Echo intensity is associated with skeletal muscle power and cardiovascular performance in elderly men

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The purpose of the present study was to investigate the relationship between echo intensity, neuromuscular and cardiorespiratory performances in the elderly. Thirty-one healthy elderly men (65.5±5.0) participated in this study. Echo intensity of rectus femoris and quadriceps femoris muscle thicknesses was determined by ultrasound images. Lower-body isometric and isokinetic peak torques (60, 180 and 360°·s⁻¹), as well as rate of force development were evaluated as strength parameters. In addition, torque per unit of muscle mass was evaluated by the quotient between isometric peak torque of the knee extensors and the quadriceps femoris muscle thickness. The peak oxygen uptake (VTpeak), maximum aerobic workload (Wmax), absolute (VT1 and VT2) ventilatory thresholds, as well as workloads at VT1 and VT2 (WVT1 and WVT2) were evaluated during a maximal incremental test on a cycle ergometer. There were significant negative correlations between the individual values of echo intensity with the corresponding individual values of isometric and isokinetic peak torques (60, 180 and 360°·s⁻¹) (r = −0.48 to r = −0.64; P < 0.05), as well as with WVT1 (r = −0.46) and WVT2 (r = −0.50) (P < 0.05). In addition, significant positive correlations were observed between torque per unit of muscle mass and cardiovascular parameters (r = 0.52 to r = 0.60; P < 0.001). The present results suggest that the echo intensity analysis using computer-aided gray-scale analysis is a low cost, easily accessible, and a safe method to evaluate the muscle quality, and may contribute to the research of neuromuscular and cardiovascular performances in the elderly.

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1. Introduction

The aging process leads to changes in muscle quality and quantity, e.g., sarcopenia (Visvanathan and Chapman, 2010). These changes include increases in the amount of adipose and connective tissues in the muscles (Seene et al., 2012), reductions in the number and size of muscle fibers (Larsson et al., 1978; Lexell et al., 1988; Lynch et al., 1999), a reduction in the maximal voluntary agonist activation and an increase in the antagonist coactivation (Izquierdo et al., 1999; Klein et al., 2001; Suett et al., 2004). These physiological factors result in impairments in muscle strength, power and functional capacity (Izquierdo et al., 1999, 2001, 2003). In addition, a decline in cardiorespiratory capacity can be observed in elderly persons; this decline is primarily associated with a decrease in maximal heart output, changes in the arteriovenous oxygen difference (Izquierdo et al., 2001) and declines in neuromuscular function (Izquierdo et al., 2001, 2003; Cadore et al., 2011a).

The accumulation of connective and adipose tissues in the muscles, i.e., changes in muscle quality, can be assessed by computed tomography imaging which shows a reduced attenuation coefficient due to increased fat infiltration (Goodpaster et al., 2000). Muscle quality can also be assessed using the non-invasive, easily accessible and safe method of ultrasound imaging, whereby enhanced echo intensity represents changes caused by increased intramuscular connective and adipose tissues (Pillen et al., 2009; Fukumoto et al., 2012). Evidence suggests that ultrasonography can detect structural muscle changes caused by impaired neuromuscular function. Indeed, it has been shown that elderly populations present greater gray scale values when compared with young populations (Arts et al., 2010), and these changes have been associated with enhanced intramuscular adipose tissue (Kent-Braun et al., 2000; Arts et al., 2010; Fukumoto et al., 2012).
Although impairments in the neuromuscular and cardiovascular functions may occur in parallel with increases in the gray scale values in the elderly, studies investigating the relationship between echo intensity and physical fitness parameters in this population are scarce. Sipilä and Suominen (1991, 1994) showed that the echo intensity of the quadriceps femoris was associated with knee extensor strength in an elderly population. Unfortunately, their results were based on echo intensity values generated by visual scoring, which did not control operator-induced error. In another study using computer-aided grayscale analysis, Fukumoto et al. (2012) observed negative correlations between grayscale values and isometric strength in elderly men, suggesting that the subjects with greater adipose and connective tissues, i.e., those with greater echo intensity values, had lower strength performance. Nevertheless, there are limited data regarding the association between echo intensity and strength performance, and no studies have investigated the relationship between echo intensity and other parameters related to physical fitness in the elderly, such as neuromuscular and endurance performances. In addition to neuromuscular function, cardiorespiratory fitness has been associated with functional capacity in elderly populations. In this context, it would be interesting to determine the association between the muscle echo intensity and cardiovascular fitness.

