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EFFECTS OF ELBOW FLEXOR MUSCLE RESISTANCE TRAINING ON STRENGTH, ENDURANCE AND PERCEIVED EXERTION

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ABSTRACT
Purpose. To verify the effects of resistance training at the electromyographic fatigue threshold (EMG_{FT}) based on one-repetition maximum strength (1RM), heart rate (HR), rate of perceived exertion (PE) and endurance time (EndT). **Methods.** Nineteen subjects (training group [TG]: $n = 10$; control group [CG]: $n = 9$), performed 1-min bicep curl exercises sets at 25%, 30%, 35% and 40% 1RM. Electromyography (biceps brachii and brachiorradialis), HR and PE were registered. Biceps brachii EMGFT was used to create a load index for an eight-week resistance training programme (three sets until exhaustion/session, two sessions/week) for the TG. The CG only attended one session in the first week and another session in the last week of the eight-week training period for EndT measurement. EndT was determined from the number of repetitions of each of the three sets performed in the first and last training sessions. After training, 1RM, EMGFT, EndT, HR and PE at the different bicep curl load intensities were again measured for both groups. **Results.** Increases in 1RM (5.9%, $p < 0.05$) and EndT (> 60%, $p < 0.001$) after training were found. In addition, PE was reduced at all load intensities ($p < 0.05$), while no changes were found for HR and EMGFT after training. **Conclusions.** Strength-endurance training based on the EMGFT improved muscular endurance and also, to a lesser extent, muscular strength. Moreover, the reduced levels of physical exertion after training at the same intensity suggest that endurance training exercises may improve comfort while performing strength exercises.

Key words: elbow flexion, electromyography, endurance, perceived exertion, training

Introduction

Increased muscular strength, muscular volume (hypertrophy), endurance and fat tissue loss are the usual adaptations of skeletal muscle tissue to resistance training [1, 2]. In addition, neural drive facilitation measured by analysing surface electromyography (EMG) is also reported following resistance training, which is related to increased EMG activity for agonist muscles and reduced activation for antagonist muscles [3–6]. However, the literature on the topic shows controversial results in terms of EMG activity following resistance training, some reported increased EMG [3, 4], others an absence of changes [5] and also one a reduction [4] among the trained muscles. These contrasting observations relate to different training protocols, such as training volume/duration, session frequency and intensity [1, 4]. Unfortunately, training intensities based on EMG data have been rarely studied, even though the use of the electromyographic fatigue threshold (EMG_{FT}) has been previously discussed [7, 8] and suggested as an alternative training index [9].

The determination of EMG_{FT} was originally suggested by using different load intensities performed until exhaustion, usually at one intensity per day [10]. However, Oliveira et al. [8] verified that by performing shorter sets (30–60 seconds), the EMG slopes (EMG activity *vs.* time) and subsequent EMG_{FT} are similar to those obtained after more exhaustive periods of exercise. Therefore, this allows accurate EMG_{FT} to be determined within a single session. Previous investigations that applied EMG_{FT} as a training intensity found increased elbow flexor strength and reduced EMG activity for the biceps brachii (BB) and brachioradialis (BR) muscles and, concomitantly, reduced activity for antagonist muscles (triceps brachii) [9].

Resistance training has been associated with neuromuscular and also metabolic and/or psychological adaptations. Previous investigation has found reduced heart rate (HR) following high-repetition lower limb resistance training [11], which may suggest an attenuation in the fatigue process during exercise. For the upper limbs, previous studies have reported increases in HR and perceived exertion (PE) at higher load levels [12–14]. Oliveira et al. [9] have verified on average HR at 140bpm and PE at 8 (on a scale of 0 to 10) for bicep curls at the end of a 1-min set at 40% one repetition maximum (1RM). Thus, low load intensities can elicit significant effort demands for smaller muscular groups.

Metabolic and psychological measurements such as HR and PE have been well correlated to elbow flexor EMG activity during fatiguing exercises [13, 14], which may suggest similar modulation for neuromuscular and metabolic/psychological properties during exercise

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[12–14]. Based on the above, we hypothesized that resistance training focused on endurance performance, such performed at the EMG_{FT}, can enhance time to exhaustion and reduce HR and PE. Such strength-endurance training may be aided by the use of individualized load intensities estimated from the EMG_{FT}, which could eventually optimize endurance. Therefore, the aim of the present study was to investigate the effects of individualized resistance training on muscular endurance and metabolic/psychological demands during the bicep curl.

