3 Different Types of Strength Training in Older Women

Key words
- rapid strength training
- elderly women
- functional capacity
- reaction time
- muscle thickness

Abstract
The objective of the present study was to evaluate and compare the neuromuscular, morphological and functional adaptations of older women subjected to 3 different types of strength training. 58, healthy women (67 ± 5 year) were randomized to experimental (EG, n = 41) and control groups (CG, n = 17) during the first 6 weeks when the EG group performed traditional resistance exercise for the lower extremity. Afterwards, EG was divided into three specific strength training groups; a traditional group (TG, n = 14), a power group (PG, n = 13) that performed the concentric phase of contraction at high speed and a rapid strength group (RG, n = 14) that performed a lateral box jump exercise emphasizing the stretch-shortening-cycle (SSC). Subjects trained 2 days per week through the entire 12 weeks. Following 6 weeks of generalized strength training, significant improvements occurred in EG for knee extension one-repetition (1RM) maximum strength (+19%), knee extensor muscle thickness (MT, +15%), maximal muscle activation (+44% average) and onset latency (~31% average) for vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) compared to CG (p < 0.05). Following 6 more weeks of specific strength training, the 1RM increased significantly and similarly between groups (average of +21%), as did muscle thickness of the VL (+25%), and activation of VL (+44%) and VM (+26%). The onset latency of RF (TG = 285 ± 109 ms, PG = 252 ± 76 ms, RG = 203 ± 43 ms), reaction time (TG = 366 ± 99 ms, PG = 274 ± 76 ms, RG = 201 ± 41 ms), 30-s chair stand (TG = 18 ± 3, PG = 18 ± 1, RG = 21 ± 2) and counter movement jump (TG = 8 ± 2 cm, PG = 10 ± 3 cm, RG = 13 ± 2 cm) was significantly improved only in RG (p < 0.05). At the end of training, the rate of force development (RFD) over 150 ms (TG = 2.3 ± 9.8 N·s⁻¹, PG = 3.3 ± 3.2 N·s⁻¹, RG = 3.8 ± 6.8 N·s⁻¹, CG = 2.3 ± 7.0 N·s⁻¹) was significantly greater in RG and PG than in TG and CG (p < 0.05). In conclusion, rapid strength training is more effective for the development of rapid force production of muscle than other specific types of strength training and by consequence, better develops the functional capabilities of older women.

Introduction
Biological aging is associated with a decline in neuromuscular function and morphology, resulting in a decrease in maximal strength, power [1,24,25] and neuromuscular reaction time [39,40]. The factors include changes in neural recruitment pattern of motor units, and declines in maximal firing rate and synchronization of motor units [19,43]. The morphological changes are associated mainly with muscle fiber atrophy, with consequent decreases in cross-sectional area and muscle thickness (MT), especially in type II fibers, which have the greatest motor unit strength, power and speed of contraction. These changes negatively affect the muscles of the lower limbs, particularly at the knee and ankle [6,20], leading to impaired mobility and ability to perform activities of daily living (ADL). For example, Skelton et al. showed that aging decreases strength and power capacities and these variables are related to the ability to perform functional activities like standing and stepping up [48]. The impact of aging on the neuromuscular system differs not only in terms of muscle groups and type of contraction studied [21,29,50], but also in the onset latency of muscle activation (OM) [37]. From a functional and therapeutic perspective, the capacity for the rapid applica-
tion of strength (including reaction time) has an impact on the ability to recover from a loss of balance as Tang et al. [49] and Thelen et al. [50] have demonstrated. In turn, the ability to rapidly produce force is vital and can serve as a preventive mechanism in falls [51].

