NEUROMUSCULAR ECONOMY, STRENGTH, AND ENDURANCE IN HEALTHY ELDERLY MEN

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ABSTRACT

Cadore, EL, Pinto, RS, Alberton, CL, Pinto, SS, Lhullier, FLR, Tartaruga, MP, Correa, CS, Almeida, APV, Silva, EM, Laitano, O, and Kruel, LFM. Neuromuscular economy, strength, and endurance in healthy elderly men. *J Strength Cond Res* 24(x): 000–000, 2010—Declines in muscular strength resulting from reduced neural activity may influence the reduction in aerobic capacity in older men. However, there has been little investigation into the relationship between muscular strength and economy of movement during aerobic exercise in elderly subjects. Thus, the purpose of this study was to investigate the possible relationship between strength, aerobic performance, and neuromuscular economy in older men. Twenty-eight aged men (65 ± 4 years old) were evaluated in dynamic (1 repetition maximum test), isometric strength (maximal voluntary contraction), and rate of force development. Peak oxygen uptake, maximal workload, and ventilatory threshold were determined during a ramp protocol on a cycle ergometer. Throughout the same protocol, the neuromuscular economy (electromyographic signal) of the vastus lateralis was measured. Significant correlations were found between muscular strength, cardiorespiratory fitness, and neuromuscular economy ($r = 0.43–0.64$, $p < 0.05$). Our results suggest that cardiorespiratory capacity and economy of movement are associated with muscular strength during aging.

KEY WORDS aging, strength development, EMG, aerobic fitness

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INTRODUCTION

Aging is associated with a decline in muscular strength, power (17,22,28), and a reduction in cardiorespiratory capacity (1,12). The decrease in strength associated with aging results from a reduction in the size of muscle fibers and their loss (18,21), a reduction in maximum voluntary neural activation of the muscles, and the degree of antagonist activation (5,6).

The decline in cardiorespiratory capacity in the elderly is primarily associated with a decrease in the maximal heart output caused by the reduction in the maximum stroke volume and heart rate and the change in the oxygen arterovenous difference (12). Furthermore, some authors have demonstrated that strength development is also important for endurance performance in young athletes (24,26,27) and elderly sedentary men (12,13). Thus, muscle strength may be another aspect that could influence the decline in cardiorespiratory fitness in the elderly. Nevertheless, little is known regarding the extent to which the reduction in muscular strength influences the decrease in aerobic capacity during aging.

Some authors have demonstrated a relationship between maximum strength and the cardiorespiratory capacity in elderly untrained men and women (2,12). However, no data were found in the literature concerning the relationship between cardiorespiratory capacity and other parameters related to muscular strength, such as the rate of force development (RFD) and muscular endurance during the aging process. Moreover, although the strength capacity has been positively associated with metabolic economy during aerobic tasks or exercise (8,13), the relationship between muscular strength and the muscular activation during dynamic exercise, with the aim of evaluating neuromuscular economy, has not been investigated in older populations.

Understanding the relationship between muscular strength and aerobic capacity is important in determining what type of strength training can best aid the development of cardiorespiratory fitness in aged men. Given the lack of data in the literature concerning the relationship between cardiorespiratory and neuromuscular parameters in older men, the aim of the present study was to investigate the relationship between parameters related to muscular strength and aerobic capacity in elderly men. In addition, the present investigation aims to analyze a possible neuromuscular economy related to muscular strength during dynamic exercise in this population. Our hypothesis is that the stronger elderly will have a lower muscular activation during aerobic exercise.

Methods

Experimental Approach to the Problem

To investigate a possible relationship between neuromuscular and cardiorespiratory parameters in older men, physical evaluations were carried out using surface electromyography (EMG), ergospirometry, and dynamometry. For this purpose, the participants in the present study attended the Laboratory on several different occasions, because the evaluations of maximum dynamic strength, muscular endurance, isometric strength, and aerobic capacity were made on separate days. By measuring and correlating all these variables, we attempted to get an insight into the relationship among them in the elderly, because physiological concepts might explain possible correlations. Before data collection, the participants took part in a familiarization session for each test. After 4 weeks, all physical measurements were taken again at the same time of the day to control any possible physiological performance levels and learning effects. Because no difference between the 2 measurements was observed, we used the first values to investigate the correlations between the physiological parameters.

