Leg muscle power is enhanced by training in people with Parkinson’s disease: a randomized controlled trial

Serene S Paul1, Colleen G Canning1, Jooeun Song1, Victor SC Fung2,3 and Catherine Sherrington4

Abstract
Objective: To determine the effects of leg muscle power training in people with Parkinson’s disease.
Design: Randomized controlled trial.
Setting: University laboratory (outcome measures and experimental intervention), community (control intervention).
Subjects: Community-dwelling people with Parkinson’s disease.
Interventions: Leg muscle power training using pneumatic variable resistance equipment (experimental) was compared with low intensity sham exercise (control). Both groups exercised twice weekly for 12 weeks.
Main measures: Primary outcomes were peak power of four leg muscle groups. Secondary outcomes were measures of muscle strength, mobility, balance and falls.
Results: Exercise adherence was high in both groups. Leg muscle power was significantly better in the experimental group than the control group in all four primary outcome measures at 12 weeks after adjusting for baseline values: leg extensors (57.9 watts, 95% confidence interval (CI) 22.0–93.7, p = 0.002); knee flexors (29.6 watts, 95% CI 7.4–51.8, p = 0.01); hip flexors (68.1 watts, 95% CI 19.6–116.5, p = 0.007); and hip abductors (37.4 watts, 95% CI 19.9–54.9, p < 0.001). The experimental group performed significantly better on tests of leg muscle strength (p < 0.001 to 0.07) and showed trends toward better performance in the Timed Up and Go (p = 0.13) and choice stepping reaction time (p = 0.11). There was a non-significant reduction in the rate of falls in the experimental group compared with the control group (incidence rate ratio 0.84, p = 0.76).
Conclusions: This programme significantly improved muscle power in all trained muscle groups.

Keywords
Parkinson’s disease, muscle strength, exercise programme, balance, mobility

Received: 18 April 2013; accepted: 10 September 2013

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Introduction

Muscle power is the product of the force and speed of muscle contraction, i.e. muscle power is a reflection of a person’s ability to use their muscles quickly. Reduced leg muscle power has recently been confirmed as a motor impairment in people with Parkinson’s disease. Despite optimal medical management, deficits in muscle power are common in people with Parkinson’s disease and appear to be greater than deficits in muscle strength. Reduced leg muscle power has been shown to be associated with reduced mobility, reduced balance and past falls in both the general older population and in people with Parkinson’s disease. Previous studies also suggest that the ability of an individual to generate sufficient leg muscle power may be critical for recovering quickly from a loss of balance in order to avoid falling.

The extent to which leg muscle power can be improved in people with Parkinson’s disease is not yet known, but leg muscle power training may be a method for improving balance and mobility task performance in people with Parkinson’s disease. Leg muscle power training (i.e. resistance training where the concentric component of the movement is performed as quickly as possible) in general older populations has been shown to improve muscle power, strength and mobility. Leg muscle power training may be particularly useful in people with Parkinson’s disease as it can target both muscle weakness and bradykinesia simultaneously.

The primary aim of this study was to determine the impact of leg muscle power training on leg muscle power of the leg extensors, knee flexors, hip flexors and hip abductors. Participants were randomly allocated to an experimental group or a control group following baseline assessment. Randomization was done in blocks of four using a computer-generated random number schedule. Randomization was performed off-site by an investigator not involved in recruitment or assessment (CS). Outcome assessors were blinded to group allocation. This study was approved by the relevant Human Ethics Committee and all participants gave written informed consent prior to assessment.

Participants

Community-dwelling participants with idiopathic Parkinson’s disease were recruited from Sydney, Australia, through Parkinson’s support groups and neurology clinics. Participants were eligible to participate if they were aged over 40 years and were able to walk independently with or without an aid. Participants were excluded if they had significant cognitive impairment (Mini-Mental State Examination score <24) or suffered from any unstable cardiovascular, orthopaedic or neurological conditions that would interfere with the safety of assessment and/or interpretation of results. Potential participants were screened by a physiotherapist and received clearance from their medical practitioner to participate.

Background information including age, height, weight, falls history in the previous 12 months, time since Parkinson’s disease diagnosis and Parkinson’s disease severity were recorded. Parkinson’s disease severity was ascertained from the motor section of the Movement Disorders Society-sponsored version of the Unified Parkinson’s Disease Rating Scale.