Injuries as a result of falls and their associated complications (hospitalization, surgery to implant prostheses, etc...) result in high costs and represent a serious public health problem [51]. Moreover, falls in the elderly often result in death. The incidence of falls in older women is higher than in older men, due to their low level of physical activity [46] and can threaten the independent lifestyle of these individuals. The adoption of a regular and systematic program of strength training (ST) reduces the speed at which the muscle fibers deteriorate, increases absolute and relative strength, improves balance and increases muscle power helping the elderly reduce fall risk as well as maintain ADL and independence [18,52]. In this context, participation in traditional strength training, power training, or rapid strength training that uses the stretch-shortening-cycle (SSC) should aid in the development of maximal strength, power and rapid muscle contractions, respectively, which are essential for the maintenance of motor health and quality of life in older adults.

Among the 3 types of strength training above, power training has been shown to be more suitable for the improvement of functional abilities in older men that traditional strength training [28,45]. Since rapid strength training, or plyometric training, is purported to improve numerous aspects of muscle performance (i.e., maximal strength, power and reaction time), from a neuromuscular point of view it may be the most appropriate training modality to increase muscle responsiveness for older women. However, to the authors' knowledge there are no published studies that have evaluated and compared the effects of three different types of strength training on neuromuscular and morphological parameters as well as the functional capabilities of older women. Therefore, the purpose of this study was to evaluate and compare the neuromuscular and morphological adaptations, and functional abilities of older women subjected to 3 different types of strength training. Our hypothesis was that rapid strength training would be more effective than traditional strength training for the improvement of reaction and muscle activation times resulting in greater improvement in functional performance.

Methods

Subjects

The volunteer sample was comprised of 58 older women, age 67 ± 5 years, with a mean height of 158.1 ± 10.2 cm and 38.0 ± 5.3% body fat, who had not engaged in regular and systematic ST for at least 1 year before the study. The study excluded individuals with a history of severe endocrine, metabolic and neuromuscular diseases. Subjects were recruited through advertisement in a widely read local newspaper. Prior to participation, subjects were carefully informed of the design of the study, especially the possible risks and discomforts related to the procedures. Subjects then gave their written, informed consent. The study was performed according to the ethical standards of the IJSM [27] and the protocol was approved for the use of human subjects by the University’s Institutional Ethics and Research Committee (Protocol No. 19322).

Body composition

Body mass and height were measured using an ASIMED (MG, Brazil) analog scale (resolution of 0.1 kg) and a stadiometer (resolution of 1 mm), respectively. Body composition was assessed using the skinfold technique. The same technician obtained all anthropometric measurements on the right side of the subject’s body. Skinfold thickness was obtained with a Cescorf skinfold calliper. A 7-site skinfold equation was used to estimate body density [13,31] and body fat was subsequently calculated using the Siri equation [14].

Experimental design

The experiment was divided into 2 phases. In the first phase, consisting of 6 weeks, the subjects were randomly divided into an experimental group (EG, n=41) that performed traditional resistance exercise and a non-exercising control group (CG, n=17). The randomization resulted in no significant difference between groups for any of the performance variables (Table 1) prior to training. The EG performed leg press, knee extension, and knee flexion exercises, twice a week for six weeks, with linear, progressive increases in intensity and volume, accrued [5,35] over two meso-cycles. During weeks one to three the EG performed two sets of each exercise with a maximum of 15–20 repetitions (RM), and during weeks 4–6, performed three sets of 12–15 RM with a time interval between sets and exercises of 120 s.

In the second phase of the study also lasting 6 weeks, the EG was further divided into 3 subgroups that carried out traditional strength training (TG, n=14), power training (PG, n=13), and rapid strength training (RG, n=14) (Fig. 1). This phase had a similar periodization scheme that used 3 sets of 10–12 RM during weeks 7–9 and 4 sets of 8–10 RM during weeks 10–12. TG and PG performed the same exercises for the lower limbs as was done in the first 6 weeks (leg press, knee extension and knee flexion). However, in the second phase while TG performed these exercises in a controlled fashion (e.g. 2 s concentric, 2 s eccentric), PG performed the exercises with maximal speed during the concentric phase but maintained a 2 s pace during the eccentric movement. In RG the leg press exercise was replaced by a lateral box jump exercise (Fig. 2) that relied heavily on the SSC (i.e., a plyometric exercise) characterized by a high-intensity eccentric component (Fig. 2c) followed immediately by a rapid and powerful concentric contraction (Fig. 2b) [32,33,42]. The exercise consisted of rapidly, and explosively, jumping up, over the box, and down with the alternate leg on a box with a pre-defined height of either 10, 20 or 30 cm (increased 10 cm every 2 weeks). 3 sets of the lateral box jump exercise were performed during weeks 7–9 and 4 sets during weeks 10–12. This body-weight resisted exercise required dynamic knee and hip extension with the goal of performing the maximum number of side-to-side repetitions in the allotted time (15–20 s). The CG did not perform any resistance exercise during the 12 weeks of the intervention.