Material and methods

Nineteen healthy male (age 21 ± 1.1 years, height 174.2 ± 4.3 cm, body mass 71.4 ± 7.7 kg; mean ± SD) volunteered for the experiment. The characteristics of the participants are shown in Table 1. None had been taking part in any systematic form of upper limb resistance training six months prior to the beginning of the study, and were asked to maintain their normal daily activities throughout the investigation period. All subjects were informed of the procedures, the risks and benefits associated with participating in the study and signed an informed consent term previously approved by the Local Ethics Committee.

The participants were randomly divided in two groups, a training group (TG, $n = 10$) and a control group (CG, $n = 9$), and tested over a 12-week period. The testing procedure was as follows: Week 1 – dynamic 1RM test was performed by both groups for the biceps curl; Week 2 – EMG_{FT} was determined during one day of testing; from Week 3 to Week 10 – subjects in the TG took part in an endurance training program conducted twice a week for the elbow flexor muscles based on biceps brachii EMG_{FT} [8]; the CG did not participate in any resistance training. The CG was asked not to participate in any resistance training during the duration of the eight-week training period, but required to attend one training session in the first and last week (Weeks 3 and 10) of the resistance training programme when endurance time (EndT) for all sets was measured for both groups. An additional 1RM test was performed at the beginning of Week 7 in order to evaluate potential strength improvements. After the training period was completed, the test procedures from the first two weeks were repeated for both groups (in Weeks 11 and 12).

Table 1. Anthropometric characteristics of participants in the control group (CG: $n = 9$) and training group (TG: $n = 10$); mean ± SD

	Age (years)	Mass (kg)	Height (cm)
CG	20.8 ± 1.2	73.76 ± 7.88	177.95 ± 3.90
TG	21.2 ± 1.4	70.48 ± 7.73	174.40 ± 5.50

1RM test and familiarization

The procedure to assess maximal strength during the biceps curl exercise has been described elsewhere [9]. The initial load was set to 30kg and increased/decreased if necessary. The participants needed to perform the full range of motion, starting from a full extension in order to avoid compensation by the shoulders or trunk. Invalid trials were those in which the participant could not perform the full range of motion and/or performed trunk/shoulder compensative movements to raise the bar.

The participants were familiarized with the bicep curl with a demonstration showing correct posture and movement rhythm. They were instructed to remain standing 1.5 m in front of a mirror with the trunk in a fixed position; their execution of the exercise was assisted by a frame specially designed to avoid compensation [9]. The rhythm was fixed at 40 bpm by a metronome (1.5 seconds for the concentric and 1.5 seconds for the eccentric phase of each repetition). In addition, the subjects were familiarized with the OMNI physical exertion scale [15], ranging from 0 (extremely easy) to 10 (extremely hard). This scale was positioned in front of the subject, fixed at eye height on the mirror frame.

EMG_{FT} determination, heart rate and perceived exertion

The participants performed four sets of 1-min bicep curl exercises at 25%, 30%, 35% and 40% 1RM in a randomly selected order, with a 10-min rest interval provided between sets. Verbal encouragement and feedback on posture was constantly provided during movement execution. The rhythm was fixed at 40 bpm, similar to the one used in the familiarization session, and the range of motion was fixed from approximately 15° to 125° elbow flexion (0° = full elbow extension). EMG activity was recorded for the biceps brachii (BB) and brachioradialis (BR) muscles at each load intensity by using pairs of adhesive, pre-gelled silver/silver chloride Medi-Trace surface electrodes (Covidien, USA) with a 10 mm caption area placed at an inter-electrode distance of 20 mm. Surface EMG signals were recorded (model CAD 1026, Lynx, Brazil) at a 4000 Hz sampling frequency, amplified (1.000x) and band pass filtered (20–500 Hz). Further details about EMG acquisition and calculation are available elsewhere [9]. Offline kinematic analysis, synchronized with the surface EMG measurements, were used to determine 90° elbow flexion for every concentric action. The root mean square (RMS) was calculated in a 250 ms time-window commencing at 90° elbow flexion. Linear regressions between RMS *vs.* time for each set were then calculated, from which the slopes and intercepts were obtained. A new linear regression model was calculated for slopes *vs.* load, and the intercept of this linear regression was defined as the EMG_{FT} for each participant [9, 10]. An illustration of the methods used for EMG_{FT} estimation is presented in Figure 1.