Given the relevance of the neuromuscular and cardiovascular performances to the functional capacity in the elderly, to investigate the relationship between echo intensity and these functional parameters may help to justify the use of the non-invasive and safe method of ultrasound imaging to evaluate the muscle quality in the elderly. Thus, the purpose of the present study was to investigate the relationships among echo intensity, neuromuscular and cardiorespiratory performances. Our hypothesis was that the echo intensity would be associated with several parameters of neuromuscular and cardiorespiratory performances.

2. Methods

2.1. Experimental design

In order to investigate a possible relationship between echo intensity with strength development, as well as with cardiorespiratory parameters in older men, physical evaluations were carried out using ergospirometry, dynamometry and ultrasonography. For this purpose, the participants in the present study attended the Laboratory on several different occasions, since the evaluations of echo intensity, isometric and isokinetic torques and aerobic capacity were made on several different occasions, since the evaluations of echo intensity, isometric and isokinetic torques and aerobic capacity were made on separate days. By measuring and correlating all these variables, we attempted to get an insight regarding the relationship among them in the elderly, since physiological concepts might explain possible correlations. Prior to data collection, the participants took part in a familiarization session for each test. The ambient conditions were kept constant during all tests (temperature: 22–24 °C).

2.2. Subjects

Thirty-one healthy elderly men (mean ± SD: 64.7 ± 4.1 years), who were not engaged in any regular and systematic training programs in the previous 12 months, volunteered for the study after completing an ethical consent form. The subjects volunteered for the present investigation following announcements in a widely read local newspaper. Subjects were carefully informed about the design of the study with special information given regarding the possible risks and discomfort related to the procedures. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of Federal University of Rio Grande do Sul, Brazil. Exclusion criteria included any history of neuromuscular, metabolic, hormonal and cardiovascular diseases. Subjects were not taking any medication with influence on hormonal and neuromuscular metabolisms. Medical evaluations were performed using clinical anamn- nesis and effort electrocardiograph test (ECG), to ensure subject suitability for the testing procedure. The physical characteristics of subjects are shown in Table 1. Body mass and height were measured using an Asimed analog scale (resolution of 0.1 kg) and an Asimed stadiometer (resolution of 1 mm), respectively. Body composition was assessed using the skinfold technique. A seven-site skinfold equation was used to estimate body density (Jackson and Pollock, 1978) and body fat was subsequently calculated using the Siri equation (Siri, 1993).

2.3. Isometric and isokinetic peak torques

Maximal isometric and isokinetic peak torques were obtained using an isokinetic dynamometer (Biodex, New York, USA). Subjects were positioned and seated with their hips and thighs firmly strapped to the seat of the dynamometer, with the hip angle at 85°. After that, subjects warmed up for 10 knee extension/flexion repetitions at angular velocity of 90°.s⁻¹, performing a submaximal effort. The dynamometer was connected to an A/D converter (Dataq Instruments Inc. Akron, Ohio–USA), which made it possible to quantify the torque exerted when each subject executed the knee extension at the determined angle. After having their right leg positioned by the dynamometer at an angle of 120° in the knee extension (180° represented the full extension), the subjects were instructed to exert maximum strength possible and as fast as possible when extending the right knee. The subjects had three attempts at obtaining the maximum voluntary contraction (MVC) of the knee extensors, each lasting 5 s, and an additional contraction was obtained if a torque variation higher than 10% was observed between consecutive contractions (Cadore et al., 2012b). In the last part of the protocol, subjects performed five dynamic repetitions of concentric knee extensions/flexions at 60, 180 and 360°.s⁻¹, in order to obtain the isokinetic peak torque in each angular velocity. The rest interval between each attempt of the protocol was 2 min. During all the maximum tests, the researchers provided verbal encouragement so that the subjects would feel motivated to produce their maximum force. The force–time curve was obtained and analyzed using Biodex software. Signal processing included filtering with a Butterworth low-pass filter of 4th order at a cut-off frequency of 9 Hz. Maximal peak torque was defined as the highest value of the torque (N.m) recorded during the unilateral knee extension. The test–retest reliability coefficients (ICC) were over 0.94 for all the variables in the isometric and isokinetic protocols.