Maximal dynamic strength

Maximal strength was assessed using the one-repetition maximum knee extension test (1RM) in a knee extension machine (World Sculptor-RS, Brazil). 1 week prior to the test day, subjects were familiarized with all procedures. On the test day, the subjects warmed up for 5 min on a cycle ergometer, stretched all major muscle groups, and performed the specific movements of the exercise test. Each subject’s maximal load was determined...
with no more than 5 attempts with a 4-min recovery between attempts. Performance time for each contraction (concentric and eccentric) was 2 s and was controlled by an electronic metronome (Quartz, CA, USA). The test-retest reliability coefficient (ICC) was 0.99 for KE 1RM.

**Muscle thickness**

The evaluation of muscle thickness (MT) was performed using images obtained with an ultrasound device (Philips, VMI, Industries e Commercial Ltda. Lagoa Santa, MG, Brazil) in B-mode. During the evaluation of MT, subjects remained in a supine position with the assessed leg extended and relaxed for 10 min to restore the normal flow of body fluids. A transducer with a sampling frequency of 7.5 MHz was positioned perpendicularly to the muscles. For image acquisition, we used a water-based gel that promotes acoustic contact without causing pressure with the transducer over the skin. The subcutaneous adipose tissue and bone tissue were identified by the ultrasound image, and the distance between them was defined as the MT. The evaluation of MT in the knee extensors was performed at the following points: the vastus lateralis (VL); the midpoint between the greater trochanter and lateral epicondyle of the femur; the vastus medialis (VM), measured at 30% of the distance from the lateral epicondyle of the femur to the greater trochanter; rectus femoris (RF), measured at two-thirds of the distance from the greater trochanter of the femur to the lateral epicondyle and 3 cm lateral from the midline of the limb [34].

### Table 1

Comparison of muscle performance between those conducting generalized strength training and controls, before and after 6 weeks of strength training.

<table>
<thead>
<tr>
<th>Variables</th>
<th>EG, n = 42</th>
<th>CG, n = 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 RM-KE (kg)</td>
<td>Pre</td>
<td>Week 6</td>
</tr>
<tr>
<td></td>
<td>42.5 ± 8.1</td>
<td>50.4 ± 8.4*</td>
</tr>
<tr>
<td>MT-VL (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MT-VM (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MT-RF (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMG-VL (μV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMG-VM (μV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMG-RF (μV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM-VL (ms)</td>
<td>324.5 ± 69.4</td>
<td>293.6 ± 54.4*</td>
</tr>
<tr>
<td>OM-VM (ms)</td>
<td>356.8 ± 68.7</td>
<td>298.7 ± 67.9</td>
</tr>
<tr>
<td>OM-RF (ms)</td>
<td>346.2 ± 66.3</td>
<td>275.9 ± 49.9*</td>
</tr>
<tr>
<td>RT (ms)</td>
<td>473.2 ± 67.1</td>
<td>318.3 ± 50.1</td>
</tr>
<tr>
<td>RFD-0–0.15 s (N·s⁻¹)</td>
<td>2.3 ± 7.3</td>
<td>2.6 ± 7.9</td>
</tr>
<tr>
<td>RFD-0–0.25 s (N·s⁻¹)</td>
<td>1.6 ± 4.1</td>
<td>1.8 ± 4.8</td>
</tr>
<tr>
<td>STS (n° repetition)</td>
<td>14.1 ± 1.5</td>
<td>17.2 ± 1.3*</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>7.4 ± 2.5</td>
<td>8.2 ± 2.1</td>
</tr>
</tbody>
</table>

