ABSTRACT

**Purpose.** To verify the effects of resistance training at the electromyographic fatigue threshold (EMGFT) 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 brachioradialis), 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

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Based on the above, we hypothesized that resistance training focused on endurance performance, such performed at the EMGFT, 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 EMGFT, 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 – EMGFT 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 (after the training period was completed, the test 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  |

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 compensatory movements to raise the bar.

The participants were familiarized with the biceps 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.

**EMGFT determination, heart rate and perceived exertion**

The participants performed four sets of 1-min biceps 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 Med-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 kinetic 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 EMGFT for each participant [9, 10]. An illustration of the methods used for EMGFT estimation is presented in Figure 1.
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<sub>FT</sub>

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<sub>FT</sub> (%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<sub>FT</sub> 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<sub>FT</sub> 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<sub>FT</sub>

No changes in 1RM strength were found for the CG throughout the test protocol (Week 1: 36.1 ± 3.9 kg,
Both the CG and TG at all load intensities ($p < 0.001$). In addition, at $60\,\text{s}$, PE at $25\% \, 1\text{RM}$ was significantly lower than at $40\% \, 1\text{RM}$ ($p < 0.01$). Conversely to HR, lower PE levels were verified for all load intensities ($p < 0.01$) after training for $15\,\text{s}$ and $60\,\text{s}$, except at $40\% \, 1\text{RM}$ at $15\,\text{s}$. 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.

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 $15\,\text{s}$ of exercise when compared to $60\,\text{s}$ for all load intensities ($p < 0.05$), except at $25\%$ and $30\% \, 1\text{RM}$ for the CG (Fig. 3). Load intensity had minor effects on HR; only for the TG by the end of the exercise ($60\,\text{s}$) was HR at $25\% \, 1\text{RM}$ significantly lower than that at $40\% \, 1\text{RM}$. 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 ($15\,\text{s}$) when compared to the end ($60\,\text{s}$) for both the CG and TG at all load intensities ($p < 0.001$). On the other hand, resistance training increased $1\text{RM}$ strength for the TG (Week 1: $36.9 \pm 3.7 \, \text{kg}$, Week 7: $38.9 \pm 4.1 \, \text{kg}$, Week 11: $39.3 \pm 4.3 \, \text{kg}$; $p < 0.05$). No significant effects of training were found for the TG on EMGFT (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 EMGFT, as well as between CG and TG ($p > 0.05$).

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 EMGFT (Fig. 5). Significant increases were found from the first set ($68.6 \pm 46\%, p < 0.001$) to the second set ($81.9 \pm 43\%, p < 0.001$) and third set ($78.9 \pm 38\%, p < 0.001$) at the end of the training period for TG, with no changes observed among the CG.
The primary objective of the present study was to verify whether individualized resistance training based on EMGFT 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 EMGFT improved on average at least 60% of EndT, therefore endurance improvements by training at the EMGFT 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 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 EMGFT) may be able to reduce discomfort caused by fatigue.

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 EMGFT) 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 EMGFT may be a useful alternative for prescribing a training program focused on improving endurance.

Acknowledgements

We wish to thank the participants in this study and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for their financial support. Oliveira A.S. is currently supported by a CAPES international PhD fellowship (No. 0293-09-1).

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Paper received by the Editor: November 26, 2012
Paper accepted for publication: April 5, 2013

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HUMAN MOVEMENT
M. Gonçalves, A.S.C. Oliveira, Endurance training at EMGFT