Subjects

The sample consisted of 28 sedentary healthy aged men (65 ± 5 years), who had not engaged in any regular or systematic physical training for at least 6 months before the study. The participants were recruited through an advertisement placed in a widely distributed newspaper and the group selected was very homogeneous regarding strength and aerobic fitness. The adopted exclusion criteria were a history of cardiovascular, endocrine, metabolic and neuromuscular diseases, and the use of any drug that influences the neuromuscular metabolism. The participants underwent a medical assessment involving clinical history anamnesis and an effort electrocardiograph to identify any possible exclusion factors. Before participating in the study, all the men signed a free informed consent document in which they were made aware of the risks associated with the tests to be undertaken. This study was approved by the Research Ethics Committee of the Federal University of Rio Grande do Sul, which is in accordance with the Helsinki Declaration. The physical characteristics are shown in Table 1.

Table 1. Physical characteristics.*

Age (y)	65.1 ± 4
Height (cm)	174.4 ± 6.6
Body mass (kg)	72.6 ± 3.7
Fat mass (%)	27.4 ± 3.3
Lean mass (%)	80.6 ± 5.6

*Values are mean ± *SD*.

Body Composition

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. The same technician obtained all anthropometric measurements, on the right side of the subject's body. Skinfold thickness was obtained with a Cescorf skinfold caliper. A 7-site skinfold equation was used to estimate body density (15), and body fat was subsequently calculated using the Siri equation (9).

Maximal Dynamic Strength

Maximal strength was assessed using the 1-repetition maximum test (1RM) in the bilateral knee extension (World, Porto Alegre, Brazil). One week before the test day, at a prior session, the subjects were familiarized with all the procedures. On the test day, they warmed up for 5 minutes on a cycle ergometer, stretched all major muscle groups, and performed specific movements for the exercise test. Each participant's maximal load was determined in a maximum of 5 trials. A 4-minute rest was allowed between trials, and the performance time for each contraction (concentric and eccentric) was 2 seconds, controlled with an electronic metronome (KORG, Melville, NY, USA). The test–retest reliability coefficient (intraclass coefficient [ICC]) was 0.99.

Muscular Endurance

This test involved evaluating the maximum number of maximum repetitions achieved with 60% of the 1RM load. For this test, the participants performed the same familiarization, warm-up, and execution time procedures as in the 1RM test. This test was completed when the participants were unable to perform more repetitions within the established execution time (2 seconds in each contraction phase) and with full movement amplitude. The test–retest reliability coefficient (ICC) was 0.87.

Maximum Isometric Strength and Rate of Force Development

To obtain the maximum isometric strength (kilograms) and RFD ($N \cdot s^{-1}$), the participants warmed up for 5 minutes on a cycle ergometer and were then positioned on a knee extension exercise machine (Taurus, Porto Alegre, Brazil), fitted with a load cell coupled to the cable that displaced the load. The load cell was connected to an analogical to digital converter (Miotool 400, Miotec, Porto Alegre, Brazil), which made it possible to quantify the traction exerted when each subject executed the knee extension at the determined angle. The participants were positioned seated with the hip at an angle of 110° and strapped to the machine at waist height.

After having their right leg positioned by the evaluators at an angle of 110° of knee extension (180° representing full extension), the participants were instructed to exert their maximum strength when trying to extend the right knee and to produce the strength as fast as possible. The participants had 3 attempts at obtaining the maximum voluntary contraction (MVC), each lasting 5 seconds, with a 3-minute interval between each attempt. During this test, the researchers provided verbal encouragement so that the participants would feel motivated to produce their maximal strength. The force–time curve was obtained using Miograph software (Miotec), with an acquisition rate of 2,000 Hz and later analyzed using SAD32 software. Signal processing included filtering with a Butterworth band-pass filter at a cut-off frequency of 0–9 Hz. Later, to determine the highest MVC, a 1-second slice was made in the plateau of force, between the second and fourth seconds of the force–time curve. The MVC with the highest value was used to obtain the RFD, which was considered the largest increase in strength at fixed intervals of 50 milliseconds. To calculate RFD, Matlab version 5.3 software was used. The test–retest reliability coefficient (ICC) was 0.94 for MVC and 0.81 for RFD.

