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Original Article

Analysis of myoelectric activity, blood lactate concentration and time under tension in repetitions maximum in the squat exercise

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Abstract:
The purpose of the present study was to compare the load influence on the time under tension (TUT), electromyographic activity (EMG) and blood lactate concentration (LAC) in 8, 10, and 12RM and the relationship between the TUT and the number of repetitions in the squat exercise. The sample consisted of ten military men (age: 18.90 ± 0.32 years, height: 1.73 ± 0.05 m, body mass: 67.55 ± 4.96 kg, body fat: 6.54 ± 1.87%). The TUT for 8, 10, and 12RM was verified by kinematic using the timing technique of the Kinovea software. After 48 hours, the subjects performed the squat exercise with the TUT and the load obtained in the tests, where the EMG and LAC were evaluated. The electrodes to capture the EMG signal were positioned in the following muscles: vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), and femoral biceps (FB). The ANOVA showed significant differences in all protocols in the TUT and LAC variables ($p < 0.05$) in increasing order to the number of repetitions (8 RM < 10RM < 12RM). The EMG showed a significant reduction in the RF activation in the 10RM for the 12RM in comparison with 8RM, as well as at VL activation for the 8 and 12RM protocols in comparison with 10RM. The study concluded that smaller loads and higher numbers of repetitions generate higher TUT and LAC. However, they result in smaller muscle activation for RF and VL. According to the results of the present study, there is no difference between 8, 10 and 12RM for the VM and FB muscles in the squat exercise.
Key Words*:* resistance training, strength, time under tension, lactate, electromyography.

Introduction

Resistance training (RT) has been practiced not only by athletes looking for gains in sports performance but also by individuals who aim to improve the realization of their activities of daily living (Fleck & Kraemer, 2014). This type of training is established as an effective method for the development of musculoskeletal fitness and it is recommended to improve health and performance (Henwood, 2016). Thus, RT is usually applied to load the musculoskeletal system and stimulate the progressive increase of muscle strength (ACSM, 2017).

The force-velocity relationship describes the ratio of force generated by a muscle as a function of speed under constant load conditions (Pareja-Blanco et al., 2014). During the concentric phase, the speed of muscle shortening depends on muscle-resistant strength. As the load decreases, the speed of muscle contraction increases. This continues until the muscle reaches the maximum rate of contraction. It is important to note that the force drops rapidly as the contraction speed increases, reaching values near zero when the speed approaches the maximum (Henselmans & Schoenfeld, 2014).

However, recent evidence has shown that training until concentric failure, as when the level of force production is increased to the consequent total loss of speed, does not necessarily improve gains in muscle strength and may even be malefic, as it may induce excessive fatigue, mechanical and metabolic stress, and possibly undesirable transition to slower fibers (Fry, 2004). Although the force-velocity relationship was established long ago (Hill, 1938), it was little used as a method to control the intensity of the load in the resistance training.

Although the close relationship between the speed of movement and the production of force for a variety of exercises in isokinetic devices is already described in the literature, these devices allow only unnatural movements and are not a common form of training (Jidovtseff et al., 2011). The speed in prescribing and controlling endurance training is interesting, although until recently it was not possible to accurately measure velocity and the consequent time under tension (TUT) in typical strength training exercises.

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The protocols with different speed execution and numbers of repetitions present differences in mechanical characteristics, a factor that has also been associated with distinct neuromuscular adaptations in RT (Mohamad et al., 2012; Earp et al., 2015). Gentil et al. (2006) also verified that the duration of repetition influences blood lactate concentration (LAC). Based on the results of studies by Tanimoto and Ishii (2006) and Lacerda et al. (2016), when all other variables are standardized, a longer duration of repetition implies a higher concentration of blood lactate (Tanimoto & Ishii, 2006) and electromyographic activity (EMG). In this context, different loads influence the TUT and can also generate different LAC e EMG. The analysis of these responses allows characterizing different domains of exercise intensity (Gentil et al., 2006).

The execution of strength exercises with different loads can change the execution speed, the repetition duration, the TUT and, consequently, the training results (González-Badillo et al., 2010; Mangine et al., 2015; Schoenfeld et al., 2014; Schoenfeld et al., 2017). However, it is not clear in the scientific literature, which is the mean TUT for maximal velocity exercises and muscular responses, and there is no agreement on the evidence found in other studies. Thus, it is necessary to control the TUT to the possibility that the volume/intensity ratio of RT prescription programs can reach the proposed objective. In this context, the monitoring of muscle activity and the physiological responses are a necessary information to verify the effect of the training performed. Hence, it is hypothetically believed that the load used for the largest number of repetitions (8 versus 12) will decrease and, consequently, the capacity to produce strength will also decrease. On the other hand, it can allow the performance of higher speeds in the initial phase, which may permit the assimilation of TUT in these executions. However, even under these conditions, it is expected that, even with a lower load, the higher number of repetitions and consequent TUT stimulate the higher concentration of lactate, making it possible to verify muscular fatigue. In the EMG activity, the largest signal is expected to be verified in smaller TUT and higher loads.

