Effects of Strength and Power Training on Neuromuscular Variables in Older Adults

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The purpose of this study was to compare the neuromuscular adaptations produced by strength-training (ST) and power-training (PT) regimens in older individuals. Participants were balanced by quadriceps cross-sectional area (CSA) and leg-press 1-repetition maximum and randomly assigned to an ST group (n = 14; 63.6 ± 4.0 yr, 79.7 ± 17.2 kg, and 163.9 ± 9.8 cm), a PT group (n = 16; 64.9 ± 3.9 yr, 63.9 ± 11.9 kg, and 157.4 ± 7.7 cm), or a control group (n = 13; 63.0 ± 4.0 yr, 67.2 ± 10.8 kg, and 159.8 ± 6.8 cm). ST and PT were equally effective in increasing (a) maximum dynamic and isometric strength (p < .05), (b) increasing quadriceps muscle CSA (p < .05), and (c) decreasing electrical mechanical delay of the vastus lateralis muscle (p < .05). There were no significant changes in neuromuscular activation after training. The novel finding of the current study is that PT seems to be an attractive alternative to regular ST to maintain and improve muscle mass.

Keywords: cross-sectional area, electrical mechanical delay, ballistic isometric contraction

Aging is accompanied by a progressive loss of muscle mass caused by several factors such as a decrease in the number of motor neurons in the spinal cord and fast-twitch fibers in the skeletal muscles. This reduction in muscle mass has been associated with a lower muscle-force-production capacity and an inability to perform activities of daily living in older individuals (Doherty, 2003; Izquierdo, Aguado, Gonzalez, Lopez, & Hakkinen, 1999).

Strength training has been widely used to counteract these aging-related effects by increasing voluntary activation, muscle mass, and muscle-force-production capacity, even in the oldest individuals (Donnelly et al., 2009; Fiatarone et al., 1990; Frontera, Meredith, O’Reilly, Knuttgen, & Evans, 1988; Hakkinen et al., 2001; ...)
Sueta et al., 2004). However, these adaptations do not seem to greatly affect the ability of older individuals to perform activities of daily living (Earles, Judge, & Gunnarsson, 2001) because of the low movement speed used in strength-training regimens (Henwood, Riek, & Taaffe, 2008).

On the other hand, power training has been recommended for older individuals (Donnelly et al., 2009) because of improvements in functionality produced by the high movement speed used in the exercises (Bean et al., 2009). Training using high movement speed seems to decrease the activation threshold of fast-twitch motor units and increase their initial firing rates (Van Cutsem, Duchateau, & Hainaut, 1998). These adaptations in motor-unit behavior are likely to improve power production and the rate of torque development, variables that are positively related to the functional status of older individuals (Hakkinen et al., 2001; Kyrolainen et al., 2005).

Despite the importance of power training, most studies have only investigated the neuromuscular adaptations produced by traditional (i.e., high-load, low-velocity) strength-training regimens. Moreover, to the best of our knowledge no study has attempted to compare neural and morphological adaptations produced by these training regimens in older individuals. Therefore, the purpose of this study was to compare the neuromuscular adaptations produced by strength- and power-training regimens in older individuals.