Maximal Workload, Peak Oxygen Uptake, and Ventilatory Threshold

The variables maximal workload (W_{max}), peak oxygen uptake ($\dot{V}O_2$peak), and ventilatory threshold (VT_2) were determined using an incremental test on a cycle ergometer. The participants began the test with a 25-W load, and this was increased by 25 W every 3 minutes, while a cadence of between 70 and 75 rpm was maintained, until the participants claimed exhaustion, or they were no longer able to maintain a cadence of over 70 rpm. The W_{max} (W) was calculated using the formula: $W_{max} = W_{com} + (t/180) \cdot \Delta W$, where W_{com} is the load at the last stage completed, t is the time at the last incomplete stage, and ΔW is the load increment in the last stage (25 W) (13). The maximum $\dot{V}O_2$ value ($ml \cdot kg^{-1} \cdot min^{-1}$) obtained close to exhaustion was considered the $\dot{V}O_2$peak. The VT_2, expressed as a percentage of the $\dot{V}O_2$peak, was determined using the ventilation curve corresponding to the point of exponential increase in the ventilation in relation to the load (7). In addition, to confirm the data, the VT_2 was determined using the CO_2 ventilatory equivalent ($\dot{V}E/\dot{V}CO_2$). The corresponding points were determined by 3 experienced, independent physiologists. For the data analysis, the curves of the exhaled and inhaled gases were smoothed using the "median 5 of 7" method provided by the *Cardiorespiratory Diagnostic Software Breeze Ex* version 3.06. This method consists of using 5 median points from each 7 points and excluding the highest and lowest values. The maximum test was considered valid if

Table 2. Strength, cardiorespiratory, and hormonal parameters.*†‡

Variables	
Maximal dynamic strength (kg)	61.9 ± 11.6
Muscular endurance (no of repetitions)	15.9 ± 2.9
Maximal isometric strength (kg)	44.5 ± 10.4
Rate of force development ($N \cdot s^{-1}$)	1114 ± 667
W_{max} (W)	119.4 ± 26.4
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	26.3 ± 3.5
Ventilatory threshold (%)	79 ± 6.8
Neuromuscular economy VL 25 W (%)	10.7 ± 6.7
Neuromuscular economy VL 50 W (%)	16.8 ± 8.7
Neuromuscular economy VL 75 W (%)	25.2 ± 13.3

*VL = vastus lateralis; A.u. = arbitrary units.
†Values are Mean ± *SD*.
‡Neuromuscular economy variables are expressed in percent of maximal activation during a maximal isometric strength test. Ventilatory threshold expressed in percent of $\dot{V}O_2$peak.

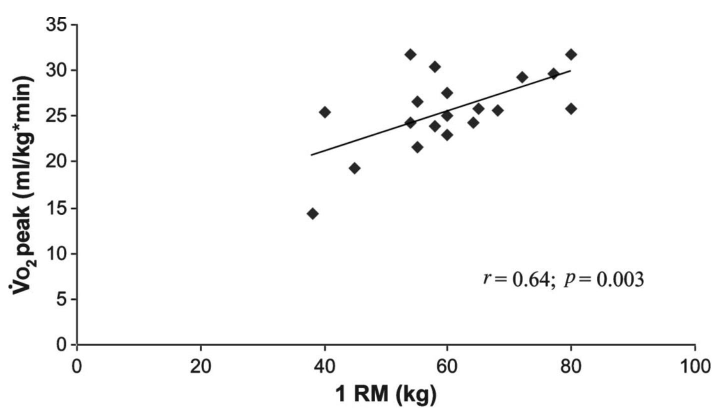

Figure1. Relationship between dynamic maximal strength (1 repetition maximum [1RM; kg]) and peak oxygen uptake ($\dot{V}O_2$peak), $n = 28$.

at least 2 of the 3 listed criteria were met: (a) the maximum heart rate predicted by age was reached (220 − age); (b) the impossibility of continuing to pedal at a minimum velocity of 70 rpm; and (c) a respiratory exchange ratio (RER) > 1.1 was obtained (23). All the tests were supervised by a medical doctor. The test–retest reliability coefficients (ICCs) were 0.88 for W_{max}, 0.85 for $\dot{V}O_2$peak, and 0.83 for VT_2.