Therefore, the aim of the present study was to compare the load influence on the TUT, EMG, and LAC in the accomplishment of 8, 10, and 12RM and the relationship between the TUT and the number of repetitions performed in the squat exercise.

Material & methods

Participants

The present investigation is a comparative and cross-sectional study (Thomas et al., 2012). Ten military men, without prior experience in resistance exercises, were evaluated, chosen randomly by lottery using the following inclusion criteria: a) physically active; b) absence of musculoskeletal or articular lesion in the period of collect data; and c) practicing physical exercises for at least six months with a minimum weekly frequency of two days. It was excluded from the sampling process the subjects: a) who were not in agreement with the terms of the commitment made by the researcher; b) missed a collect data day; c) who for some reason felt uncomfortable with any procedure proposed in the course of the research; d) subjects with some pain that could interfere in the correct exercise execution; and e) with positive PAR-Q (Thomas et al., 1992).

After the sampling procedures, all participants became aware of the study procedures and signed an informed consent form. The present study was submitted and approved by the Ethics Committee in Research involving human beings of the Pedro Ernesto University Hospital (HUPE/UERJ), under the number 1.823.683.

Experimental protocol

The current study was developed in four stages: 1) sample characterization; 2) description of the technique of movement; 3) load test; and 4) experimental protocol. Stages 1 and 2 occurred on the same laboratory visit. For each desired RM, there were visits on different days, one day being exclusive for 8RM, one for 10RM and another day for 12RM. Stages 3 and 4 took place with an interval of not less than 48 hours between them. There were five laboratory visits. The entry of participants into the protocols occurred randomly.

Four evaluators followed the data collection: a) execution appraiser (responsible for verifying the movement pattern, encouraging the participant and validating the collection); b) EMG appraiser (responsible for electrode fixation and manipulation of instrumentation); c) camera appraiser (responsible for filming and subsequent analysis of the footage); d) blood appraiser (responsible for the collection and analysis of blood). Before the application of the protocol, the participants completed a warming up set of 15 repetitions with 50% of the load obtained in the RM test, adopting a three-minute interval before starting the protocol. Individuals received the instruction to perform the exercise as fast as possible.

Each participant subsequently performed the exercise with the load obtained in the test, this time being asked to perform as many repetitions as possible in the mean TUT reached by the group on the day of the preliminary protocol. This procedure allowed to verify the relationship between the TUT and the number of repetitions. The EMG signal corresponding to the TUT of 8, 10 and 12RM was checked and blood samples were collected at the time before exercise and 30 seconds after finishing each protocol.

Data collection procedures

Body mass was measured through a mechanical scale (Filizolla®, Brazil) and height was measured using a portable stadiometer (Seca®, Baystate Scale & Systems, USA) to calculate the body mass index (BMI). The protocol adopted to estimate the percentage (%) of body fat was three skinfolds (Jackson & Pollock, 1978).

Squat exercise protocol

The participants of the present study received information about the execution techniques patterns of the proposed exercise, as well as educational exercises about the correct execution. The individual remained standing, perpendicular to a fixed bar of the Smith machine, with both feet parallel and aligned with shoulders and hip, with knees and hip flexed in 90º degrees. In this position, to check the proposed limit angle, a rope suspended by two trestles served as a movement limiter. In order for the participant to have sensory feedback of this position, it was instructed that, as soon as the gluteus muscle touched the rope, the subject would restart the movement. The execution of the exercise consisted in the complete extension of the knee and hip to 0º, this being the endpoint. This point was marked by a label placed on the support bar of the Smith machine and served as the execution limit, being observed for movement failure (Wirth et al., 2016). A manual goniometer (Carci, Brazil) was used to determinate the proposed angle in the exercise.

Determination of RM load and time under tension

The RM tests were performed on different days with at least 48 hours of an interval between them. The 8, 10 and 12 RM tests had the purpose of performing the consecutive repetitions with the maximum load at the highest possible speed (Simão et al., 2012). The intervals between the attempts during the RM test were set at five minutes. Before the execution, the participants performed a specific warm-up consisted of 15 repetitions of the exercise proposed in the apparatus only with the weight of the bar. For the test sequence, a 10 kg implement was used at each attempt.