2.4. Echo intensity and muscle thickness

The echo intensity (EI) and muscle thickness (MT) were measured using B-mode ultrasound (Philips, VMI, MG, Brazil). A 7.5-MHz scanning head was placed on the skin perpendicular to the tissue interface, the scanning head was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. Subjects were evaluated in supine position, after 15 min resting and after 72 h without any vigorous physical activity. The EI was determined by gray-scale analysis using the standard histogram function in

Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
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</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65.5 ± 5.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.2 ± 5.8</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>81.8 ± 12.0</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>27.4 ± 3.0</td>
</tr>
<tr>
<td>Echo intensity (A.u.)</td>
<td>126.5 ± 22.9</td>
</tr>
</tbody>
</table>

Image-J (National Institute of Health, USA, version 1.37). A region of interest was selected in rectus femoris as much of the muscle was possible without any bone or surrounding fascia. For echo intensity analysis, the depth setting was fixed at 5 cm. When this setting was insufficient to display the entire muscle, only the superficial part of the muscle was used for EI analyses. The EI in the region of interest was expressed in values between 0 and 256 (0: black; 256: white).

The MT images were determined in the lower-body muscles vastus lateralis (VL), vastus medialis (VM), vastus intermedius (VI), and rectus femoris (RF). The measurement for the VL was taken at midway between the lateral condyle of the femur and greater trochanter (Kumagai et al., 2000), whereas the measurement VM was taken at 30% of the distance between the lateral condyle of the femur and the greater trochanter (Korhonen et al., 2009), yet the measurement for the VI and RF was measured as 60% of the distance from the greater trochanter to the lateral epicondyle and 3 cm lateral to the midline of the anterior thigh (Chilibbeck et al., 2004). The sum of the four lower-body muscles MT was considered as representative of the quadriceps femoris (QF) muscle mass. The images were digitalized and after they were analyzed in software Image-J (National Institute of Health, USA, version 1.37). The subcutaneous adipose tissue–muscle interface and the muscle–bone interface were identified, and the distance from the adipose tissue–muscle interface was defined as MT. The same investigator made all measurements of EI and MT. Force per unit of active muscle mass was calculated from the quotient between the maximal isometric torque (PTiso) of the right leg and the sum of the muscle thickness (MT) of the muscles of quadriceps femoris (QF) adjusted by allometric scaling (i.e., $R \propto M_{MT}^{1/2}$) (Jaric et al., 2002). The QF MT was composed by the VL, RF, VM, and VI MT. Thus, the force per unit of muscle mass was calculated following the formula: $MQ = PT_{\text{iso}} (\text{Nm})$ of the right leg/MT $QF_{\text{sum}}$ of (VL + VM + VI + RF) $\left(\text{mm}^{1.07}\right)$. The MT test–retest reliability coefficients (ICC) were 0.94 for VL, 0.91 for VM, 0.92 for VI and 0.95 for RF.