**Methods**

**Participants**

Verbal invitations, flyers, and radio advertisements were directed to older individuals (age 60–80 years) living close to the university. One hundred thirty-three individuals responded to the advertisements and were screened according to the following inclusion criteria: being sedentary or performing light aerobic activities no more than twice a week and not presenting dementia (Mini Mental State Examination; Folstein, Folstein, & McHugh, 1975), depression (Hotatian, 2002), musculoskeletal disorders, osteoporosis, hypertension, or cardiovascular problems. Fifty-nine individuals met the inclusion criteria and signed an informed-consent form approved by the institutional review board before participation. All participants lived in their own homes and performed all their activities of daily living without assistance. To obtain homogeneous groups regarding the most important dependent variables, leg-press one-repetition maximum (1RM) and quadriceps muscle cross-sectional area (CSA) obtained by magnetic resonance imaging (MRI) were assessed before training initiation. Then, participants were classified into quartiles. Participants from each quartile were randomly assigned to a strength-training group (ST: 63.6 ± 4.0 years, 79.7 ± 17.2 kg, and 163.9 ± 9.8 cm), a power-training group (PT: 64.9 ± 3.9 years, 63.9 ± 11.9 kg, and 157.4 ± 7.7 cm), or a control group (63.0 ± 4.0 years, 67.2 ± 10.8 kg, and 159.8 ± 6.8 cm). The participants who were not in the same quartile for both variables (leg-press 1RM and quadriceps CSA, n = 13) were equally divided into the groups. A one-way ANOVA between groups assured us of similar initial values for both the leg-press 1RM and quadriceps CSA (p > .05). Figure 1 depicts the steps to recruit and allocate the participants to the experimental groups.
Figure 1 — Schematic representation of participant recruitment and allocation. ST = strength training; PT = power training.
Experimental Design

In the 3 weeks before the experimental period, participants were interviewed by a trained physician and an exercise science specialist, who assessed for health and functional status, habitual physical activity level, anthropometrics, hypertension, and cardiovascular diseases. In the following week, participants performed three familiarization sessions on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, USA) and on the leg-press and chest-press isoinertial machines. In the fifth week, they performed knee-extension maximum voluntary ramp and ballistic isometric contractions (Ricard et al., 2005; Wallerstein, Barroso, Tricoli, Mello, & Ugrinowitsch, 2010). Electromyography of the vastus medialis and vastus lateralis muscles was collected simultaneously during the maximum voluntary ramp and ballistic isometric contractions. After the isometric test, participants performed 1RM tests in the leg-press and chest-press exercises. Quadriceps CSA was obtained through MRI at the end of the fifth week. Finally, individuals were assigned to the experimental groups, and both strength and power training occurred from the 6th to the 21st week. Posttest assessments were performed in the week after the end of the training period.

Leg-Press and Chest-Press 1RM Test

The procedures for leg-press and chest-press 1RM test followed ASEP guidelines (Brown & Weir, 2001). Initial load was based on values obtained during familiarization sessions. Participants warmed up on the treadmill at 5 km/hr for 5 min and then performed a set of five repetitions at approximately 50% of the estimated 1RM, which was followed by another set of three repetitions at 70% of the estimated 1RM. Warm-up sets were separated by 2-min intervals. After the completion of the second set, subjects rested for 3 min and had up to five attempts to obtain the 1RM weight, with 3-min intervals between attempts.

Maximum Voluntary Ramp and Ballistic Isometric Contractions

Before the tests, participants performed a specific warm-up on the isokinetic dynamometer, which consisted of three 4-s submaximal isometric contractions separated by 3-min intervals. Three minutes after the warm-up period, participants performed, in a random order, two 4-s ramp isometric contractions and two 3-s ballistic isometric contractions separated by a 3-min interval. In the ramp contraction, participants were instructed to progressively increase torque production through 1–2 s, hold at maximum torque for 2 s, and then relax. In the ballistic isometric contraction, individuals were instructed to produce torque as fast and hard as possible, hold at maximum torque for a couple of seconds, and then relax. Strong verbal encouragement and visual feedback via the computer screen were provided during the tests. The highest peak torque on each test was used for statistical analyses.

EMG

Muscle electrical activity was recorded (Miosystem, Miosystem Co., São Paulo, Brazil) using Ag/AgCl electrode bars with an interelectrode distance of 2 cm. The
skin area was shaved, abraded, and cleaned with an isopropyl alcohol pad to reduce skin impedance before electrode placement. The electrodes were attached to the bellies of the vastus lateralis and vastus medialis muscles, aligned in parallel to the expected muscle-fiber orientation. In addition, a ground electrode was positioned at the midtibia on its medial side. The EMG signals were differentially amplified with a gain of 1,000 and bandwidth filter of 20–500 Hz at –3 dB. The EMG amplifiers had an input noise below 1 μV root mean square and an effective common rejection mode of 85 dB. Knee-extensor torque and EMG data were synchronized in the EMG unit through a 12-bit A/D convertor at a sampling rate of 1,000 Hz and analyzed offline. The root mean square of the EMG signal was calculated over a 1,000-ms interval around peak torque. EMG analysis was performed using customized software (Visual Basic, Microsoft).