Values are mean ± SD
† Significant difference between pre and week 6 (p < 0.05)
* Significant difference between Experimental Group (EG) and control group (CG) (p < 0.05)
1RM = One Repetition Maximum, KE = knee extension, MT = muscle thickness, VL = vastus lateralis, VM = vastus medialis, RF = rectus femoris, EMG = electromyography for maximal muscle activation, OM = Muscle Onset Latency, RT = Reaction Time, RFD = Rate of Force Development, STS = 30-s Sit-to-Stand, CMJ = Counter-Movement Jump
Muscle activation
Muscle activation was determined by recording the surface electromyogram (EMG) during a maximal isometric leg press. First, the electrode sites were prepared by shaving the area and cleaning the skin by abrasion with cotton moistened with alcohol gel as reported by Hakkinen et al. [22]. The electrodes were placed in a bipolar configuration, along the direction of the muscle fibers over the muscle belly of VL, VM and RF of the right leg. The distance between electrodes was fixed at 2.2 cm (MIOTEC model HALL), and for each collection, the level of resistance between the electrodes was measured by a multimeter to be below 3000 Ohms. A reference electrode was placed on the tibial tuberosity of the right leg. The subjects were positioned in the leg press with a load cell attached to the equipment to measure force which was recorded synchronously with the EMG signal of VL, VM and RF muscles. The load cell and EMG signal conductor cables were connected to a 4 channel, analog to digital (A/D) board (Miotool 400) and the data were sampled at 2000Hz using a personal computer and acquisition software (MIOTEC, Biomedical Equipment, Porto Alegre- Brazil). The EMG signal was digitally conditioned using a fifth-order, band-pass Butterworth filter, with cutoff frequencies of 20 and 500Hz and the force data were filtered using a Butterworth filter with cutoff frequencies of 0–9Hz [3, 12].

Participants performed 3, maximal, voluntary, isometric contractions (MVIC), for 5 s in response to a light stimulus during which they were verbally encouraged to produce a maximal effort. The angles of the hip, knee and ankle were positioned and maintained at approximately 90° and 3–5 min of recovery was provided between attempts. The raw EMG signal obtained during contraction was quantified as the root mean square (RMS). Maximal activation of muscle was taken as the highest RMS EMG observed during the plateau of the force curve. The determination of onset latency of the VL, VM and RF, as well as reaction time and the rate of force production (RFD) are described below. Consistent positioning of EMG electrodes at the different test times was controlled by means of marks made on the skin of each individual with a pen and the mapping technique proposed by Narici et al. [44]. All data were analyzed using Matlab software (version 5.3).

Reaction time and muscle onset latency
The force vs. time and EMG vs. time curves were used to determine reaction time and the onset latency of VL, VM and RF muscles, respectively. The reaction time and muscle onset latency were recorded in milliseconds (ms) and analyzed by an algorithm developed in Matlab (version 5.3). The reaction time was defined as the time between the light stimulus to the point where the force curve increased more than 3 standard deviations (SD) above the baseline reference period (25 ms period prior to force development). The onset latency of VL, VM and RF muscles was defined as the time between the light stimulus to the point where the RMS EMG signal rose more than 3 SD above the mean baseline electrical activity of the muscles (200 ms period prior to the MVIC) for a minimum of 25 ms [9].

Rate of force development (RFD)
The RFD was measured from the force vs. time curve that was obtained during the maximal isometric leg press and was calculated as the change in force divided by the change in time (slope of the force vs. time curve). The RFD (N·s⁻¹) was calculated in Matlab from the MVIC that elicited the highest force [4] at 2 different time intervals (0–0.15 s and 0–0.25 s) similar to the methods of Aagaard et al. [2].

