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MAXIMUM NUMBER OF REPETITIONS, TOTAL WEIGHT LIFTED AND NEUROMUSCULAR FATIGUE IN INDIVIDUALS WITH DIFFERENT TRAINING BACKGROUNDS

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ABSTRACT: The aim of this study was to evaluate the performance, as well as neuromuscular activity, in a strength task in subjects with different training backgrounds. Participants (n = 26) were divided into three groups according to their training backgrounds (aerobic, strength or mixed) and submitted to three sessions: (1) determination of the maximum oxygen uptake during the incremental treadmill test to exhaustion and familiarization of the evaluation of maximum strength (1RM) for the half squat; (2) 1RM determination; and (3) strength exercise, four sets at 80% of the 1RM, in which the maximum number of repetitions (MNR), the total weight lifted (TWL), the root mean square (RMS) and median frequency (MF) of the electromyographic (EMG) activity for the second and last repetition were computed. There was an effect of group for MNR, with the aerobic group performing a higher MNR compared to the strength group (P = 0.045), and an effect on MF with a higher value in the second repetition than in the last repetition (P = 0.016). These results demonstrated that individuals with better aerobic fitness were more fatigue resistant than strength trained individuals. The absence of differences in EMG signals indicates that individuals with different training backgrounds have a similar pattern of motor unit recruitment during a resistance exercise performed until failure, and that the greater capacity to perform the MNR probably can be explained by peripheral adaptations.

KEY WORDS: electromyography, performance, strength

INTRODUCTION

Neuromuscular fatigue is a complex phenomenon related to many physiological processes that occur during exercise that lead to a performance decrease. Fatigue can have peripheral origin (intracellular muscle fibre) or central origin (reduction of the number of active motor units activated and/or fire rate). Usually there is predominance of one of these mechanisms, although fatigue can be started from the interaction among them [12].

It is known that various factors (e.g. training background) can affect the fatigue process and consequently result in reduced performance. Many studies have shown that endurance athletes (runners, cyclists and triathletes) have a higher resistance to fatigue in strength tasks when compared to sprinters and jumpers [13,14], martial arts athletes [4,6] and weightlifters [6]. These studies suggest that subjects with a better aerobic fitness may be more resistant to fatigue, although none of these studies have really evaluated the subjects' aerobic fitness. Moreover, all these studies have evaluated fatigue in isokinetic movements, which do not represent the dynamic nature of the sports, and are not normally used in typical training sessions for these sports.

Neuromuscular central fatigue can be evaluated during a strength task through electromyographic signal analyses, including motor unit recruitment pattern by signal amplitude (RMS) and motor unit firing rate by median frequency (MF) [1]. Although is not clear which are the mechanisms responsible for differences in fatigue degree, it is know that subjects with different training background can present different neuromuscular responses and that strength trained individuals present greater co activation of the antagonist muscle [4,13] and agonist muscle activation [4] in RMS values, accomplished with lower resistance to fatigue in force tasks, evidencing the effect of the training background in central neural adjustments. Knowledge about the fatigue pattern in strength tasks in subjects with different training backgrounds is important to improve the strength session's prescription. Given the importance of this aspect and the absence of studies evaluating neuromuscular fatigue in exercises commonly used in training sessions (i.e., isotonic type strength exercises), associated with both maximum strength levels and aerobic power, the aim of this study was to evaluate the performance (maximum number of repetitions and total weight lifted), as well as neuromuscular activity (MF and RMS) in a strength task in subjects with different training backgrounds, i.e. subjects with different aerobic fitness and maximum strength levels. We hypothesized that fatigue resistance would be greater in the more aerobically trained subjects, with greater neuromuscular fatigue (rise in RMS and decrease in MF) in the strength trained group.