2.5. Cardiovascular performance

Subjects performed an incremental test on a cycle ergometer (Cybex, USA) in order to determine the peak oxygen uptake (VO2peak), the first (VT1) and second (VT2) ventilatory thresholds, maximal workload (Wmax), and the workloads at VT1 (WVT1) and VT2 (WVT2). They initially cycled with a 25 W load, which was progressively increased by 25 W every 2 min, while maintaining a cadence of 70–75 rpm, until exhaustion (Izquierdo et al., 2003). The test was halted when subjects were no longer able to maintain a cadence of over 70 rpm. All the incremental tests were conducted in the presence of a physician. The expired gas was analyzed using a metabolic cart (CPX/D, Medical Graphics Corporation, St. Paul, MN) breath by breath. The VT1 and VT2 were determined using the ventilation curve corresponding to the points of exponential increase in the ventilation in relation to the load (Cadore et al., 2011a, 2011b). In addition, to confirm the data, VT2 was determined using the CO2 ventilatory equivalent (VE/CO2) (Wasserman, 1986). The maximum VO2 value (ml.kg⁻¹.min⁻¹) obtained close to exhaustion was considered the VO2peak. The Wmax (watts) was calculated using the formula: $W_{\text{max}} = W_{\text{om}} + \left(\text{t}/180\right) \Delta W$, in which $W_{\text{om}}$ is the load at the last stage completed, t is the time at the last incomplete stage and $\Delta W$ is the load increment in the last stage (25 W) (Izquierdo et al., 2001, 2003). The maximum test was considered valid if at least 2 of the 3 listed criteria were met: 1) the maximum heart rate predicted by age was reached (220–age); 2) the impossibility of continuing to pedal at a minimum velocity of 70 rpm; and 3) an RER greater than 1.1 was obtained. Three experienced, independent physiologists determined the corresponding points. For the data analysis, the curves of the exhaled and inhaled gases were smoothed by visual analysis using the software Cardiorespiratory Diagnostic Software Breeze Ex version 3.06. The heart rate (HR) was measured using a Polar monitor (model FS1, Shangai, CHI). The test–retest reliability coefficients (ICC) were 0.88 to VO2peak and Wmax as well as 0.85 to VT1 and VT2.

2.6. Statistical analysis

Normal distribution parameters were checked with Shapiro–Wilks test. Descriptive results are reported as mean ± SD. The Pearson product moment correlation test was used to investigate possible associations between the parametric parameters analyzed. In the non-parametric data, Spearman correlation test was used. Significance was accepted as P < 0.05 and the analysis were made in SSPS version 18.0.

3. Results

Tables 1 and 2 show the physical characteristics, echo intensity, muscle isometric and isokinetic strengths, as well as cardiovascular values of the participants.

3.1. Relationships between echo intensity, strength and cardiovascular performance

Significant negative correlations were observed between the individual values of rectus femoris echo intensity and the corresponding individual values of isometric peak torque and isokinetic peak torque at $60^{\circ}$.s⁻¹, $180^{\circ}$.s⁻¹ and $360^{\circ}$.s⁻¹ (range from $r = -0.48$ to $r = -0.64$; $P < 0.05$) (Table 3 and Fig. 1). In addition, significant negative correlations were observed between rectus femoris echo intensity and the workload at VT1 ($W_{\text{VT1}}$) ($r = -0.46$, $P = 0.013$), and the workload at VT2 ($W_{\text{VT2}}$) ($r = -0.50$, $P = 0.009$) (Table 4 and Fig. 2).

3.2. Relationships between muscle mass, strength and cardiovascular performance

Significant correlations were observed between individual values of muscle thickness and the corresponding values of isometric and isokinetic peak torques (range from $r = 0.44$ to $r = 0.62$, $P < 0.001$ to $P < 0.05$) (Table 3). No significant correlations were found between any muscle thickness measure (i.e., VL, VM, VI, RF and QF) with any cardiorespiratory parameter (Table 3).

3.3. Relationships between strength and cardiovascular performance

Significant correlations were observed between the individual values of the force per unit of muscle mass and cardiovascular values (range from $r = 0.52$ to $r = 0.60$, $P < 0.001$ to $P$) (Table 3 and Fig. 3). In addition, significant correlations were observed between the