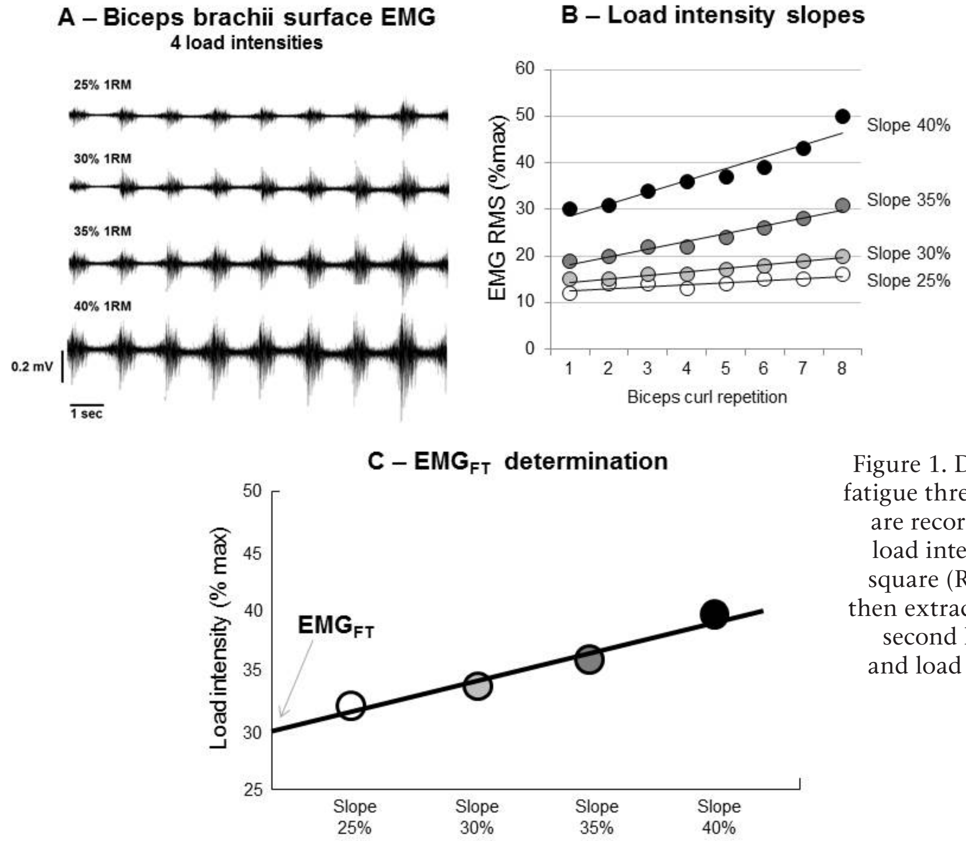


Figure 1. Determination of electromyographic fatigue threshold (EMG_{FT}): surface EMG signals are recorded during bicep curls at different load intensities (A); slope of the root mean square (RMS) values for each repetition are then extracted from the linear correlations (B); second linear correlation between slopes and load intensities generates a Y-intercept, defining the EMG_{FT} (C)

HR was recorded at 15 s into the set and at its end (60 s) by using a heart rate monitor (model S150, Polar, Finland). Concomitantly, subjects were asked to numerically rate how they felt their active muscles working using the previously cited PE scale as a guide.

Training program based on EMG_{FT}

The training group's resistance training programme was conducted during an eight-week period with two sessions held each week. The training sessions consisted of performing three sets of biceps curls exercise until exhaustion (failure to maintain complete range of motion and/or movement velocity/rhythm), each set was interspaced with 2-min rest. Training intensity (load) was individually determined by the biceps brachii EMG_{FT} (%1RM). At the end of the fourth week, 1RM levels were re-evaluated in order to adjust the training intensity if necessary so as to maintain EMG_{FT} as a percentage of the current strength. Throughout the sessions and during the sets the participants were strongly encouraged to give their maximum and maintain correct execution until exhaustion.

Statistical analysis

Data was measured as mean ± SD for all variables. Two-way mixed model ANOVA was used to verify the effects of training protocol (PRE-training x POST-training – within-subject factor) and group (CG x TG – between-subject factor) on the dependent variables: 1RM; EMG_{FT} for BB and BR; EndT for first, second and third sets; HR; and PE. In addition, in order to verify the effects of load intensity (25% x 30% x 35% x 40% 1RM) and exercise duration (15 s x 60 s) on HR and PE as dependent variables, two-way ANOVA was used. Tukey's post-hoc test was applied when necessary. The significance level was set at $p < 0.05$.