MATERIALS AND METHODS

Subjects. Twenty-six male individuals voluntarily participated in the present study after reading and signing an informed consent form explaining all the risks and benefits of the present investigation. All athletes were non-smokers, and none of them received any pharmacological treatments or had any type of neuromuscular disorder or cardiovascular, respiratory or circulatory dysfunction. The participants were selected according to their training background, and following some criteria: Aerobic Group (AG): middle distance runners with time inferior to 37 minutes in a 10 km race; Mixed Group (MG): athletes of intermittent sports who were practising aerobic and strength training systematically; Strength Group (SG): individuals with exclusive strength training practice. All participants had a minimum of two consecutive years' experience in their sport.

The AG was composed of eight middle distance runners with experience in strength training (weight training aimed at strength endurance improvement). The MG was composed of five handball players, one basketball player, two racket sports players and two crossfit athletes. For the SG, seven individuals with exclusive strength training practice (weightlifting and powerlifting) were included. All procedures received local ethics committee approval (16/2009).

Experimental design

The participants were submitted to three sessions. In the first session, after measurement of body mass and height and collecting information about their training experience, the subjects were submitted to an incremental treadmill test to volitional exhaustion to determine the peak oxygen uptake ($\dot{V}O_{2peak}$) and the peak velocity attained (V_{peak}) and followed by a maximum strength test (1RM) familiarization session, conducted 15 min after the treadmill test. In the second session the subjects performed just the 1RM test, and in the last session the participants performed the strength exercise composed of the maximum number of repetitions performed in four sets at 80% of the maximum strength. Athletes were familiarized with all procedures. All tests were conducted in the same period of the day and the period chosen was one that the athletes used for training. Athletes were evaluated in the competitive period, at least one week apart from competitions and a 24 h interval after training sessions was used before the tests were conducted. Temperature was not controlled, but it was registered during the test procedures and varied between 23°C and 25°C.

Procedures

Maximal aerobic test

The subjects performed an incremental treadmill test to volitional exhaustion. The initial speed was set at 6 $km \cdot h^{-1}$ for the SG, 8 $km \cdot h^{-1}$ for the MG, and 10 $km \cdot h^{-1}$ for the AG. First they performed a 3-min warm-up stage at the initial speed. After this each stage lasted 1 minute and the speed was increased by 1 $km \cdot h^{-1}$ per stage until the subject could no longer continue. The oxygen uptake was measured throughout the test and the average of the last 30 s was defined as $\dot{V}O_{2peak}$ (k4b[2] Cosmed, Rome, Italy) . The maximal velocity reached in the test was defined as V_{peak}. If the subject was not able to finish a complete stage (1 minute), the speed was expressed according to the permanence time in the last stage.

Maximum strength test

Maximum dynamic strength (1RM) for the half squat was assessed using a Smith machine. The test was performed according to standard procedures [2]. The subjects began the test with a general warm-up, consisting of cycling for 5 min (70 rpm at 50 W), followed by two specific warm-up sets. In the first set, the subjects performed 8 repetitions at 50% of the estimated 1RM, and for the second set, they performed 3 repetitions at 70% of the estimated 1RM with a two-minute interval between each set. After the specific warm-up the subjects rested for two minutes and then had up to five trials to achieve the 1RM load (i.e., maximum weight that could be lifted once with proper technique), with a three to five minute interval between trials.

For better control of the movement, during the 1RM test there was conducted a registration concerning feet position and movement amplitude (approximately 90-degree knee angle). This standardization was repeated in the subsequent experimental session.

Strength exercise

The subjects performed a general warm-up consisting of cycling for 5 min (70 rpm at 50 W), followed by four sets of maximum repetitions using 80% of the 1RM in the half squat in the Smith machine. Each set was separated by a two-minute interval. The maximum number of repetitions (MNR) correctly executed was computed and the total weight lifted for each set (TWL) performed was calculated (maximum number of repetitions multiplied by the weight lifted).