30 s sit-to-stand
The 30 s sit-to-stand test began with the participant seated in the center of a chair (height 43 cm) with the back straight and feet on a flat surface positioned about shoulder-width apart, arms crossed at chest height, with an angle of approximately 90° for hip and knee flexion. At a verbal signal, the participant rose to a full upright position and then returned to the initial seated position. The participant was encouraged to complete as many repetitions as possible within a 30 s period [28, 48].

Counter movement jump (CMJ)
To carry out the CMJ, subjects were positioned on a force platform (Advanced Mechanical Technology, Inc. Watertown, MA, USA, Model OR6-WP-1000) and were familiarized to the procedure by performing several jumps. They were instructed to jump with their hands on their waist while avoiding the bending of their legs during flight and trying to achieve the maximal possible time in the air. After the familiarization, the subjects performed 3 CMJ on the force platform with 2 min rest intervals. There was no restriction on the angle of knee flexion during the eccentric phase of the CMJ [15, 30, 33]. The greatest jump height was used for analysis and was determined by the equation provided by Bosco et al. [10]: [(height – 9.8·(flight time)²/6)], using Matlab software.

Statistical analysis
Descriptive statistics were calculated and are presented as mean±SD. Normality of the data was assessed using the Kolmogorov-Smirnov test and Levene’s homogeneity of variance test. For comparisons between groups prior to training, and following 6 and 12 weeks of strength training, a 2-way repeated measures analysis of variance (ANOVA) was used (2 groups × 3 times), with Bonferroni post-hoc tests. In addition, a one-way ANOVA was performed to compare the relative changes (% between the experimental and control groups at different times in the study (after 6 and 12 weeks of training). The significance level for all statistical tests was p<0.05 and all analyses were performed using SPSS statistical software version 17.0.

Results
During the initial 6 weeks of strength training, when there was no division between different types of training, a significant increase occurred in EG for maximal dynamic strength (1RM), maximal activation of the quadriceps muscles (VL, VM and RF), muscle thickness (VL, VM, and RF) and the number of chair stand repetitions (p<0.05, Table 1). During the same period, significant decreases occurred for muscle onset latency (VL, VM and RF) and reaction time (p<0.05). There were no significant changes for these variables for CG. This resulted in significant differences between EG and CG at 6 weeks for maximal strength, muscle thickness, muscle activation, muscle onset latency, reaction time and sit-to-stand performance (p<0.05). Following the initial 6-week period there were no changes in RFD or CMJ height for either group. After the division of the general strength training group (EG) into specific training groups (TG, PG and RG, from 6–12 weeks), significant increases in knee extension 1RM (Fig. 3a), muscle

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thickens of VL, muscle activation of the VM and VL muscles occurred in each of the training groups (Table 2, p < 0.05) with no differences between groups. Over the same period there were no changes in any of the measures for CG. Reaction time (Fig. 3c) and muscle onset latency were significantly reduced in RG but not in the other training groups. Likewise, the performance in 30-s Sit-to-Stand (Fig. 3b) and CMJ (Fig. 3d) was significantly higher in RG compared to TG and PG groups. The RFD in the period from 0–0.15 s of contraction was significantly higher in RG and PG groups following training (p < 0.05), but not in TG (Table 2).

Discussion

The major findings of this study were that rapid strength training was more effective than traditional strength training and power training for 30-s Sit-to-Stand and counter movement jump performance tests as well as for the activation of the VL and VM. In addition, 3 specific types of strength training (TG, PG and RG) resulted in equal increases in maximal dynamic knee extension strength and quadriceps muscle thickness.