Neuromuscular Economy

During the cycle ergometer protocol, the EMG signal from the vastus lateralis was measured during the 25-, 50-, and 75-W stages with the aim of identifying the existence of any relationship between strength and the muscular activation level during dynamic exercise. For this purpose, surface electromyography was used on the vastus lateralis. Electrodes were positioned on the muscular belly in a bipolar configuration parallel to the orientation of the muscle fibers, according to Leis and Trapani (19). Shaving and abrasion with alcohol were carried out in the muscular belly of the vastus lateralis, as previously described elsewhere (10). The EMG signal was acquired using a 4-channel electromyograph (Miotool), with a sampling frequency of 2,000 Hz per channel, connected to a personal computer (Dell Vostro 1000, São Paulo, Brazil). After its acquisition, the EMG signal was recorded for 20 seconds as from the beginning of the third minute of each stage of the test and then exported to the SAD32 software, where it was filtered using the Butterworth band-pass filter with a cut-off frequency between 20 and 500 Hz. After filtering, the signal equivalent to 10 pedaling cycles

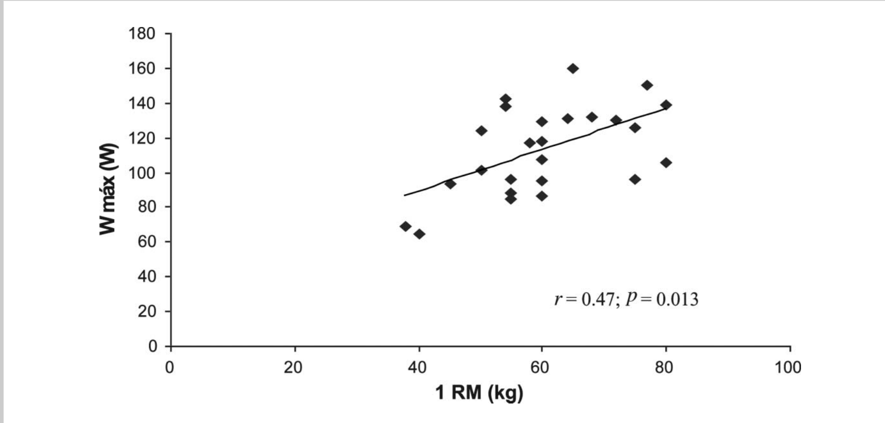

Figure 2. Relationship between dynamic maximal strength (1 repetition maximum [1RM; kg]) and maximal workload on cycle ergometer (W_{max}; W), $n = 28$.

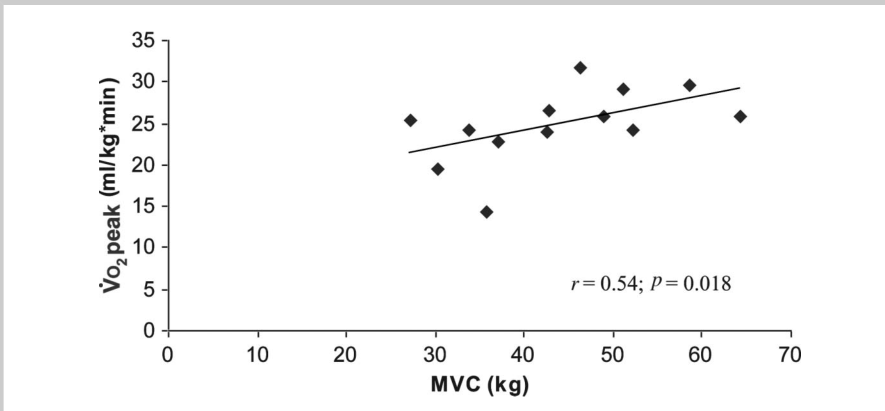

Figure 3. Relationship between maximal isometric strength (MVC; kg) and peak of oxygen uptake ($\dot{V}O_2$peak; $ml \cdot kg^{-1} \cdot min^{-1}$), $n = 28$.