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Values are mean ± SD of strength, cardiopulmonary and muscle thickness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Isometric PT (N.m)</td>
<td>231.1 ± 34.1</td>
</tr>
<tr>
<td>Isokinetic PT 60°.s⁻¹ (N.m)</td>
<td>169.5 ± 31.7</td>
</tr>
<tr>
<td>Isokinetic PT 180°.s⁻¹ (N.m)</td>
<td>107.6 ± 21.3</td>
</tr>
<tr>
<td>Isokinetic PT 360°.s⁻¹ (N.m)</td>
<td>77.0 ± 13.1</td>
</tr>
<tr>
<td>Torque per unit of muscle mass (Nm.mm⁻⁰.⁶⁷)</td>
<td>13.1 ± 1.8</td>
</tr>
<tr>
<td>VL muscle thickness (mm)</td>
<td>20.6 ± 2.7</td>
</tr>
<tr>
<td>VM muscle thickness (mm)</td>
<td>19.3 ± 3.8</td>
</tr>
<tr>
<td>VI muscle thickness (mm)</td>
<td>14.2 ± 3.5</td>
</tr>
<tr>
<td>RF muscle thickness (mm)</td>
<td>18.4 ± 3.6</td>
</tr>
<tr>
<td>QF muscle thickness (mm)</td>
<td>72.6 ± 9.0</td>
</tr>
<tr>
<td>VO2peak (ml.kg.min⁻¹)</td>
<td>26.7 ± 6.3</td>
</tr>
<tr>
<td>Wmax (W)</td>
<td>122.6 ± 23.7</td>
</tr>
<tr>
<td>VT1 (ml.kg.min⁻¹)</td>
<td>142.7 ± 27.4</td>
</tr>
<tr>
<td>VT2 (ml.kg.min⁻¹)</td>
<td>20.2 ± 4.6</td>
</tr>
<tr>
<td>WVT1 (W)</td>
<td>61.2 ± 13.0</td>
</tr>
<tr>
<td>WVT2 (W)</td>
<td>101.7 ± 19.6</td>
</tr>
</tbody>
</table>

PT, peak torque; VL, vastus lateralis; VM, vastus medialis; VI, vastus intermedius; RF, rectus femoris; QF, quadriceps femoris; VO2peak: Peak oxygen uptake; Wmax: maximal workload; VT1 and VT2: ventilatory thresholds; WVT1 and WVT2: workloads at VT1 and VT2.
individual values of cardiovascular performance and the corresponding values of isometric and isotonic torques (range from \( r = 0.38 \) to \( r = 0.67 \); \( P < 0.001 - 0.05 \)) (Table 4).

### 4. Discussion

A unique finding of the present study was the associations found between muscle echo intensity with the neuromuscular and cardiorespiratory performances in the elderly. In addition, the force per unit of muscle mass was associated with cardiovascular performance, suggesting that this parameter is an optimal neuromuscular factor associated with endurance performance in this population. Moreover, our results showed that the isokinetic peak torques obtained at higher velocities (180 and \( 360°\cdot s^{-1} \)) were more closely associated with endurance performance in elderly subjects. The present results suggest that the echo intensity measured using computer-aided grayscale analysis is a low-cost, easily accessible and a safe method for evaluating muscle quality that may contribute to further studies of neuromuscular and cardiovascular functions in the elderly.

In addition to the limited data regarding the association between echo intensity and strength performance, to the best of the authors' knowledge, no studies have investigated the relationship between echo intensity and cardiorespiratory fitness in elderly men. A unique finding of the present study was the negative associations found between rectus femoris echo intensity and the workloads at the ventilatory thresholds. These results suggest that the connective and adipose tissue accumulation reported by the grayscale analysis may also influence cardiorespiratory capacity. A possible explanation for these results may be the aging-related increase in the amount of intramuscular connective tissue that is associated with a decreased number of capillaries and results in greater isolation of each capillary from the adjacent muscle fiber, which disturbs the blood supply of the muscle fibers (Tyml and Mathieu-Costello, 2001; Egginton and Gaffney, 2010). Since the muscle capillarization is an important factor to the cardiorespiratory capacity, this deleterious process associated with lower muscle quality may also impair cardiorespiratory capacity. It should be highlighted that the workloads performed at the aerobic and anaerobic thresholds are markers of economy of movement (Izquierdo et al., 2001, 2003; Cadore et al., 2011a, 2012a), and these endurance parameters are associated with the capacity to perform daily activities in the elderly (Hartman et al., 2007).