In relation to the development of maximal strength, our results agree with previous studies that observed improvement in strength related to increases in muscle activation and muscle hypertrophy [7, 17, 18, 26]. In the present study there was an increase in muscle activation of VM and VL muscles suggesting an increased recruitment and firing frequency of motor units, with no significant difference between training type [23, 24]. Morphological adaptations were evident as there was an increase in muscle thickness of VL in all strength training groups indicating that hypertrophy likely contributed to the increased maximal, dynamic strength [6, 13, 28]. However, the resistance training program used in this study was short (12 weeks) and the differences in neuromuscular adaptation demonstrated between training groups in this study should be investigated over longer periods (e.g. 1 year). Nonetheless, these results are important because they show that the RG group that replaced a
before and after six weeks of specific strength training. Table 2 Comparison of muscle performance between those conducting generalized strength training, power training, reactive strength training and controls, before and after six weeks of specific strength training.

<table>
<thead>
<tr>
<th>Variables</th>
<th>TG, n = 14</th>
<th>PG, n = 13</th>
<th>RG, n = 14</th>
<th>CG, n = 17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 6</td>
<td>Week 12</td>
<td>Week 6</td>
<td>Week 12</td>
</tr>
<tr>
<td>MT-VL (mm)</td>
<td>17.8 ± 1.6</td>
<td>21.8 ± 2.9</td>
<td>18.0 ± 2.3</td>
<td>23.2 ± 3.9</td>
</tr>
<tr>
<td>MT-VM (mm)</td>
<td>15.2 ± 3.1</td>
<td>16.1 ± 2.3</td>
<td>15.6 ± 2.6</td>
<td>16.9 ± 3.6</td>
</tr>
<tr>
<td>MT-RF (mm)</td>
<td>18.2 ± 2.9</td>
<td>19.8 ± 3.6</td>
<td>18.1 ± 3.2</td>
<td>19.9 ± 3.1</td>
</tr>
<tr>
<td>EMG-VL (µV)</td>
<td>136.3 ± 32.2</td>
<td>182.0 ± 39.4</td>
<td>139.3 ± 55.2</td>
<td>195.9 ± 37.8</td>
</tr>
<tr>
<td>EMG-VM (µV)</td>
<td>117.1 ± 29.4</td>
<td>144.8 ± 14.6</td>
<td>120.9 ± 19.3</td>
<td>143.7 ± 18.9</td>
</tr>
<tr>
<td>EMG-RF (µV)</td>
<td>99.3 ± 37.1</td>
<td>119.6 ± 30.7</td>
<td>89.6 ± 39.9</td>
<td>118.7 ± 27.6</td>
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<tr>
<td>OM-VL (ms)</td>
<td>194.3 ± 51.6</td>
<td>272.6 ± 98.2</td>
<td>195.7 ± 42.3</td>
<td>229.2 ± 75.7</td>
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<tr>
<td>OM-VM (ms)</td>
<td>205.1 ± 54.3</td>
<td>254.9 ± 94.6</td>
<td>218.9 ± 38.7</td>
<td>239.1 ± 96.7</td>
</tr>
<tr>
<td>OM-RF (ms)</td>
<td>255.9 ± 49.9</td>
<td>285.9 ± 109.0</td>
<td>233.7 ± 51.4</td>
<td>252.8 ± 63.7</td>
</tr>
<tr>
<td>RFD-0–0.15 s (N·s⁻¹)</td>
<td>2.6 ± 0.8</td>
<td>2.3 ± 0.9</td>
<td>2.3 ± 0.3</td>
<td>3.3 ± 0.3</td>
</tr>
<tr>
<td>RFD-0–0.25 s (N·s⁻¹)</td>
<td>1.8 ± 0.6</td>
<td>1.7 ± 0.4</td>
<td>1.8 ± 0.3</td>
<td>2.3 ± 0.7</td>
</tr>
</tbody>
</table>

Values are mean ± SD
†Significant difference between week 6 and week 12 of specific strength training (p<0.05)
*Significant difference between TG = Reactive Strength Training in relation to TG = Traditional Strength Training and PG = Power Training (p<0.05)
€Significant difference between RG = Reactive Strength Training and PG = Power Training in relation to TG = Traditional Strength Training (p<0.05)
CG = Control Group, MT = muscle thickness, VL = vastus lateralis, VM = vastus medialis, RF = rectus femoris, EMG = electromyography for maximal muscle activation, OM = Muscle Onset Latency, RFD = Rate of Force Development