**Electrical Mechanical Delay**

The electrical mechanical delay (EMD) of the vastus lateralis and vastus medialis muscles was calculated during the ballistic isometric contraction, taking the time difference between the EMG and torque (i.e., Biodex torque) onset. EMG onset was determined when EMG values reached the mean resting EMG value (200-ms window) plus 2 SDs from the mean resting value. Torque onset was determined following the same procedures.

**Rate of Torque Development**

The rate of torque development (RTD) was estimated using the time–force traces obtained during the ballistic isometric contraction and was calculated from the torque onset to 100 ms. A customized software routine (Visual Basic, Microsoft, USA) was also used to perform EMD and RTD analyses.

**Quadriceps CSA**

Quadriceps CSA was obtained through MRI (Signa LX 9.1, GE Healthcare, Milwaukee, WI). Subjects lay in the device in a supine position with legs straight. A bandage was used to restrain leg movements during the test. An initial image was captured to determine the perpendicular distance from the greater trochanter of the femur to the inferior border of the lateral epicondyle of the femur, which was defined as segment length. Quadriceps CSA was measured at 50% of the segment length with 0.8-cm slices for 3 s. The pulse sequence was performed with a view field between 400 and 420 mm, time of repetition of 350 ms, echo time from 9 to 11 ms, two signal acquisitions, and matrix of reconstruction of 256 × 256. The images were transferred to a workstation (Advantage Workstation 4.3, GE Healthcare, Milwaukee, USA) to determine quadriceps CSA. In short, the segment slice was divided into skeletal muscle, subcutaneous fat tissue, bone, and residual tissue. Then, muscle CSA was determined subtracting the bone and subcutaneous fat area from the total area.

**Training Protocol**

The ST (i.e., exercise load 70–90% of 1RM) and PT (i.e., exercise load 30–50% of 1RM, high-velocity execution) groups performed the following exercises: horizontal
leg press, bilateral knee flexion, unilateral hip extension, plantar flexion in the horizontal leg press, lat pull-down, and upright row. The rest interval between sets and exercises was 3 min. Participants trained twice a week for 16 weeks. The 1RM values for the leg- and chest-press exercises were reassessed every 4 weeks for loading-adjustment purposes, according to the training periodization (Table 1). Participants did not perform 1RM tests for the remaining exercises because of time constraints and the fact that they were not dependent variables. Thus, exercise load was adjusted to produce the same load perception (i.e., Omni scale) as in the leg press and chest press.

Statistical Analysis

Data normality and the absence of extreme observations (outliers) were guaranteed through Shapiro–Wilk test and standard visual inspection, respectively. A number of mixed models (SAS 9.2, USA) having group (ST, PT, and control) and time (pre and post) as fixed factors and subjects as a random factor were used for each dependent variable. Kenward–Roger degrees-of-freedom adjustment was used to adjust for data imbalance. In case of significant $F$ values, Tukey’s adjustment was used for multicomparison purposes. Significance level was set at $p < .05$, and data are presented as $M \pm SD$.

Results

Leg-press 1RM increased similarly for the ST and PT groups from pre- to post-training (42.7% and 33.8%, respectively), $F(2, 40) = 26.34, p < .001, \eta^2_p = .57$. The control group presented a nonsignificant drop of 6.7% (Figure 2[a]). Similar results were found for the chest-press exercise. The ST and PT increased chest-press 1RM by 31% and 25.4%, respectively, $F(2, 40) = 21.59, p < .001, \eta^2_p = .52$ (no differences between groups) after the training protocol (Figure 2[b]).