Results

Maximal strength and EMG_{FT}

No changes in 1RM strength were found for the CG throughout the test protocol (Week 1: 36.1 ± 3.9 kg,

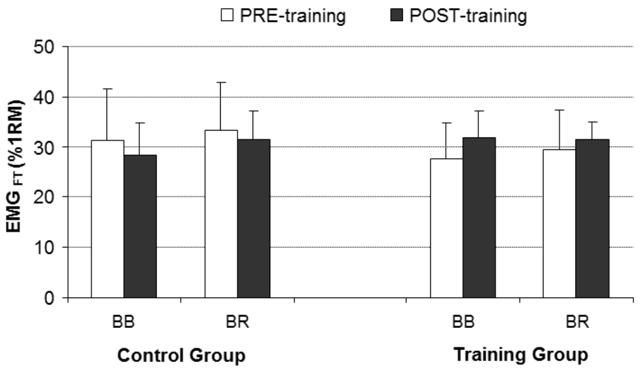
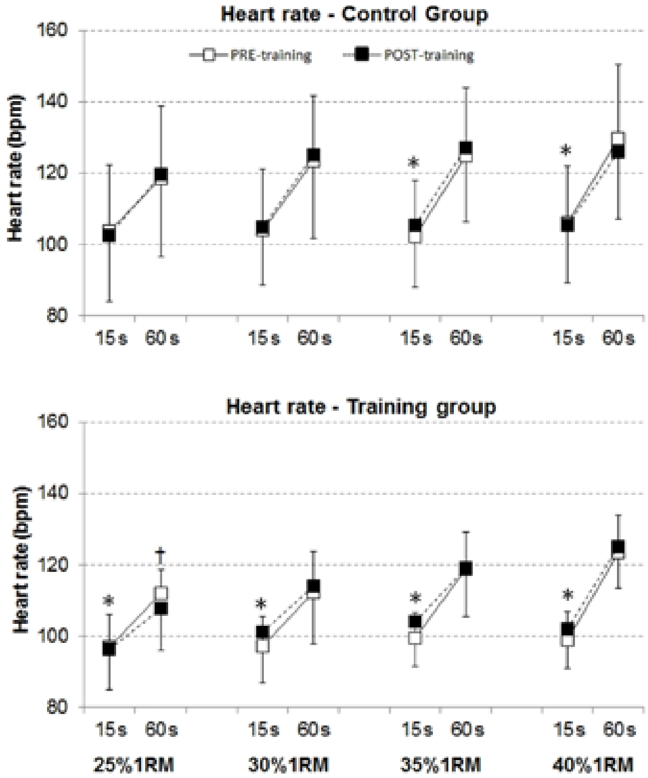
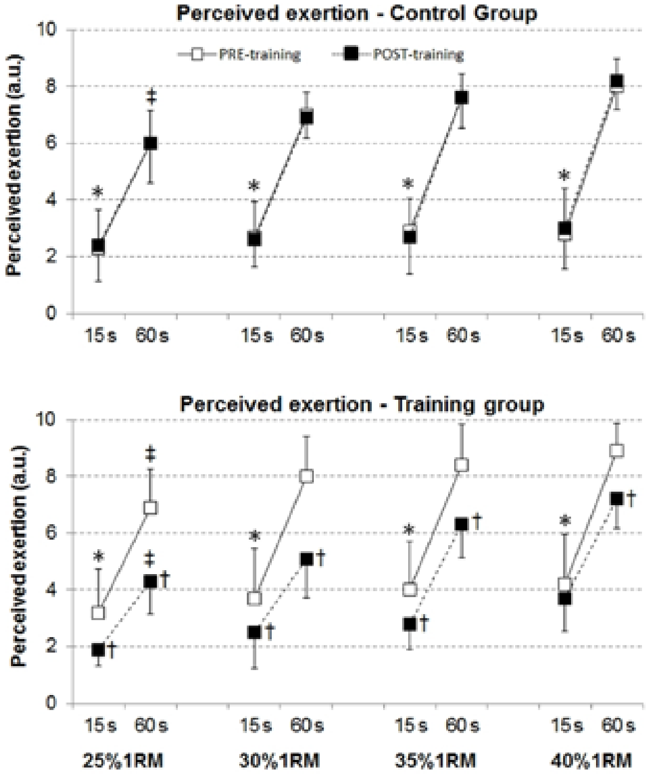