In addition to maximal muscle activation, muscle onset latency and reaction time are critical to the evaluation of the neuromuscular responsiveness of older adults [49]. In the present study, we observed a significant reduction in muscle onset latency for the RF muscle in RG, demonstrating faster muscle activation in the group that performed the rapid strength exercise. In addition, RG showed a faster reaction time, which represents a practically significant improvement in neuromuscular responsiveness in older women. Our results agree with previous literature, which demonstrated that the use of strength exercises in which SSC is present, as in the lateral box jump exercise used in this study, improves the speed of activation and reaction time of biarticular muscles such as RF [16]. Functionally, the faster muscle onset and reaction time should increase the ability of older women to avoid obstacles and reduce the frequency of falls [36,45]. In fact, LaRoche et al. [38] showed that older women with a lower propensity for falls had faster motor times of the ankle and knee muscles. The absence of change in muscle onset latency of the mono-articular muscles VL and VM may possibly be due to changes in muscle recruitment strategy during the evaluation task [43]. It has been shown that neuromuscular adaptations to training may not occur in all muscle groups assessed [48].

In this study, 6 weeks of rapid strength training was effective at further reducing neuromuscular reaction time which did not occur with traditional strength or power training (Fig. 3c).

result demonstrates that RG, in addition to increasing the maximal dynamic force to the same extent as PG and TG, improved the ability to quickly activate the knee extensors. Our results corroborate the findings of Caserotti et al. [15], who showed increases in the rate of force application in the knee extensors of older adults, after 12 weeks of explosive, high resistance strength training, in just 2 sessions per week with a load of 70–80% 1RM. As in the present study, these authors demonstrated that a training rate of only 2 times a week can improve the power of older women. The rate of force development is one variable that represents the ability to quickly generate force and has high correlation with functional capacity in the elderly [11,47]. In this study, the RFD in 0.15 s was significantly increased in RG and PG, whereas TG showed no change in RFD after training. This is likely due to specificity of training as the speed of muscle contraction was higher in these types of training. These results emphasize the importance of performing exercises with maximal or near maximal speed since the performance of exercises with greater speed seems to be more effective for the development of rapid muscle strength [8,11]. Improving RFD may have additional functional benefits as it has been shown to be positively related to neuromuscular economy during aerobic exercise, as well as aerobic power in elderly [14].

The rapid development of force, along with the concomitant increase in maximal strength and muscle mass is of great importance for functional capacity in older women. The results of this study suggest that rapid strength training appears to be the best strategy for development of these capabilities with the added benefit of faster neuromuscular reaction times. In parallel with the neuromuscular parameters, rapid strength training was shown to be most effective for increasing the performance of functional tests, as demonstrated by the increase in the number of repetitions in the 30-s Sit-to-Stand and height of the CMJ. With respect to performance during CMJ, our results are consistent with other studies showing that traditional strength training results in little or no improvement in the performance of jumps [15,30]. This implies the need for developing strategies that use exercises that rely on the SSC (e.g., jumping) [33] as well as on the rapid production of force of the lower limbs as these are key factors contributing to the maintenance of ADL in older adults [15,18,48]. It should be noted that the rapid strength training
program employed in this study was preceded by a general strength training which may have prepared the nervous, muscular, ligamentous and skeletal systems of individuals in RT to tolerate the SSCs exercise. However, our results emphasize that short periods of rapid strength training seem to be sufficient to improve lower-extremity functional performance.

Conclusion

Rapid strength training enhances neuromuscular parameters related to muscle force production, it decreases the time of muscle activation, and improves the functional capacity of elderly women in greater magnitude than traditional strength and power training. Moreover, substituting a rapid strength exercise for a traditional high-load exercise does not prevent the development of maximal dynamic strength, muscle thickness, or activation of the quadriceps muscles as these adaptations were similar between the specific types of strength training.

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