Electromyographic analysis

An electrogoniometer was fixed into the knee joint in order to establish the duration of each half squat repetition for the electromyographic (EMG) analysis. Knee joint angle was sampled at 2000 Hz, and low-pass filtered at 10 Hz. EMG activity was recorded from the vastus lateralis muscle using Ag/AgCl bipolar surface electrodes (10 mm diameter) placed in participants' right thigh along the long axis of the muscle fibres (according to SENIAM project, Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles). The skin was shaved, cleaned, and scrubbed before application of the electrodes. Online

EMG signals were amplified at a gain of 1000 and sampled at 2000 Hz. The offline EMG signal was band-pass filtered at 20-450 Hz. EMG median frequency (MF) was obtained by performing a fast Fourier transformation during an entire repetition. Stationarity of the EMG signal was assessed and guaranteed by the KPSS test. Maximum EMG amplitude was obtained from root mean square (RMS) after being rectified for each movement repetition. RMS was normalized for each squat repetition by the RMS of the entire set. Only the second and last repetitions in each set were chosen for subsequent statistical testing.

Statistical analysis

The data were analysed using the Statistical Package for Social Sciences 18.0 (SPSS Inc., Chicago, USA). The descriptive analyses consisted of the mean and standard deviation. For all measured variables, the sphericity estimated was verified according to Mauchly's W test, and the Greenhouse–Geisser correction was used when necessary. The data normality was verified using the Shapiro-Wilk test. The comparison of the variables related to the characteristics of the participants (age, body mass, height and training experience) and the performance in the maximum tests (1RM, $\dot{V}O_{2peak}$, V_{peak}) among the different groups was conducted through an one-way analysis of variance. When a significant difference was observed, a Tukey test was conducted.

The comparison of the total weight lifted and maximum number of repetitions performed in the four sets of half squats was conducted through a two-way analysis of variance (group and set) with repeated measurements in the second factor. The comparison of the RMS and MF in the second and last repetitions in each set of the four sets was conducted through three-way analysis of variance (group, set, and repetition) with repeated measurements in the third factor. When a significant difference or interaction was observed, a Tukey test was conducted.

The effect size (eta-squared; η^2) of each test was calculated for all analyses. Moreover, the relationships between the variables related to maximum strength as well as aerobic fitness and the maximum number of repetitions and the total weight lifted were analysed using the Pearson correlation coefficient. Statistical significance was set at $P < 0.05$.

RESULTS

The characteristics of the participants and the performance in the maximum tests are expressed in Table 1.

There was no significant difference between groups for age, height and training experience in their modalities. However, there was a significant difference for body mass ($F_{2,25} = 14$; $P < 0.001$; $\eta^2 = 0.556$), with lower values observed in the AG compared to the MG ($P < 0.001$) and SG ($P = 0.001$). For the maximum strength, there was a significant difference between the groups analysed ($F_{2,25} = 35$; $P < 0.001$; $\eta^2 = 0.750$), with higher values observed in the SG ($P < 0.001$) compared to the MG ($P < 0.001$) and AG ($P < 0.001$), and higher values in the MG compared to the AG ($P = 0.004$). There was a significant difference between the groups for the $\dot{V}O_{2peak}$ ($F_{2,25} = 17$; $P < 0.001$; $\eta^2 = 0.600$), with higher values observed in the AG compared to the MG ($p = 0.025$) and to the SG ($p < 0.001$), and higher values observed in the MG compared to the SG ($p = 0.004$). Moreover, there was a significant difference between groups concerning the V_{peak} ($F_{2,25} = 24$;

TABLE 1. AGE, BODY MASS, HEIGHT, MAXIMUM STRENGTH, PEAK OXYGEN UPTAKE ($\dot{V}O_{2peak}$), TRAINING EXPERIENCE AND PEAK VELOCITY (V_{peak}) IN THE AEROBIC GROUP (AG), STRENGTH GROUP (SG) AND MIXED GROUP (MG)

	AG (n = 8)	MG (n = 11)	SG (n = 7)
Age (years)	29 ± 6	28 ± 6	28 ± 5
Height (cm)	177 ± 7	181 ± 6	174 ±3
Body mass (kg)	68 ± 8 ^{b,c}	85 ± 9	84 ± 5
Training experience (years)	7 ± 6	8 ± 5	7 ± 4
Half squat 1RM (kg)	166 ± 20 ^{b,c}	219 ± 25 ^{a,c}	257 ± 14 ^{a,b}
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	60.3 ± 6.6 ^{b,c}	51.3 ± 6,8 ^{a,c}	39.4 ± 7.3 ^{a,b}
Vpeak ($km \cdot h^{-1}$)	21.3 ± 1.6 ^{b,c}	18.9 ± 1.0 ^{a,c}	15.8 ± 1.5 ^{a,b}