Intervention

The experimental group undertook muscle power training for four separate muscle groups: the leg extensors, knee flexors, hip flexors and hip abductors, using pneumatic variable resistance equipment (Keiser A420, Keiser Sports Health Equipment, Fresno, CA). We targeted these muscles as they prevent collapse of the lower limb and also contribute to stepping. Participants trained in pairs for 45 minutes twice a week for 12 weeks, with at least a day’s rest in between training sessions, in a university
laboratory under full supervision of a physiotherapist. Each participant performed three sets of eight repetitions as fast as possible for each muscle group on each leg, cued by the physiotherapist to ‘go as fast as possible’ before each repetition. Participants took turns exercising for a set and then rested while observing their partner during the interval between each set. The values used for each participant was obtained from the baseline one repetition maximum. The first set was performed at 40% of the one repetition maximum, the second set at 50% of the one repetition maximum and the third set at 60% of the one repetition maximum. When participants were able to perform 10 repetitions in the third set while maintaining good form and speed of movement, the one repetition maximum was increased by 5% and the exercises were progressed accordingly.

The control group performed low intensity exercises for the trunk, leg flexors, leg extensors and hip abductors independently at home. In order to provide a credible sham programme to control for non-specific (placebo) effects of the intervention, these exercises were prescribed at an intensity thought to be insufficient to achieve a training effect. The physiotherapist conducted initial home visits to teach the home programme to each participant. Participants were then requested to perform two sets of each exercise twice each week for 12 weeks. For the first four weeks, participants performed eight repetitions per set, which was then increased to 10 repetitions per set for the next four weeks and then to 12 repetitions per set for the final four weeks. The physiotherapist monitored and progressed the exercises via fortnightly phone calls. Control participants recorded their completed exercise sessions in an exercise diary.

**Outcome measures**

The primary outcomes were peak muscle power for the leg extensors, knee flexors, hip flexors and hip abductors. Muscle power of each leg was measured using pneumatic variable resistance equipment (Keiser A420, Keiser Sports Health Equipment, Fresno, CA). The one repetition maximum was measured for each muscle group and muscle power was tested at six relative loads (30% to 80% of the one repetition maximum at 10% increments) in order to identify peak muscle power. The leg extensors were measured using the seated leg press, the knee flexors using the seated leg curl, and the hip flexors and hip abductors using the standing hip device.

The secondary outcomes included maximal muscle strength and movement speed of lower limb muscles; measures of mobility, balance and freezing of gait; participants’ perception of the effect of intervention; the number of falls in six months of follow-up; and peak muscle power and maximal strength of the shoulder flexors and elbow extensors.

Muscle strength of the same four leg muscle groups was determined by the one repetition maximum, which is the maximal load that a person is able to lift once through complete range of motion, using the pneumatic variable resistance equipment. Movement speed for the four leg muscle groups was extracted from the muscle power tests and measured in two ways: (i) movement speed at peak power and (ii) the rate of power production, i.e. the time taken to reach peak power from the onset of movement. Muscle power and strength of the shoulder flexors and elbow extensors were measured using the seated chest press by the methods outlined above.

Fast and preferred walking pace were timed over 10 m using a handheld stopwatch; participants performed two trials at each pace and the best score for each was used for data analysis. The Timed Up and Go was performed twice at a comfortable pace and timed using a handheld stopwatch; the best score was used for data analysis.

Balance was measured using tests of stepping, maximum balance range and single leg stand. Choice stepping reaction time involved the participant standing on a mat marked with six rectangular panels. The participant started with their feet within two of the rectangles and when verbally instructed, the participant was required to step one foot to one of the other four rectangles (i.e. the right foot forward, the right foot to the side, the left foot forward or the left foot to the side) and then return to the starting position as quickly as possible while maintaining balance. Twenty instructions about which foot and direction to step were presented in a standard order and the time taken to complete the last 12 steps was timed using a handheld stopwatch,
with the score recorded to the nearest millisecond. Maximum balance range in the anterior–posterior direction\textsuperscript{22} required each participant to lean forward and backward from the ankles three times without losing balance and the total distance was measured in millimetres. Single leg stand was timed up to 60 seconds on each leg using a handheld stopwatch. The presence of freezing of gait was determined by the New Freezing of Gait Questionnaire.\textsuperscript{23}

Participants’ perception of the effect of intervention on their mobility and balance was measured using an 11-point visual analogue scale, ranging from −5 (very much worse) through 0 (unchanged) to +5 (very much improved).\textsuperscript{24} The number of falls sustained by each person was monitored prospectively over six months using monthly falls diaries.