Peak torque obtained in the ramp isometric contraction increased significantly for the ST and PT groups after training, $F(2, 38) = 3.94, p = .030, \eta^2_p = .18$, by 22.3% and 17.1%, respectively. There were no changes in ramp isometric

Table 1 Training Protocol for the Strength-Training (ST) and Power-Training (PT) Groups Throughout a 16-Week Training Period

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Strength training</th>
<th>Power training</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>$2 \times 10$ (70%)</td>
<td>$3 \times 7$ (30%)</td>
</tr>
<tr>
<td>3 and 4</td>
<td>$2 \times 10$ (75%)</td>
<td>$3 \times 7$ (35%)</td>
</tr>
<tr>
<td>5 and 8</td>
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<td>$3 \times 7$ (30%), $1 \times 6$ (40%)</td>
</tr>
<tr>
<td>9 and 12</td>
<td>$3 \times 8$ (80%)</td>
<td>$4 \times 6$ (40%)</td>
</tr>
<tr>
<td>13 and 14</td>
<td>$2 \times 8$ (80%), $2 \times 6$ (85%)</td>
<td>$2 \times 6$ (40%), $2 \times 4$ (45%)</td>
</tr>
<tr>
<td>15 and 16</td>
<td>$4 \times 4$ (90%)</td>
<td>$2 \times 6$ (45%), $2 \times 4$ (50%)</td>
</tr>
</tbody>
</table>

Note. Values are Sets $\times$ Repetitions. Percentage within parentheses indicates the training load—percent of one-repetition maximum.
Figure 2 — One-repetition-maximum (1RM) values for the (a) leg-press and (b) chest-press exercises for the control, strength-training (ST), and power-training (PT) groups, pre- and posttraining ($M \pm SD$). *Posttest values greater than pretest values, $p < .0001$. †Greater than the control group at the posttest, $p < .0429$. 
contraction for the control group from pre- to posttraining (Figure 3[a]). There was only a main time effect for the ballistic isometric torque, \( F(1, 38) = 29.69, p < .001, \eta_p^2 = .12 \), of 6.3%, 19.8%, and 16.4% for the control, ST, and PT groups, respectively (Figure 3[b]).

The RTD showed a main time effect, \( F(1, 38) = 10.01, p = .003, \eta_p^2 = .21 \), in which the posttest values were greater than the pretest values. The values ranged from 434.5 ± 156.5 to 560.7 ± 203.3 (28.7%) N · m⁻¹ · ms⁻¹ for the control group, from 562.5 ± 237.7 to 637.3 ± 337.5 (13.3%) N · m⁻¹ · ms⁻¹ for the ST group, and from 595.0 ± 199.5 to 669.7 ± 282.2 (12.6%) N · m⁻¹ · ms⁻¹ for the PT group from pre- to posttraining assessments, respectively.

EMG values at peak torque presented a main time effect for both the ramp and ballistic isometric contractions only for the vastus medialis muscle, \( F(1, 38) = 4.739, p = .036, \eta_p^2 = .12 \) and \( F(1, 38) = 5.09, p = .030, \eta_p^2 = .13 \), respectively (Table 2). There were no changes in vastus lateralis muscle neural activation.

The EMD did not change from pre- to posttraining for the vastus medialis muscle. On the other hand, the EMD of the vastus lateralis decreased significantly, \( F(2, 38) = 3.77, p = .032, \eta_p^2 = .17 \), for the PT (32%) and ST (28%) groups. There were no differences between the training groups in the posttraining assessment (Table 2).

Quadriceps CSA increased only for the training groups from pre- to posttest, \( F(2, 36) = 8.47, p = .001, \eta_p^2 = .113 \) (ST 6.5%, PT 3.4%), for the left thigh (Figure 4). There were no differences between training groups for quadriceps CSA in the posttest assessment.

Discussion

The purpose of this study was to compare neural and morphological adaptations produced by strength- and power-training regimens in older individuals. The main findings were that these training protocols were equally effective in increasing maximum dynamic (1RM) and ramp isometric strength, increasing quadriceps muscle CSA, and decreasing EMD of the vastus lateralis muscle.