Figure 2. Biceps brachii (BB) and brachioradialis (BR) electromyographic fatigue threshold (EMG_{FT}) before (PRE) and after (POST) eight-week endurance training; mean ± SD



* denotes significant difference in relation to 60 s time for both PRE- and POST-training ($p < 0.01$)
† denotes significant difference in relation to 60 s time at 40% 1RM for both PRE- and POST-training ($p < 0.05$)

Figure 3. Heart hate at the beginning (15 s) and the end (60 s) of biceps curl exercise at different load intensities for the Control Group and Training Group before (PRE) and after (POST) eight-week endurance training; mean ± SD



* denotes significant difference in relation to 60 s time for both PRE- and POST-training ($p < 0.01$)
† denotes significant difference in relation to PRE-training ($p < 0.05$)
‡ denotes significant difference in relation to 60 s time at 40% 1RM for both PRE- and POST-training ($p < 0.05$)

Figure 4. Perceived exertion at the beginning (15 s) and end (60 s) of bicep curl exercise at different load intensities for the Control Group and Training Group before (PRE) and after (POST) eight-week endurance training; mean ± SD

Week 7: 36.7 ± 3.1 kg, Week 11: 37.1 ± 4.0 kg; $p > 0.05$). On the other hand, resistance training increased 1RM strength for the TG (Week 1: 36.9 ± 3.7 kg, Week 7: 38.9 ± 4.1 kg, Week 11: 39.3 ± 4.3 kg; $p < 0.05$). No significant effects of training were found for the TG on EMG_{FT} (Fig. 2), with only an increasing trend observed after the training period ($p = 0.08$). No significant changes were also verified between BB and BR EMG_{FT}, as well as between CG and TG ($p > 0.05$).

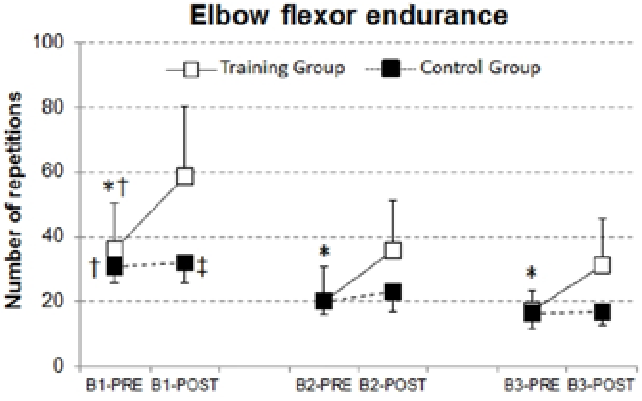
Heart rate and perceived exertion

Heart rate measurements performed before and after the study period found that both the CG and TG showed lower HR at 15 s of exercise when compared to 60 s for all load intensities ($p < 0.05$), except at 25% and 30% 1RM for the CG (Fig. 3). Load intensity had minor effects on HR; only for the TG by the end of the exercise (60 s) was HR at 25% 1RM significantly lower than that at 40% 1RM. The training program did not affect HR for any load intensity, moreover no significant differences between the CG and TG were found.

Similar to HR, PE (Fig. 4) was lower at the beginning of the exercise (15 s) when compared to the end (60 s) for both the CG and TG at all load intensities ($p < 0.001$). In addition, at 60 s, PE at 25% 1RM was significantly lower than at 40% 1RM ($p < 0.01$). Conversely to HR, lower PE levels were verified for all load intensities ($p < 0.01$) after training for 15 s and 60 s, except at 40% 1RM at 15 s. Due to this training effect, PE for the TG after completing the 8-week training programme (Week 12) was significantly lower than PE tested at the same time for the CG ($p < 0.05$) for all load levels and test times during the exercise.

Elbow flexor endurance time

EndT for the biceps curl was significantly lower from the first set in relation to the second and third set ($p < 0.01$) for both the CG and TG (Fig. 5). In addition to improving muscular strength, resistance training also improved EndT for the biceps curl exercise at the EMG_{FT} (Fig. 5). Significant increases were found from the first set (68.6 ± 46%, $p < 0.001$) to the second set (81.9 ± 43%, $p < 0.001$) and third set (78.9 ± 38%, $p < 0.001$) at the end of the training period for TG, with no changes observed among the CG.