All outcome measures except for number of falls were collected at baseline and within one week of completing the 12 weeks of intervention. Participants were tested when ‘on’ medication and each testing session lasted approximately 2.5 hours. Prospective falls data were collected for six months from randomization. Adverse events were monitored and recorded for all participants during the 12-week intervention period.

**Statistics**

A priori power calculations showed that a sample size of 18 participants per group was required to detect a 20\% improvement in peak leg extensor muscle power (90 watts, SD 165 watts)\textsuperscript{4} in the experimental group compared with the control group, with a power of 0.8, alpha of 0.05 and correlation of 0.8 between pretest and posttest, allowing for a 15\% drop-out rate.

Linear regression analysis adjusted for baseline scores (analysis of covariance (ANCOVA)) was used to compare the experimental and control groups on the primary and secondary outcome measures following 12 weeks of intervention. Visual inspection revealed that the Timed Up and Go had a non-normal distribution owing to the presence of an outlier lying >5 SD above the mean at baseline and following intervention. The Wilcoxon–Mann–Whitney statistic was therefore used to determine between-group differences from pretest to posttest for this secondary outcome measure. The difference in participants’ perception of the effect of intervention was determined using an independent samples $t$-test (two-sided tail). Fall rates in each group were compared using incidence rate ratios from negative binomial regression, with the days of follow-up included as an exposure term in the model. Visual inspection of the distribution of falls showed the presence of two multiple fallers with >10 falls. Data from these two participants were capped at 10 falls for the analysis of fall rates. The between-group difference in the proportion of fallers was determined using the relative risk statistic with Fisher’s exact $p$ (two-sided tail). Standardised between-group effect sizes were calculated using Cohen’s $d$. An intention-to-treat approach was used for all analyses. Data were analysed using Stata v12 (College Station, TX).

**Results**

Forty participants were randomized to the experimental (power training) or control (sham exercise) groups. Figure 1 shows the study design and flow of participants through the study. Participant characteristics are described in Table 1. One participant in the experimental group had a deep brain stimulator in situ.

Exercise adherence records were available for all participants. Of the prescribed 24 exercise sessions for each group, the experimental group attended a mean 20.2 (SD 5.6) power training sessions, while the control group completed a mean 22.6 (SD 11.2) home exercise sessions. Two participants from each group discontinued training: in the experimental group, one participant sustained a pelvic fracture unrelated to the intervention, while another participant’s pre-existing low back pain was exacerbated by power training; in the control group, two participants’ pre-existing hernias worsened during the intervention period but this was not attributable to the home exercise programme. The physiotherapist made temporary minor modifications to the power training loads for six participants in the power training group to account for transient pain, joint inflammation or illness. None of the control participants required modification to their home exercise programme. No participant fell during power training
**Figure 1.** Flow of participants through the trial.

*One drop-out in each group could not complete posttest for primary outcomes measures, but did complete some secondary outcome measures.*
and no participant reported falling while performing
the home exercises.

Gains in leg muscle power were significantly
greater in the power training group than the control
group in all four primary outcome measures at 12
weeks (standardised effect sizes 0.95–1.43) (Table 2).
The same pattern of results was observed for leg
muscle strength (Table 3), with the power training
group demonstrating significantly greater gains in
hip muscle strength compared with the control
group (standardised effect sizes 0.92–1.42). The
gains in knee flexor and leg extensor strength
favouring the power training group compared with
the control group (standardised effect sizes 0.61–
0.66) did not reach statistical significance.
Movement speed of the knee flexors at peak power
improved in the power training group compared
with the control group, and there was also a trend
favouring the muscle power training
group that did not reach statistical significance.