Maximum ramp voluntary isometric torque increased significantly and similarly in the ST and PT groups (22.4% and 17.1%). These increments are higher than those reported by Reeves, Maganaris, and Narici (2005; i.e., 9%) after 14 weeks of strength training. On the other hand, there was no significant increase in ballistic voluntary isometric torque for the ST (19.8%) and PT (16.4%) groups compared with the control group (6.3%). Furthermore, the increments in maximum dynamic strength were also similar between the ST (22.3%) and PT (17.1%) groups for the lower limb muscles. Taken together, our muscle-strength assessments and those reported by others (Fielding et al., 2002; Miszko et al., 2003) suggest that the strength- and power-training regimens are equally effective in increasing muscle-force-production capacity, even when training with large differences in training intensity.

The observed increments in force-production capacity depend on both neural (i.e., EMG) and morphological (i.e., CSA) adaptations (Moritani & deVries, 1979). The data reported herein suggest similar neural and morphological adaptations after 16 weeks of power and strength training (Figure 3, Table 2).
Figure 3 — (a) Ramp and (b) ballistic maximum voluntary isometric peak torque (MRVIC) of the knee extensors for the control, strength-training (ST), and power-training (PT) groups, pre- and posttraining ($M \pm SD$). *Posttest values greater than pretest values, $p < .0008$. ‡Main time effect, $p < .0001$. 
<table>
<thead>
<tr>
<th>Muscle</th>
<th>Control</th>
<th>Strength Training</th>
<th>Power Training</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS</td>
<td>VM pre</td>
<td>VM post</td>
<td>VL pre</td>
<td>VL post</td>
</tr>
<tr>
<td>MRVIC, μV</td>
<td>32.7 ± 28.4</td>
<td>37.3 ± 37.2‡</td>
<td>26.5 ± 19.3</td>
<td>37.8 ± 60.1</td>
</tr>
<tr>
<td>RMS</td>
<td>28.4</td>
<td>52.6‡</td>
<td>19.3</td>
<td>60.1</td>
</tr>
<tr>
<td>MBVIC, μV</td>
<td>31.8 ± 28.7</td>
<td>33.5 ± 28.7‡</td>
<td>28.7 ± 22.7</td>
<td>35.0 ± 52.2</td>
</tr>
<tr>
<td>EMDa</td>
<td>29.2</td>
<td>47.3*</td>
<td>22.7</td>
<td>52.2</td>
</tr>
<tr>
<td>MBVIC, ms</td>
<td>197.4 ± 308.5</td>
<td>207.4 ± 212.5</td>
<td>229.6 ± 215.7</td>
<td>129.6 ± 151.7</td>
</tr>
<tr>
<td></td>
<td>85.8</td>
<td>81.6</td>
<td>69.8</td>
<td>65.8</td>
</tr>
</tbody>
</table>

*Note. MRVIC = maximum ramp voluntary isometric peak torque; MBVIC = maximum ballistic voluntary isometric peak torque.
*aCalculated only for the ballistic isometric contraction.
‡Main time effect, \( p = .0359 \). *Main time effect, \( p = .0299 \). ¥Posttest values lower than pretest values, \( p < .0354 \).
The vastus lateralis EMG did not reveal significant training effects, suggesting a lack of change in muscle activation. Furthermore, a main time effect was identified for the vastus medialis EMG in both the ramp and ballistic isometric contractions after the experimental period. The lack of significant neural-activation training effects reported herein corroborates the findings of LaRoche, Roy, Knight, and Dickie (2008) and Morse et al. (2005) and may be a result of the fact that strength assessments have a higher sensitivity in detecting training adaptations when the same exercises are performed during the training and the testing protocols (Abernethy, Wilson, & Logan, 1995). Thus, it is conceivable that neuromuscular activation should be tested using exercises similar to the ones employed in the training protocol. Nevertheless, the assessment of neuromuscular activation during dynamic contractions (i.e., leg-press exercise) through surface EMG has been severely criticized (De Luca, 1997). The muscle tissue underneath the electrodes’ recording area moves, changing the recorded motor units through the concentric and eccentric phases, decreasing the validity of the test (De Luca, 1997). Moreover, older individuals present higher coactivation levels (Macaluso et al., 2002; Reeves, Narici, & Maganaris, 2006). Decreased coactivation has been observed after resistance training (Hakkinen et al., 2001; Hakkinen, Alen, Kallinen, 