Similar to the relationship observed between echo intensity and cardiorespiratory fitness, significant negative relationships were observed between echo intensity and muscle strength. In agreement with the present results, Fukumoto et al. (2012) have shown a negative correlation between quadriceps echo intensity and isometric muscle strength (\( r = -0.40, P < 0.01 \)) using grayscale analysis. However, despite their interesting result, their study only evaluated elderly women, and only one strength variable was measured. The present results expand the data regarding the association between muscle echo intensity and strength performance in the elderly because a relationship was also observed with explosive performance (\( r = -0.64 \) to \( -0.67, P < 0.001 \)). Thus, the negative association between echo intensity and strength reinforces the idea that not only muscle size but also muscle quality, i.e., the amount of connective and adipose tissues in the muscle, is associated with high-speed isokinetic performance.

In the present study, positive associations were observed between the force per unit of muscle mass and \( \dot{V}O_2\text{peak}, \dot{W}T_1 \) and \( \dot{W}T_2 \). Although the force per unit of muscle mass has previously been associated with functional capacity (Misić and Evans, 2007; Korhonen et al., 2009; Granacher et al., 2010), a unique finding of the present study was the association between this neuromuscular parameter and cardiovascular function in the elderly. Some studies have shown positive correlations between strength variables and cardiorespiratory fitness (Izquierdo et al., 2001, 2003; Brentano et al., 2008; Cadore et al., 2011a). Interestingly, in the present study, the isometric peak torque and the muscle thickness measures QF, VI, VM, VL and RF were not associated with the aerobic variables \( \dot{V}O_2\text{peak}, \dot{W}T_1 \) and \( \dot{W}T_2 \). Thus, because the force per unit of muscle mass provides an estimation of

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**Table 3**

<table>
<thead>
<tr>
<th>Isometric PT (N.m)</th>
<th>PT 60°\cdot s^{-1} (N.m)</th>
<th>PT 180°\cdot s^{-1} (N.m)</th>
<th>PT 360°\cdot s^{-1} (N.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo intensity (A.u.)</td>
<td>(-0.51^{**})</td>
<td>(-0.48^{**})</td>
<td>(-0.64^{***})</td>
</tr>
<tr>
<td>VI MT (mm)</td>
<td>0.42^{**}</td>
<td>0.53^{**}</td>
<td>0.51^{**}</td>
</tr>
<tr>
<td>VM MT (mm)</td>
<td>0.42^{**}</td>
<td>0.53^{**}</td>
<td>0.62^{***}</td>
</tr>
<tr>
<td>QF MT (mm)</td>
<td>0.43^{**}</td>
<td>0.57^{***}</td>
<td>0.63^{***}</td>
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</table>

**Table 4**

<table>
<thead>
<tr>
<th>VO(_2)peak</th>
<th>W(_{\text{max}})</th>
<th>(\dot{W}T_1)</th>
<th>(\dot{W}T_2)</th>
<th>(\dot{W}T_{\text{VT1}})</th>
<th>(\dot{W}T_{\text{VT2}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo intensity (A.u.)</td>
<td>0.08</td>
<td>-0.29</td>
<td>0.14</td>
<td>0.05</td>
<td>-0.46</td>
</tr>
<tr>
<td>Torque per unit of muscle mass</td>
<td>0.60^{***}</td>
<td>0.30</td>
<td>0.52^{**}</td>
<td>0.60^{***}</td>
<td>0.38^{*}</td>
</tr>
<tr>
<td>Isometric PT (N.m)</td>
<td>0.23</td>
<td>0.36^{*}</td>
<td>0.25</td>
<td>0.32</td>
<td>0.40^{*}</td>
</tr>
<tr>
<td>PT 60°\cdot s^{-1} (N.m)</td>
<td>0.14</td>
<td>0.40^{*}</td>
<td>0.20</td>
<td>0.21</td>
<td>0.38^{*}</td>
</tr>
<tr>
<td>PT 180°\cdot s^{-1} (N.m)</td>
<td>0.14</td>
<td>0.47^{**}</td>
<td>0.10</td>
<td>0.18</td>
<td>0.41^{*}</td>
</tr>
<tr>
<td>PT 360°\cdot s^{-1} (N.m)</td>
<td>0.12</td>
<td>0.46^{**}</td>
<td>0.04</td>
<td>0.13</td>
<td>0.35</td>
</tr>
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</table>

**Fig. 1.** Relationship between rectus femoris echo intensity (A.u.) and knee extensors peak torque at 180°\cdot s^{-1} (N.m).