Note: Data are mean ± standard deviation; ^{a} = different from AG (P < 0.05); ^{b} = different from MG (P < 0.05); ^{c} = different from SG (P < 0.05)

TABLE 2. MAXIMUM NUMBER OF REPETITIONS AND TOTAL WEIGHT LIFTED (KG) IN FOUR SETS OF HALF SQUAT AT 80% OF THE 1RM PERFORMED IN THE AEROBIC GROUP (AG), MIXED GROUP (MG), AND STRENGTH GROUP (SG)

	Set 1	Set 2	Set 3	Set 4
Repetitions				
AG (n = 8) ^{a}	12 ± 5	11 ± 4	12 ± 5	12 ± 7
MG (n = 11)	10 ± 4	10 ± 2	8 ± 2	7 ± 2
SG (n = 7)	10 ± 4	8 ± 3	7 ± 3	7 ± 3
Total weight lifted (kg)				
AG (n = 8)	1596 ± 608	1442 ± 508	1551 ± 600	1526 ± 835
MG (n = 11)	1808 ± 630	1672 ± 319	1476 ± 370	1357 ± 580
SG (n = 7)	2024 ± 933	1541 ± 511	1469 ± 526	1385 ± 730

Note: Data are mean ± standard deviation; ^{a} = different from SG (P < 0.05)

TABLE 3. MEDIAN FREQUENCY (HZ) IN SECOND AND LAST REPETITION IN FOUR SETS OF HALF SQUAT AT 80% OF THE 1RM PERFORMED IN THE AEROBIC GROUP (AG), MIXED GROUP (MG), AND STRENGTH GROUP (SG).

	Set 1 (Hz)		Set 2 (Hz)		Set 3 (Hz)		Set 4(Hz)	
	Second [a]	Last	Second [a]	Last	Second [a]	Last	Second [a]	Last
AG (n = 8)	70.7 ± 4.8	69.5 ± 4.8	69.4 ± 5.8	68.5 ± 72.2	72.2 ± 7.3	71.6 ± 6.0	73.4 ± 5.0	73.3 ± 6.7
MG (n = 11)	71.3 ± 13.9	63.5 ± 12.1	67.3 ± 13.2	66.2 ± 14.6	69.2 ± 12.0	68.9 ± 13.2	69.7 ± 13.0	68.4 ± 14.7
SG (n = 7)	72.6 ± 12.5	71 ± 10.9	76.3 ± 18.0	67.7 ± 11.3	70.6 ± 9.3	67.7 ± 12.5	68.6 ± 11.9	66.3 ± 6.1

Note: Data are mean ± standard deviation; [a] = different from last repetition (P < 0.05)

TABLE 4. ROOT MEAN SQUARE (ARBITRARY UNITS) IN SECOND AND LAST REPETITION IN FOUR SETS OF HALF SQUAT AT 80% OF THE 1RM PERFORMED IN THE AEROBIC GROUP (AG), MIXED GROUP (MG), AND STRENGTH GROUP (SG)

	Set 1 (a.u.)		Set 2 (a.u.)		Set 3 (a.u.)		Set 4 (a.u.)	
	Second	Last	Second	Last	Second	Last	Second	Last
AG (n = 8)	2.8 ± 1.0	2.9 ± 0.5	2.4 ± 0.9	2.9 ± 0.8	2.4 ± 0.6	3.2 ± 1.0	2.6 ± 0.6	2.5 ± 1.3
MG (n = 11)	2.9 ± 1.0	2.7 ± 0.3	2.8 ± 1.1	2.7 ± 1.1	2.3 ± 0.5	2.6 ± 0.7	2.6 ± 0.9	2.5 ± 1.1
SG (n = 7)	2.9 ± 0.7	2.0 ± 0.6	2.2 ± 0.7	2.3 ± 0.7	2.6 ± 0.9	2.2 ± 0.7	2.2 ± 0.5	2.5 ± 1.0

Note: Data are mean ± standard deviation; a.u. = arbitrary units

$P < 0.001$; $\eta^2 = 0.675$), with higher values observed in the AG compared to the MG ($P = 0.007$) and to the SG ($P < 0.001$), and with the MG presenting higher values than the SG ($P = 0.001$).