The power training group showed a trend toward
improvement compared with the control group for
some of the mobility and balance measures (Timed
Up and Go and choice stepping reaction time),
although these differences did not reach statistical
significance (Table 4). Sample size calculations
reveal that 164 participants would be required to
detect a statistically significant between-group
difference of 0.8 seconds in the Timed Up and Go follow-
ing power training (i.e. the between-group
difference found in the present study), assuming SD
of 2.4 seconds (the SD in the present study after
removal of one outlier), correlation of 0.71 between
pre- and post-intervention measures (from the pres-
ent study), alpha of 0.05, power of 0.8 and allowing
for a drop-out rate of 15%.

Nonetheless, participants in the power training
group self-reported average improvements in mobility
of 2.1 (SD 1.8) out of 5 compared with 0.7 (SD
1.6) for the control group, with a between-group
difference of 1.5 (95% CI 0.3–2.6, p = 0.01) favour-
ing the power training group. Power training par-
ticipants also reported average improvements in
balance of 1.5 (SD 1.8) out of 5 while the control
group reported no change (mean 0, SD 1.4), with a
between-group difference of 0.8 (95% CI 0.2–1.4, p
= 0.007) favouring the power training group.

There were no between-group differences for
rate of power production (Table 3), freezing of gait
or walking speed (Table 4). Compared with the con-
trol group, there was no difference in upper limb
muscle power, but there was a significant increase
in upper limb strength following leg muscle power
training (Table 3).

One participant in each group had incomplete
falls data. During the six-month fall monitoring
period, a total of 62 falls were reported by partici-
pants in the power training group and 110 falls by
participants in the control group. There was a 16%
reduction in fall rate in the power training group
compared with the control group, which was not

### Table 1. Participant characteristics at baseline. Mean (SD) or number (%) are reported.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Muscle power training (n = 20)</th>
<th>Control (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>68.1 (5.6)</td>
<td>64.5 (7.4)</td>
</tr>
<tr>
<td>Gender (male)</td>
<td>13 (65%)</td>
<td>12 (60%)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 (0.09)</td>
<td>1.73 (0.08)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.6 (17.1)</td>
<td>80.7 (16.0)</td>
</tr>
<tr>
<td>Mini-Mental State Exam score (0–30)</td>
<td>29.1 (1.4)</td>
<td>28.9 (1.3)</td>
</tr>
<tr>
<td>Disease duration (years)</td>
<td>7.8 (5.2)</td>
<td>7.8 (5.9)</td>
</tr>
<tr>
<td>‘On’ MDS-UPDRS motor score (0–132)</td>
<td>37.1 (11.0)</td>
<td>35.7 (14.0)</td>
</tr>
<tr>
<td>Hoehn &amp; Yahr stage (0–5)</td>
<td>2.0 (0.7)</td>
<td>1.9 (0.9)</td>
</tr>
<tr>
<td>Fallen in past year (number of participants)</td>
<td>5 (25%)</td>
<td>7 (35%)</td>
</tr>
</tbody>
</table>

MDS-UPDRS, Movement Disorders Society version of the Unified Parkinson’s Disease Rating Scale.
Table 2. Mean (SD) score, mean (SD) difference within groups and mean (95% confidence interval (CI)) difference between groups for the primary outcome measure (i.e. leg muscle power) for the experimental group and the control group. Scores reported are the average of both legs.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Score</th>
<th>Change within groups</th>
<th>Difference between groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 0</td>
<td>Week 12</td>
<td>Week 12 minus week 0</td>
</tr>
<tr>
<td></td>
<td>Exp</td>
<td>Con</td>
<td>Exp</td>
</tr>
<tr>
<td></td>
<td>n = 20</td>
<td>n = 20</td>
<td>n = 18</td>
</tr>
<tr>
<td>Peak muscle power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extensors (W)</td>
<td>388.3 (146.4)</td>
<td>409.1 (148.3)</td>
<td>455.8 (151.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee flexors (W)</td>
<td>165.8 (63.3)</td>
<td>158.4 (54.9)</td>
<td>200.1 (84.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip flexors (W)</td>
<td>171.9 (78.2)</td>
<td>160.2 (65.0)</td>
<td>251.6 (122.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip abductors (W)</td>
<td>85.4 (37.5)</td>
<td>82.7 (36.4)</td>
<td>122.2 (49.0)</td>
</tr>
</tbody>
</table>