**Figure 4** — Quadriceps muscle cross-sectional area (CSA) for left thigh for the control, strength-training (ST), and power-training (PT) groups pre- and posttraining (M ± SD). *Posttest values greater than pretest values, $p < .0028.$
Newton, & Kraemer, 2000; Hakkinen et al., 1998), allowing greater net joint torque without changing agonist muscle activation. Unfortunately, the body position of our participants during the isometric peak-torque assessments impeded recording EMG activity of the hamstrings.

A faster torque initiation may help prevent falls (Bento, Pereira, Ugrinowitsch, & Rodacki, 2010) and improve functionality (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002) among older individuals. Torque initiation can be affected by changes in both EMD and RTD. Thus, decreasing EMD or increasing RTD should improve torque initiation and thus aid in preventing falls. EMD for the vastus lateralis muscle decreased after the training protocol. No changes were observed in the EMD for the vastus medialis muscle. This finding may be associated with the fact that this muscle seems to be preferably activated in the last 20° of knee extension (Stensdotter, Hodges, Mellor, Sundelin, & Hager-Ross, 2003). Thus, it is possible that the knee-flexion angle (60°) used for assessing isometric peak torque underestimated the contribution of the vastus medialis muscle to torque production.

Two factors may affect the EMD: the stiffness of the muscle–tendon complex and the excitation–contraction coupling process (Norman & Komi, 1979). A higher stiffness of the muscle–tendon complex allows a faster and more efficient force transmission from the muscle to the bones (Narici & Maganaris, 2006). In addition, a more efficient excitation–contraction coupling may improve the initiation and rate of Ca²⁺ release from the sarcoplasmic reticulum, affecting the rate of force production (Williams, Ward, Spangenburg, & Nelson, 1998), which would also affect RTD. Unfortunately, the lack of difference between ST, PT, and control groups does not support the suggestion that training regimens would improve RTD (Aagaard et al., 2002). Aagaard et al. reported an increased RTD after a strength-training program, but they did not familiarize participants with the RTD test. In our experience, the RTD has high variability and is strongly affected by learning. In fact, three familiarization sessions are required to teach older individuals to produce force “as fast as possible” (i.e., CV ≤ 5% interday; Wallerstein et al., 2010). Taken together, it is likely that a learning effect may have produced the previously reported increase in the RTD (Aagaard et al., 2002).

Current training guidelines recommend high-resistance low-movement-velocity resistance training (similar to strength training in the current study) to counteract sarcopenia effects (American College of Sports Medicine, 2009). Conversely, reports on the effects of PT regimens on muscle hypertrophy of older individuals are still lacking. This study is the first to compare morphological adaptations after strength- and power-training regimens. Quadriceps CSA increased for both ST and PT groups (6.5% and 3.4%, respectively). These results are within the range of the gains reported in the literature (i.e., 2.7–11% after strength-training regimens; Fiatarone et al., 1990; Frontera et al., 1988). The reasons for the similar CSA increments reported herein are unknown. A previous report from our laboratory (Lamas et al., 2010) described similar increases in the gene expression of proteins related to the Akt/mTOR pathway after strength- and power-training regimens in physically active young individuals. The activation of this pathway is highly related to the muscle-hypertrophy response (Lee, Inoki, & Guan, 2007). Thus, it may be suggested that these distinct mechanical stimuli activate the protein-synthesis machinery in a similar pattern. Our findings (i.e., similar quadriceps hypertrophy between the ST
and PT groups) indicate that exercise recommendations for this age group should also consider power training as an effective strategy to counteract loss of muscle mass and force-production capacity resulting from the aging process.

In summary, strength- and power-training regimens seem to produce similar morphological adaptations. Thus, power training should also be considered to counteract age-related loss of muscle mass and strength.

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