Table 2 presents the maximum number of repetitions and the total weight lifted (kg) performed in four sets of half squat at 80% of 1RM for the different groups.

For the MNR there was no interaction effect between group and set factors. However, there was a group factor effect ($F_{2,23} = 4$; $P = 0.043$; $\eta^2 = 0.24$), with the AG performing higher MNR than the SG ($P = 0.045$). For the total weight lifted there was no effect.

Tables 3 and 4 present the MF and RMS in the second and last repetition in four sets of half squats at 80% of 1RM for the different groups.

For the MF there was an effect for the repetition factor ($F_{1,69} = 6$; $P = 0.017$ $\eta^2 = 0.22$), with higher values in the second repetition compared to the last one ($P = 0.016$). There was no significant effect for the RMS.

There was a negative correlation between the maximum strength and the maximum number of repetitions ($r = -0.49$; $P = 0.012$), and a positive correlation between the $\dot{V}O_{2peak}$ and the maximum number of repetitions ($r = 0.50$; $P = 0.034$).

DISCUSSION

The main finding was that subjects with different training backgrounds completed the same TWL during the strength training session, although via different combinations of repetitions and loads, as the AG was able to perform a superior MNR than the SG at 80% 1RM half squat. The unique modification in the neuromuscular response was the MF reduction in the last repetition compared with the second repetition for all groups and sets.

In fact, other studies have also shown that runners are able to postpone fatigue in strength endurance tasks when compared to athletes from other sports [4,14]. For example, Pääsuke et al. [14] submitted three groups, 15 participants in each, with different training backgrounds (long distance runners, untrained and sprinters/jumpers), to a 10 isometric contractions task (knee extension attempt) sustained as long as possible at 40% of the maximum voluntary contraction, with a one-minute rest between repetitions. The time in all attempts was greater for the long distance runners. In the first three attempts greater decreases occurred: 22-29% for the runners, 30-37% for the untrained subjects and 33-39% for the sprinters and jumpers. These results are similar to our findings; however, the present study analysed the fatigue resistance response using dynamic exercise, which is the kind of exercise usually performed in typical strength training sessions.

Despite differences found concerning performance, no difference was observed for the neuromuscular response. Thus, the fact that the AG performed a greater MNR than the SG cannot be explained by central fatigue. Conversely, Garrandes et al. [4] evaluated the performance in a strength training session (three sets of 31 isokinetic contractions at 70% of the maximal load for a maximal voluntary contraction, using $60^{o} \cdot s^{-1}$ angular velocity interspersed by 45 s rest) and the neuromuscular fatigue before and after the strength exercise in cyclists, triathletes and power trained athletes (martial arts athletes). The total mechanical work during sets, the knee extensor maximum torque and the electromyographic analysis (agonist and antagonist RMS) before and after exercise were analysed. Only the power trained athletes presented a decrease between the first and the third attempts in the exercises, and all groups performed the same total work output. After the strength exercise, both the concentric and isometric torque decreased, while the agonist muscle RMS signal for the eccentric contraction increased in the power trained athletes when compared to pre-exercise. Moreover, the co-activation level of the antagonist muscle in concentric and eccentric contractions of the power trained athletes increased after exercise compared to before exercise. These differences did not occur for the other groups, showing that the power trained group presented greater central fatigue.