* denotes significant difference in relation to POST-training ($p < 0.05$)
† denotes significant difference in relation to B2 and B3 ($p < 0.05$)
‡ denotes significant difference in relation to B3 ($p < 0.05$)

Figure 5. Endurance time of biceps curl exercise for the first set (B1), second set (B2) and third set (B3) before (PRE) and after (POST) eight-week endurance training; mean ± SD

Discussion

The primary objective of the present study was to verify whether individualized resistance training based on EMG_{FT} could improve muscular strength and endurance while reducing HR and PE, suggesting that muscular adaptations to endurance training can also reduce discomfort during resistance exercises. The main results of the study did confirm an increase in muscular strength with a reduction in perceived exertion. Moreover, resistance training based on EMG_{FT} improved on average at least 60% of EndT, therefore endurance improvements by training at the EMG_{FT} intensity can attenuate the discomfort felt when performing the bicep curl. Moreover, these results suggest that individualized training intensities may be essential in optimizing endurance training outcomes.

Low-to-moderate intensities have been suggested in resistance training aimed at improving endurance [1], such as the one used in the present investigation (approximately 30% 1RM). Although substantial increases in strength post-endurance training were not expected, we found a ~6% increase in 1RM for the TG. This strength gain may be predominantly credited to neural adaptations such as muscle fibre recruitment or neural drive [2], which have also been previously related to increased EMG activity after maximal endurance training [9, 11].

Upon completion of the training programme, the participants were able to perform bicep curls for a longer period of time. It is noteworthy that the training protocol was performed until exhaustion for every set, which has been credited in inducing improvements in blood flow and muscular capillarity [16]. Increased capillarity also enhances muscular oxygenation and reduces metabolite accumulation (blood lactate, K^+, inorganic phosphate, etc.) [16, 17]. Another study performed by this research group found reduced elbow flexor EMG activity at a fixed load intensity (%max) after a training program similar to the presented protocol [18], suggesting that motor unit recruitment is also enhanced after endurance training [19]. In addition, increases in muscular strength have also been corroborated with maintaining fatiguing tasks for longer periods of time [4, 17]. Therefore, the present results suggest that endurance training based on low-intensity exercises improves muscle function and attenuates the effects of fatigue. Further investigations on the use of the EMG_{FT} index in training routines should be conducted on other muscular groups such as the quadriceps and triceps surae.

Heart rate is a parameter often used in monitoring workouts by measuring the effects of exercise intensity on the cardiovascular system [9, 11, 20]. In this study, HR measured when performing the bicep curls was higher by the end of each set, although at 25% and 30% 1RM the differences were found to be insignificant, which suggests low demand on the cardiovascular system at such low intensities [20]. Nonetheless, towards the end of exercise it is necessary to increase oxygen availability to the muscles and optimize metabolite removal, which promotes increases in blood circulation and, consequently, in HR [20]. Increased cardiovascular demand has been previously described in different types of elbow flexor exercises [9], however the specific training protocol used in the present study was unable to reduce HR levels. Training protocols applying high-repetition sets for larger muscular groups such as the quadriceps muscles were able to verify changes in HR [11]. Thus, perhaps the use of endurance training based on the EMG_{FT} for larger muscular groups may elicit greater changes in HR.

Physical exertion (PE) has previously been used to predict load intensity for isometric exercises [13, 14], and EMG activity for isometric tasks [12]. In this experiment, PE scales were used to verify the psychological aspects linked to metabolic and/or neuromuscular changes during exercise [12], thus verifying whether resistance training could influence PE during fatigue. In fact, reduced PE was found after resistance training, which has been suggested as an indirect measure of muscle fatigue and exercise performance [15]. Therefore, the present investigation confirms that endurance training protocols (such as those based on EMG_{FT}) may be able to reduce discomfort caused by fatigue.

Although not shown in the present investigation, elbow flexor EMG activity was reduced following this specific training protocol [19]. Although muscle recruitment and PE are regulated by the central nervous system, perhaps other peripheral contributions can alter force output/EMG [21] and PE [12–14]. Therefore, the underlying mechanisms behind muscular activation and PE may be somehow linked, since simultaneous inputs are sent for both muscular activation and sensation during exercise [21]. It can be suggested that the endurance training used in this study was able to reduce muscular activation and, consequently, produce less discomfort while performing the bicep curl exercise.

Conclusions

Resistance training targeting elbow flexor endurance improved 1RM strength and EndT during a bicep curl exercise. In addition, reductions in PE suggest that the exercise at the same training intensity was performed with less discomfort during sets. The individualized load intensities allowed substantial improvement in EndT, suggesting that EMG_{FT} may be a useful alternative for prescribing a training program focused on improving endurance.

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