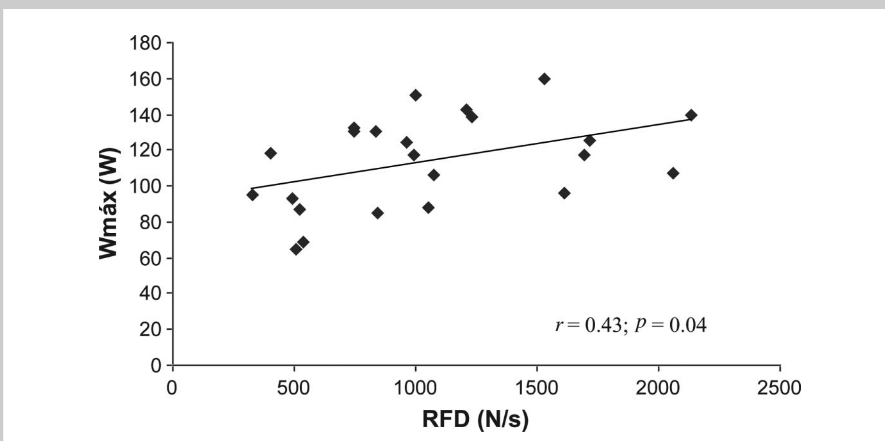

Figure 4. Relationship between rate of force development (RFD; $N \cdot s^{-1}$) and maximal workload on cycle ergometer (W_{max}; W), $n = 28$.

was sliced, and the root mean square (RMS) values for the period were determined. Each pedaling cycle was identified using a read–switch sensor coupled to the frame of the cycle ergometer, which registered each pass of the crank arm at an angle of 90° to the frame. The RMS values were normalized using the signal obtained during an MVC for the right knee extensors at an angle of 110° performed immediately before the incremental protocol and expressed as percentages (11). The test–retest reliability coefficient (ICC) was 0.83.

Statistical Analyses

Results are reported as mean ± *SD*. The Shapiro–Wilk test was used to verify the normality of date. Because of the normal distribution of data, the Pearson product–moment correlation test was used to investigate possible associations between the parameters analyzed. Possible differences between the 2 measurements were analyzed using Student paired *t* tests. In addition, the reliability of measurements was calculated using ICC values. Significance was accepted as $p \leq 0.05$, statistical power was 90%, and analyses were performed in SSPS version 13.0.

Results

The values of all variables investigated (Mean ± *SD*) related to strength, endurance performance, and EMG are presented in Table 2.

Strength and Endurance Performance

There were significant correlations between RFD and W_{max} ($r = 0.43$, $p = 0.04$); 1RM and W_{max} ($r = 0.47$, $p = 0.013$); 1RM and $\dot{V}O_2$peak ($r = 0.63$, $p = 0.003$); MVC and $\dot{V}O_2$peak ($r = 0.54$, $p = 0.018$) (Figures 1–4).

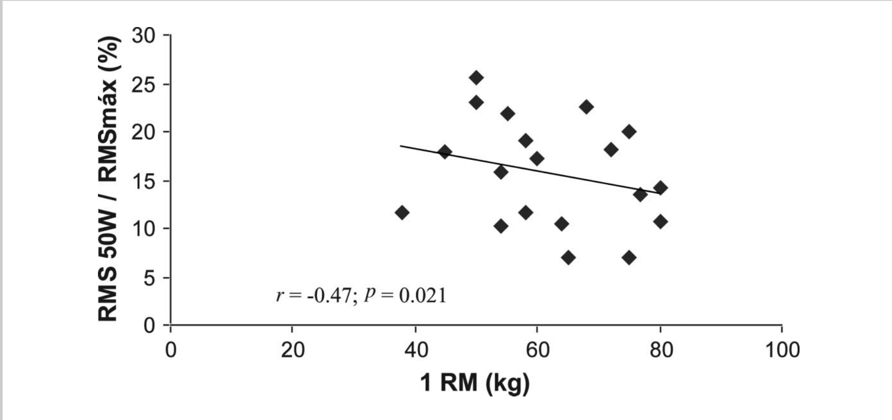

Figure 5. Relationship between dynamic maximal strength (1 repetition maximum [1RM]; kg) and relative muscular electromyographic (EMG) activity (%) at 50 W, $n = 28$.