The controversial results may be due to the protocol type used. Garrandes et al. [4] evaluated the neuromuscular fatigue during maximal voluntary contractions (concentric, eccentric, and isometric). Exercises performed at the maximal intensity as the maximal voluntary contractions are more dependent of neural factors, compared with submaximal exercise (i.e. strength endurance) [5]. Thus, this aspect explains why Garrandes et al. [4] found differences in neuromuscular fatigue between individuals with different training backgrounds whereas we did not.

Therefore, as no difference was found for the electromyographic parameters, peripheral factors may have influenced fatigue resistance [10,15]. For example, Terzis et al. [15] found a significant correlation ($r = 0.70$; $P = 0.01$) between the MNR at 70% 1RM in leg press and capillary density in vastus lateralis cross sectional area in twelve physically activity males. Thus, while Terzis et al. [15] did not compare aerobic trained subjects, it is possible to presume that a higher capillary density in runners can lead them to a better ability to extend performance into strength endurance sets.

Another study that could explain fatigue endurance in aerobically trained subjects was that of Johansen and Quistorff [10], who used nuclear magnetic resonance spectroscopy, and submitted 18 males (divided into three groups according to their training background, i.e., sprinters, 10 km runners and physically active subjects) to a strength task composed of four maximal isometric contractions with 60 s rest. It was found that sprinters reached higher strength values than the other groups, but the fatigue index (peak strength relative to lowest strength value during contraction) in the fourth contraction was higher for this group than for the other two. These results were accompanied by higher phosphocreatine depletion and ATP turnover. The total anaerobic metabolism ATP production and contraction costs were three times higher for sprinters. On the other hand, runners presented a faster ATP resynthesis than the other two groups, being the only group that could restore phosphocreatine stores during the rest intervals between contractions.

These results confirm the assertion that runners are more fatigue resistant and that this response can be mediated by peripheral mechanisms. Thus, a possible explanation for these findings is that peripheral adaptations developed by aerobic training could increase the oxidative capacity due to increases of the capillary and mitochondrial density [11,16] and oxidative enzymes of the skeletal muscle [11], which could contribute to fatigue delay and to the increased work muscle ability [15].

It is known that congenital factors can also be involved in the fatigue process, indicating that the ability to delay fatigue can be genetically influenced by some factors such as the positive relationship between a high number of slow twitch muscle fibres [3,7] as well as capillary density [15] and fatigue resistance, independently of the training background. It is difficult to extract a pure impact of the training background.

It must be highlighted that the SG showed higher absolute and relative strength when compared to runners, which could explain the lower MNR compared to the AG. In the present study, at 80% 1RM load, the SG performed the exercise with an absolute load average of nearly 206 kg (2.44 $kg \cdot kg$ body $mass^{-1}$), while the AG performed the exercise with an average load of 134 kg (1.90 $kg \cdot kg$ body $mass^{-1}$). Thus, the MNR was higher for the AG, although with a lower absolute load, which resulted in a similar total weight lifted during the four sets of half squat exercise at 80% 1RM. The absolute load can exert an influence on fatigue resistance due to the greater rise in intramuscular pressures, greater occlusion of blood flow, and greater accumulation of metabolites [8,9].

Finally, the absence of differences between the MG and the others may be due to lesser adaptations in both capacities (strength and aerobic) compared with the maximum index of these for the AG and SG, given that the SG was stronger than the MG, and the AG was more aerobically trained than the MG.

CONCLUSIONS

It can be concluded that the AG performed greater MNR than the SG in four sets at 80% 1RM half squat, but no differences were found among groups concerning total weight lifted and electromyographic responses. These results confirm that individuals with better aerobic fitness were more fatigue resistant than strength trained individuals. The absence of differences in EMG signals indicates that individuals with different training backgrounds (aerobic, strength and mixed) have a similar pattern of motor unit recruitment during a resistance exercise performed until failure, and that the greater capacity to perform MNR probably can be explained by peripheral adaptations.

The fact that individuals with better aerobic fitness present greater fatigue resistance must be investigated further to establish whether aerobic fitness is an important component to maintain the performance in strength training sessions. This would be beneficial to athletes performing sports demanding aerobic and strength development as well as people seeking health maintenance and wellness improvement.

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