate as possible” directions, whereas the control group chose to focus on the “as quickly as possible” directions. Anecdotally, many of the PD group participants reported being more cautious in their movements in general, which would have allowed more attention to be focused on accuracy. Although directional control did not improve for either group, neither did it decrease as movement velocity increased.

IMPLICATIONS AND LIMITATIONS

The present study has shown practice to be beneficial in improving and maintaining gains in movement velocity and excursion during a balance task in medicated individuals with mild to moderate PD. Furthermore, these data demonstrate that although performance deficits may persist, persons with PD can be expected to improve at similar rates to nonneurologically impaired elderly persons. To control for threats to internal validity, our design limited the examination of LOS to outcomes measured on a force plate. This aspect of the design coupled with the relatively small sample size limits the ability to generalize beyond the sample studied and the task performed. Despite these limitations, statistical measures of practical significance (effect size) ranged from medium to large26,20 (Table 3). Such effect sizes suggest that the practice-mediated changes in balance task performance may have clinical significance.29

Future research with larger sample sizes will be necessary to determine the appropriate practice schedules needed for motor learning to occur in various balance tasks. Additional research is also needed to determine which approach to motor learning is most beneficial for retention of practice benefits. In the current study, participants were provided continuous knowledge of performance during each trial but were not provided knowledge of results until after testing was completed. Although not advocated for optimal motor learning in healthy subjects,12 the provision of frequent knowledge of results may be more beneficial for persons with PD to promote motor learning.38 Also, participants in this study practiced the task in an unvaried order, and it remains unclear if the motor learning benefits observed were task specific or specific to the order of practice. Although this study demonstrated no motor learning deficits in PD, controversy remains regarding the process of motor learning and how to optimize rehabilitation outcomes.

ACKNOWLEDGMENTS

The authors acknowledge the participants and the University of Utah Rehabilitation and Wellness Clinic for providing the space and equipment for this research. This study was supported in part by a grant from the Utah Chapter of the American Parkinson Disease Association.

REFERENCES