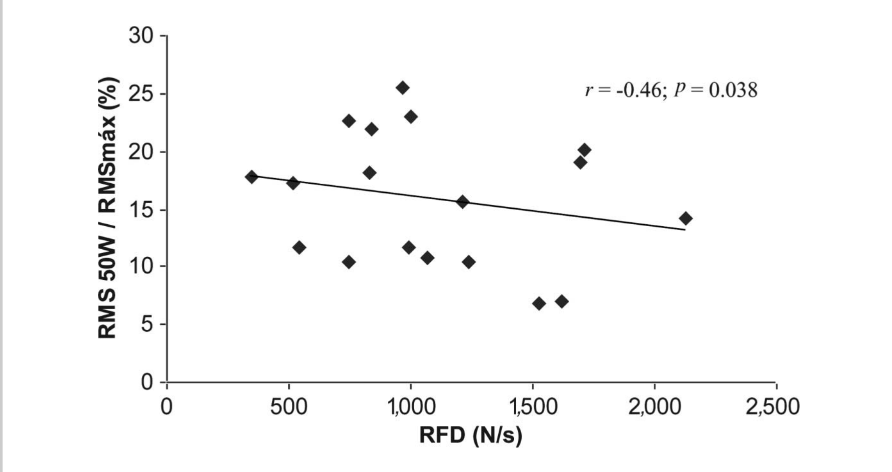

Figure 6. Relationship between rate of force development (RFD [$N \cdot s^{-1}$]; kg) and relative muscular electromyographic (EMG) activity (%) at 50 W, $n = 28$.

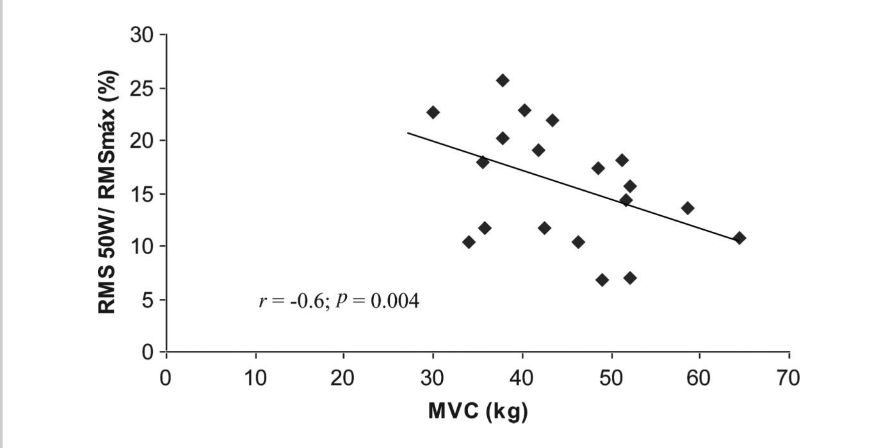

Figure 7. Relationship between maximal isometric strength (MVC; kg) and relative muscular electromyographic (EMG) activity (%) at 50 W, $n = 28$.

No significant correlations were found between VT_2 values and any of the neuromuscular parameters ($r = -0.21$ to 0.3, $p > 0.05$).

Strength Performance and Neuromuscular Economy

There were significant negative correlations between 1RM values and the relative activation of (%RMS) at stages 25 ($r = -0.45$, $p = 0.034$), 50 ($r = -0.47$, $p = 0.021$), and 75 W ($r = -0.44$, $p = 0.03$); between MVC values and %RMS at 25 ($r = -0.52$, $p = 0.016$), 50 ($r = -0.6$, $p = 0.004$), and 75 W ($r = -0.61$, $p = 0.002$) and between RFD values and %RMS at 25 ($r = -0.48$, $p = 0.034$), 50 ($r = -0.46$, $p = 0.038$), and 75 W ($r = -0.5$, $p = 0.021$) during the cycle ergometer test (Figures 5–7).

Discussion

The primary findings of the present study were the correlations between neuromuscular variables such as maximum dynamic and isometric strength, RFD, and cardiorespiratory capacity in elderly men. Furthermore, a negative correlation was shown to exist between strength parameters (1RM, MVC, and RFD), and muscular activation during the aerobic test, suggesting a neuromuscular economy in the vastus lateralis activity in stronger men. Furthermore, no relationship was seen between muscular endurance and aerobic capacity.