Exp, experimental group (i.e. muscle power training); Con, control group; W, watts. †Values adjusted for baseline (week 0) score based on ANCOVA. ‡% improvement from the intervention was calculated as the between-group difference (from linear regression analyses adjusted for baseline scores (ANCOVA)) divided by the entire sample mean at baseline.
Table 3. Mean (SD) score, mean (SD) difference within groups, and mean (95% CI) difference between groups for muscle strength and movement speed secondary outcome measures for the experimental group and the control group. Scores reported are the average of both legs or both arms.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Score</th>
<th>Change within groups</th>
<th>Difference between groups</th>
<th>Standardised effect size (Cohen’s d)</th>
<th>Between-group difference as a % of baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 0 Exp Con</td>
<td>Week 12 Exp Con</td>
<td>Week 12 minus week 0 Exp Con</td>
<td>Week 12 adjusted for week 0 Exp minus Con</td>
<td>p-value</td>
</tr>
<tr>
<td>Maximal muscle strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extensors (N)</td>
<td>807.0 (274.3) 801.8 (194.1)</td>
<td>924.7 (322.8) 822.6 (202.6)</td>
<td>89.2 (85.5) 36.8 (71.7)</td>
<td>47.2 (–4.7–99.2) 0.07</td>
<td>0.66</td>
</tr>
<tr>
<td>Knee flexors (Nm)</td>
<td>180.6 (67.9) 192.8 (58.6)</td>
<td>214.2 (83.8) 199.6 (68.4)</td>
<td>26.4 (26.9) 10.7 (24.7)</td>
<td>15.9 (–0.5–32.2) 0.06</td>
<td>0.61</td>
</tr>
<tr>
<td>Hip flexors (Nm)</td>
<td>52.3 (18.8) 51.2 (16.1)</td>
<td>73.1 (25.4) 53.8 (18.9)</td>
<td>18.3 (17.5) 4.2 (12.7)</td>
<td>14.1 (3.5–24.8) 0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>Hip abductors (Nm)</td>
<td>41.0 (17.3) 42.8 (14.6)</td>
<td>54.9 (17.1) 41.9 (14.4)</td>
<td>12.1 (8.5) 0 (8.6)</td>
<td>12.2 (6.5–18.0) &lt; 0.001</td>
<td>1.42</td>
</tr>
<tr>
<td>Instantaneous speed at peak power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extensors (m/s)</td>
<td>0.89 (0.16) 0.87 (0.17)</td>
<td>0.93 (0.20) 0.85 (0.18)</td>
<td>0.04 (0.15) −0.01 (0.13)</td>
<td>0.06 (–0.04–0.15) 0.22</td>
<td>0.36</td>
</tr>
<tr>
<td>Knee flexors (rad/s)</td>
<td>1.32 (0.22) 1.26 (0.19)</td>
<td>1.38 (0.15) 1.24 (0.14)</td>
<td>0.07 (0.18) −0.04 (0.12)</td>
<td>0.12 (0.04–0.20) 0.003</td>
<td>0.72</td>
</tr>
<tr>
<td>Hip flexors (rad/s)</td>
<td>4.63 (1.18) 4.29 (0.94)</td>
<td>4.71 (0.89) 4.37 (0.83)</td>
<td>0.18 (1.03) 0.04 (0.72)</td>
<td>0.24 (–0.23–0.72) 0.30</td>
<td>0.16</td>
</tr>
<tr>
<td>Hip abductors (rad/s)</td>
<td>2.80 (0.62) 2.51 (0.55)</td>
<td>3.12 (0.69) 2.62 (0.48)</td>
<td>0.33 (0.63) 0.12 (0.34)</td>
<td>0.32 (–0.01–0.64) 0.06</td>
<td>0.42</td>
</tr>
<tr>
<td>Time to peak power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extensors (ms)^a</td>
<td>402.2 (90.5) 437.6 (110.4)</td>
<td>427.0 (128.0) 421.6 (89.9)</td>
<td>19.0 (86.4) −11.3 (83.8)</td>
<td>23.8 (–32.2–79.8) 0.39</td>
<td>0.36</td>
</tr>
<tr>
<td>Knee flexors (ms)^a</td>
<td>349.3 (71.7) 372.8 (73.8)</td>
<td>337.2 (53.8) 361.9 (56.5)</td>
<td>−9.1 (45.6) −4.0 (40.6)</td>
<td>−12.6 (–35.8–10.5) 0.28</td>
<td>−0.12</td>
</tr>
<tr>
<td>Hip flexors (ms)^a</td>
<td>221.8 (105.6) 230.4 (81.9)</td>
<td>213.8 (85.6) 204.4 (86.9)</td>
<td>−8.6 (91.7) −23.0 (57.1)</td>
<td>12.3 (–31.8–56.4) 0.57</td>
<td>0.19</td>
</tr>
<tr>
<td>Hip abductors (ms)^a</td>
<td>299.3 (61.3) 293.3 (62.2)</td>
<td>258.7 (64.7) 287.2 (38.0)</td>
<td>−39.8 (73.9) −4.4 (54.5)</td>
<td>−30.8 (–64.3–2.7) 0.07</td>
<td>−0.55</td>
</tr>
</tbody>
</table>
Table 3. (Continued)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Score</th>
<th>Change within groups</th>
<th>Difference between groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 0</td>
<td>Week 12 minus week 0</td>
<td>Week 12 adjusted for week 0‡</td>
</tr>
<tr>
<td></td>
<td>Exp</td>
<td>Con</td>
<td>Exp</td>
</tr>
<tr>
<td></td>
<td>Week 0</td>
<td>Week 12</td>
<td>Week 12 minus week 0</td>
</tr>
<tr>
<td></td>
<td>n = 20</td>
<td>n = 20</td>
<td>n = 18</td>
</tr>
<tr>
<td>Shoulder flexors and elbow extensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak muscle power (W)</td>
<td>114.8 (57.7)</td>
<td>100.3 (48.1)</td>
<td>123.2 (55.6)</td>
</tr>
<tr>
<td>Maximal strength (N)</td>
<td>130.1 (49.3)</td>
<td>126.2 (48.1)</td>
<td>139.8 (41.3)</td>
</tr>
</tbody>
</table>