**Fig. 2.** Relationship between rectus femoris echo intensity (A.u.) and workload at the second ventilatory threshold (\(\dot{W}T_2\)) (watts).
the contribution of neural factors associated with force production (Tracy et al., 1999; Frontera et al., 2000; Reeves et al., 2004; Narici et al., 2005; Cadore et al., 2011a), our results suggest that neural factors, such as maximal recruitment capacity and firing rate (Häkkinen et al., 2000, 2001), have more influence on cardiorespiratory fitness in the elderly than morphological factors such as muscle thickness. In fact, aerobic capacity has previously been associated with neural parameters such as neuromuscular economy in the elderly (Cadore et al., 2011b) and rapid neural activation in young athletes (Nummela et al., 2006).

Another interesting finding of the present study is the greater associations observed between $W_{\text{VPE}}$ and the isokinetic peak torque at the velocities of 180 and 360°.s$^{-1}$ ($r = 0.64$ and 0.67, respectively) compared with the association observed between $W_{\text{VPE}}$ and peak torque at 60°.s$^{-1}$ ($r = 0.54$). In a study by Izquierdo et al. (2001), the maximal and submaximal aerobic capacities of elderly subjects were positively related to maximal strength and power values of the lower limbs ($r = 0.44$ to 0.56, $P < 0.05$ to 0.01). In another study, Izquierdo et al. (2003) also showed that strength training combining slow and explosive contractions significantly improved the submaximal and maximal endurance capacities in elderly subjects. Our results reinforce the idea that reduced cardiorespiratory capacity during aging may also be related to declines in neuromuscular function (Izquierdo et al., 2001, 2003; Cadore et al., 2011a). Our results also suggest that cardiorespiratory capacity in the elderly may be more enhanced by strength training aimed at developing explosive strength. Furthermore, it has been shown that explosive strength training enhances functional capacity in elderly subjects (Pereira et al., 2012; Reid and Fielding, 2012). Taken together, these results suggest that explosive strength training may improve several health parameters in the elderly, such as strength performance, functional capacity and cardiorespiratory fitness.

A possible limitation of the present study is that the ultrasound imaging does not allow the identification of what kind of intramuscular factor, such as adipose or connective tissue may contribute more to the echo intensity values. However, the association observed between echo intensity with neuromuscular and cardiorespiratory performance suggests that the gray scale analysis of ultrasound imaging may be an easy and non-invasive technic to investigate the effects of long-term strength and endurance trainings in the muscle quality in the elderly.

To conclude, our results expand the data regarding the association between muscle echo intensity and physical fitness in elderly subjects. In the present study, echo intensity was associated with several parameters of neuromuscular and cardiorespiratory performances in this population. The present results suggest that the echo intensity measured using computer-aided grayscale analysis is a low cost, easily accessible and a safe method for evaluating muscle quality that may contribute to future research on neuromuscular and cardiovascular functions in the elderly. Thus, our results have an important clinical application, since the echo intensity evaluated by grayscale analysis may be suggested as a useful tool to investigate the effects of strength and endurance trainings in the muscle quality in the elderly. Furthermore, the force per unit of muscle mass was more strongly associated with cardiovascular performance than strength or muscle thickness, which suggests that neural factors associated with strength development are related to cardiorespiratory performance in older subjects. In addition, the peak torque at higher velocities (180 and 360°.s$^{-1}$) was more closely associated with cardiorespiratory fitness than the peak torque at a lower velocity (60°.s$^{-1}$). From a practical point of view, the present results suggest that strength training aimed at developing explosive force production may also improve cardiorespiratory performance in the elderly.

Acknowledgments

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