Some studies investigating young athletes have demonstrated a relationship between strength development and aerobic capacity (10,24,27). Additionally, other studies have demonstrated that the increase in strength resulting from resistance training is positively related to enhanced aerobic capacity (2,3,8,13). However, although the relationship between muscular strength and aerobic fitness has been demonstrated in young men, it has not been widely investigated in older men. In a study by Izquierdo et al. (12), the maximal and submaximal aerobic capacities of aged participants were positively related to maximal strength values (1RM) of lower limbs ($r = 0.44$–0.55). In an earlier study in our laboratory (2), both dynamic and isometric muscular strengths were positively correlated with cardiorespiratory capacity in postmenopausal women. Moreover, it has been demonstrated that strength training positively influences aerobic capacity in elderly humans (2,13,14).

Although muscular strength does not directly influence the cardiorespiratory system, it has been suggested that an increase in muscular strength is related to movement economy (25,29), because stronger men can perform aerobic activity using a lower percentage of their strength, thus recruiting fewer type-II muscle fibers and so preferentially using fibers with a more oxidative metabolism that is more resistant to fatigue (8,16,25). In fact, in the present study, a negative correlation was found between relative muscular activation (%RMS) of the vastus lateralis during the cycle ergometer test and the 1RM, MVC, and RFD values. Our results suggest a greater economy of movement resulting from greater muscular strength, because the motor units constituted type-I fibers, besides having a more oxidative metabolism, have a lower recruitment threshold (4,6), which apparently explains the lower EMG signal seen in each incremental stage in the stronger men. Another aspect that could have influenced the relationship between cardiorespiratory and strength parameters is the type of aerobic exercise, because it has been demonstrated that subjects performing cycle ergometer exercise recruit faster type motor units, which are also recruited in strength exercises (20).

However, in the literature, there is a lack of information regarding the relationship between the capacity to produce strength quickly (RFD) and muscular endurance with aerobic fitness. In the present study, moderate correlations were seen between RFD and MVC with aerobic capacity (W_{max} and $\dot{V}O_2$peak), whereas no relationship was seen between the muscular endurance values and the aerobic parameters. Furthermore, the negative relationship observed between RFD and muscular activation on the cycle ergometer reinforces the importance of the neural component in the strength production during aerobic exercise (24,26).

Our results suggest that the decline in cardiorespiratory capacity during aging may also be related to the decline in neuromuscular function in aged men, which would agree with previous studies that observed a correlation between strength and aerobic performance (2,12). The relationship found between the maximum strength and velocity of force production with the cardiorespiratory parameters together with the absence of any relationship between these parameters and muscular endurance suggests that aerobic capacity in elderly men would be more enhanced by high-intensity strength training, aimed at increasing the maximum strength or the development of explosive strength, than by muscular endurance training, which in the present study was not related to any aerobic performance parameter. Nevertheless, muscular endurance may be more closely associated with the time of exhaustion at a determined intensity (i.e., VT_2) than with aerobic capacity itself. Alternatively, the intensity used to measure the muscular endurance in the present study (i.e., 60% of 1RM) could have been too high, which would explain the absence of an association between aerobic capacity and the time to fatigue with that intensity, represented by the number of repetitions.

In summary, the results of the present study suggest the existence of a relationship between maximum dynamic and isometric strength, RFD, and parameters related to aerobic capacity such as $\dot{V}O_2$peak and W_{max} in sedentary elderly men, while none of these parameters were related to muscular endurance. Moreover, the negative relationship between muscular activation during aerobic exercise and strength measurements suggests that there is a neuromuscular economy in stronger men, which results in the recruitment of motor units with a lower threshold for the same load, resulting in a lower EMG signal in these subjects.

Practical Applications

The relationship between the maximum strength and RFD with the cardiorespiratory parameters together with the absence of any relationship between these parameters and muscular endurance suggests that cardiorespiratory fitness in the elderly would be more enhanced by high-intensity strength training, aimed at increasing the maximum strength or the development of explosive strength rather than low-intensity strength training, aimed at developing muscular endurance.

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