Exp, experimental group (i.e. muscle power training); Con, control group; N, Newtons; Nm, Newton-metres; m/s, metres per second; rad/s, radians per second; ms, milliseconds; W, watts.
†Values adjusted for baseline (week 0) score based on ANCOVA.
‡% improvement from the intervention was calculated as the between-group difference (from linear regression analyses adjusted for baseline scores (ANCOVA)] divided by the entire sample mean at baseline.
^Lower scores indicate better performance.
Table 4. Mean (SD) score, mean (SD) difference within groups and mean (95% CI) difference between groups for mobility and balance secondary outcome measures for the experimental group and the control group. Scores for single leg stand are reported as the average of both legs.

<table>
<thead>
<tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Exp</td>
<td>Con</td>
<td>Exp minus Con p-value</td>
</tr>
<tr>
<td></td>
<td>n = 20</td>
<td>n = 20</td>
<td>n = 19</td>
</tr>
<tr>
<td>Mobility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred walking speed (m/s)</td>
<td>1.27 (0.17)</td>
<td>1.34 (0.22)</td>
<td>0.06 (0.16)</td>
</tr>
<tr>
<td>Fast walking speed (m/s)</td>
<td>1.77 (0.25)</td>
<td>1.81 (0.31)</td>
<td>0.02 (0.16)</td>
</tr>
<tr>
<td>Timed Up and Go (s)^#</td>
<td>9.7 (2.3)</td>
<td>8.3 (2.4)</td>
<td>−1.3 (2.7)</td>
</tr>
<tr>
<td>Balance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choice stepping reaction time (s)^</td>
<td>37.0 (9.5)</td>
<td>35.2 (6.2)</td>
<td>−1.0 (7.2)</td>
</tr>
<tr>
<td>Maximal balance range (cm)</td>
<td>16.7 (5.0)</td>
<td>18.4 (4.7)</td>
<td>1.4 (2.6)</td>
</tr>
<tr>
<td>Single leg stand time (s)</td>
<td>12.9 (7.2)</td>
<td>16.1 (10.3)</td>
<td>2.8 (7.2)</td>
</tr>
<tr>
<td>Freezing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Freezing of Gait Questionnaire (0–25)^</td>
<td>6.0 (8.8)</td>
<td>5.8 (7.8)</td>
<td>0.4 (3.7)</td>
</tr>
</tbody>
</table>

Exp, experimental group (i.e. muscle power training); Con, control group.
†Values adjusted for baseline (Week 0) score based on ANCOVA.
^Lower scores indicate better performance.
#The median (interquartile range) and the result of the Wilcoxon–Mann–Whitney statistic for comparison of between-group differences are reported for the Timed Up and Go owing to the presence of an outlier with a score >5 SD above the sample mean. Linear regression analyses adjusted for baseline scores (ANCOVA) show that the between-group difference for the Timed Up and Go would be −0.8 seconds 95% CI −1.9–0.4, p = 0.18 when the entire sample is included in the analysis, or −0.8 seconds 95% CI −1.9–0.2, p = 0.12 with the removal of one outlier.
significant (incidence rate ratio 0.84, \( p = 0.76 \)). Seven of the 19 (37\%) participants in the power training group fell compared with 12 of the 19 (63\%) participants in the control group, although this difference was not statistically significant (relative risk 0.58, 95\% CI 0.30–1.15, \( p = 0.19 \)).

**Discussion**

This study showed that a short duration leg muscle power training programme is effective in improving muscle power in a group of people with Parkinson’s disease without significant mobility deficits. In addition, muscle power training improved leg muscle strength. Participants who undertook power training also self-reported improvements in balance and mobility compared with control participants who performed low intensity sham exercise. Furthermore, the trends toward improvement in some of the mobility and balance measures and toward a reduction in the proportion of fallers favoured the muscle power training group.

The large gains in muscle power resulting from power training (standardised effect sizes 0.95–1.43) suggest that muscle power deficits in people with Parkinson’s disease can be reduced following a short duration targeted muscle power training programme. In contrast, a sham programme involving exercises performed quickly but without any resistance, resulted in deterioration of muscle power in some muscle groups, despite no deterioration in strength. These results and evidence from the older population suggest that providing a load is the critical stimulus for improving muscle power.4

The inconsistent gains in leg strength in the muscle power training group may reflect the variable nature of Parkinson’s disease. Prior studies have shown that people with Parkinson’s disease vary greatly in the amount of strength gained following resistance training.26 Factors, such as disease severity, baseline muscle power or strength, intramuscular fat content and neural activation,27 may influence which individuals with Parkinson’s disease have greater potential to benefit from muscle power training, and this warrants investigation in a larger sample of participants. It is encouraging that large gains in hip muscle strength were made, given that these muscles do not appear to be specifically targeted in many training programmes yet are critical for maintaining stability and taking large steps, problems that are common in people with Parkinson’s disease.31–34 It is also encouraging that moderate to large strength gains were made despite less work performed during power training compared with traditional progressive resistance training programmes.15,35

We did not find an effect of power training on the rate of power production, however, there appeared to be small benefits on movement speed at peak power for some muscle groups. Our findings are similar to results from the older population showing that power training improves the strength component more so than the speed component of muscle power.25 In the older population, studies comparing traditional low speed strength training to high-speed power training have shown that the high-speed component of power training appears to be the critical factor inducing gains in muscle power and mobility.1,10,13,36 In contrast, our study showed that the control group who performed high-speed unloaded exercises did not make gains in muscle power, which suggests that there is a lower limit of load below which gains in muscle power are not achieved. The results of the current study showing improvements in both muscle power and strength following a specific, high-speed progressive muscle power training programme, suggests that power training may have added benefit compared with traditional resistance training programmes. However, given that the training loads used for muscle power training are generally less than the loads used in traditional resistance training programmes targeting muscle strength, muscle power training may not necessarily be the most efficient way to enhance strength in people with Parkinson’s disease but this requires further investigation.

Participants from the muscle power training group self-reported improvements in mobility and balance. In addition, trends toward improvement in some of the mobility and balance measures favoured the muscle power training group but did not reach statistical significance. There are a number of possible explanations for these findings. First, the
sample size of the current study was calculated to determine a significant effect on muscle power, so improvements on some secondary outcome measures may not have been statistically significant owing to our small sample size. For example, the effect size for the Timed Up and Go in the current study (0.8 seconds reduction) is larger than that reported to be a significant effect of intervention (0.6 seconds reduction) in two recent systematic reviews.\(^37,38\) Yet sample size calculations reveal that a sample of 164 participants would be required for a between-group difference of 0.8 seconds in the Timed Up and Go, as observed in the current study, to be statistically significant (80% power). Second, we did not specifically train mobility and balance. It is possible that task-specific training on its own or combined with power training may have a greater impact on improving mobility and balance,\(^39\) and this warrants further investigation. Third, our participants did not appear to have significant mobility deficits, with baseline walking speeds of 1.22 m/s (preferred speed) to 1.72 m/s (fast speed) comparable with healthy people of a similar age.\(^40,41\) It is well known that there is a threshold above which improvements in strength do not lead to further gains in walking speed\(^42\) and this may also be the case for improvements in muscle power. Additionally, activities such as sit-to-stand and stair climbing, which are more consistently associated with muscle power than walking,\(^10,43\) were not measured in this study, but may have shown greater improvement associated with power training.

In order to determine whether effects of power training were generalisable to other muscle groups, we measured muscle power and strength in the upper limb. Our results have confirmed that muscle power training does not generalise to untrained muscle groups. An unexpected finding was that the power training group demonstrated strength gains in the upper limb muscles compared with the control group. This may be explained by the requirement that participants stabilise themselves using their arms while generating leg force rapidly when undertaking leg muscle power training.

This is the first randomized controlled trial investigating the effects of high-speed muscle power training in people with Parkinson’s disease. The high adherence and small number of transient problems associated with the power training programme show that this type of intervention is feasible for people with mild Parkinson’s disease without significant comorbidities. While this proof of principle study showed that power training is effective in this population, a limitation was that this study was conducted in a university laboratory, which is not sustainable as a long-term intervention strategy for many people with Parkinson’s disease. Future studies should investigate the efficacy of power training in community settings, e.g. using weighted vests to provide a training load for high-speed weight bearing exercises, as successfully conducted in the general older population.\(^11\) This study also had a relatively short duration of intervention, which was in part pragmatic, as half the participants had to travel to the university for their training sessions. Increasing the frequency or duration of power training may result in greater training effects. Future studies should also determine the effect of training on muscle power and strength of distal leg muscles, as these muscles also contribute to balance and gait in people with Parkinson’s disease.\(^44\) In addition, the non-significant reduction in the proportion of fallers favouring the muscle power training group suggests that this intervention warrants further investigation in future studies powered to detect an effect on falls.

### Clinical messages

- Leg muscle power training is effective in improving leg muscle power and strength in people with Parkinson’s disease.
- Leg muscle power training may have beneficial effects on mobility, balance and falls.

### Contributors

SSP was responsible for the whole of the research project, the first draft of the article and is the study guarantor. CGC and CS participated in the research project conception, CGC additionally the research organisation, and JS the research execution. Statistical analysis design, review and critique were completed with CGC and CS, and all
authors participated in the review and approval of the final manuscript.

Acknowledgements

The authors wish to thank Natalie Allen and Sandra O’Rourke for their assistance with data collection, Janine Vargas and Susan Murray for training participants, Professor Maria Fiatarone Singh for providing some of the Keiser equipment used for training and Dr Roger Adams for his advice regarding statistical analyses. We also wish to thank Parkinson’s NSW and in particular Trish Morgan for their assistance with recruitment, and most of all the people with Parkinson’s disease who participated in this research.

Conflict of interest

SS Paul received financial assistance from a National Health and Medical Research Council (NHMRC) of Australia postgraduate scholarship. C Sherrington receives salary funding from the NHMRC. VSC Fung is on advisory boards and/or has received travel grants from Abbott, Allergan, Boehringer-Ingelheim, Hospira, Lundbeck and Novartis. CG Canning and J Song declare no competing interests.

Funding

This study was supported by a Parkinson’s NSW Unity Walk Research Grant (ID: 2010-02589) and a University of Sydney Bridging Support Grant. This study was registered with the Australian New Zealand Clinical Trials Registry (trial ID: ACTRN12611000986976).

References