In order to reduce the margin of error in the tests, the examiner provided standardized instructions prior the tests, so that the participant was aware of the performing technique of the exercise and the whole routine involving data collection. As small variations in the positioning of the joints involved in the movement could trigger other muscles, leading to erroneous interpretations of the obtained scores, the examiner was aware of the position adopted by the practitioner at the time of the test. The participants received verbal stimulus during the tests so that they could maintain a high level of motivation (Paz et al., 2017). The test was discontinued whether the subject performed the movement with the incorrect technique and/or when voluntary concentric RM failures occurred. Subjects were instructed not to ingest any stimulant drink (i.e. caffeine or alcohol) and not to perform any physical activity the day before or on the day of testing. The exercise techniques were standardized and followed in all tests (Scudese et al., 2015).

Reflective markers were affixed to the hip, knees, and ankles, thus ensuring the correct execution of the exercise, and to verify the moment of beginning and end of the movement and the behavior of the angular and linear joint kinematics.

The images were acquired by a camera (Sony, Japan) positioned on a tripod in the sagittal plane to allow full movement visualization. The TUT timing of each subject in each load was verified in the execution for 8, 10 and 12RM using the technique of time counting by kinemetry with software KINOVEA 8.15 (Balsalobre-Fernández et al., 2014).

Measurement of electromyographic activity and blood lactate concentration

Passive Ag/AgCl bipolar surface electrodes with a capture area of 1 cm and a 2 cm interelectrode distance captured the EMG signal. The electrodes were positioned in the following muscles: vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) and femoral biceps (FB).

Before the electrodes were placed, trichotomy, abrasion and posterior asepsis of the skin with cotton soaked in alcohol were performed. The reference electrode was attached to the clavicle. The recommendations of the International Society of Electrophysiology and Kinesiology were followed to fix the adhesive tape both to the recording electrodes and to the reference electrode (Merletti, 1999).

To capture the Surface EMG signals, it was used an 8-channel electromyograph (EMGSystem do Brasil Ltda., São Paulo, Brazil), with total gain of 1000, common mode rejection of 110dB and bandpass filter of 8-500Hz, scanned to a computer via a 16-bit resolution A/D conversion board, and at the sampling rate of 1000Hz. In order to guarantee the quality of the obtained signal, it was treated in MyoResearch XPTM Software (Noraxon Inc., USA) and presented as Root Mean Square (RMS). For signal normalization, the EMG Signal Mean technique was used. This value is characterized by the average RMS signal of each subject in the three protocols. This is attributed to 100%, so the entire EMG signal is normalized by this value (Burden & Barlett, 1999).

For measuring the blood lactate concentration (LAC), we used a lancing device (Roche Accutrend, Switzerland) with disposable lancets to make a perforation in the distal phalanx of the right index finger, after cleaning it with alcohol. This technique allowed the placement of a drop of blood on a test strip (Roche, BM-Lactate, Switzerland) placed on a laptop lactometer (Roche Accutrend Plus, Switzerland). The collections were performed before (LACpre) and 30 seconds after the exercise squat (LACpost). Values are given in mmol/l (Baldari et al., 2009).

Statistical analysis

The IBM SPSS Statistic 20 program was used for data analysis. The descriptive statistics were presented as mean, standard deviation and minimum and maximum values. The Shapiro-Wilk and Bartlett tests were performed to verify, respectively, the normality and the sphericity of the data. One-way repeated measures ANOVA was used for comparisons between exercise sets, followed by Bonferroni post hoc to identify possible differences between protocols. The present study admitted $p < 0.05$ as the significance level.

Results

Table 1 shows the descriptive characteristics of the volunteers.

Table 1. Subject characteristics (n = 10)

Variables	Mean	SD	Maximum	Minimum	p-value (SW)
Age (years)	18.90	0.32	19.00	18.00	0.366
Body weight (kg)	67.55	4.96	75.40	61.40	0.932
Height (m)	1.73	0.05	1.82	1.63	0.874
BMI (kg/m^2)	22.56	1.89	25.19	19.95	0.904
% BF	6.54	1.87	9.40	4.10	0.912

SD = standard deviation; BMI = body mass index; % BF = percentage of body fat; SW = Shapiro-Wilk.

Figure 1 presents the data of the test load, TUT and number of repetitions performed in the squat exercise. The TUT verified in the 12RM protocol was significantly higher than that of the TUT of 8RM ($p < 0.001$) and that of the TUT10 ($p = 0.043$). A significant difference was also found for TUT10 compared to TUT8 ($p = 0.009$). In the experimental protocol for squatting, the number of repetitions performed with the mean TUT of the sample represented the same values of repetitions with the individual load of the RM test.

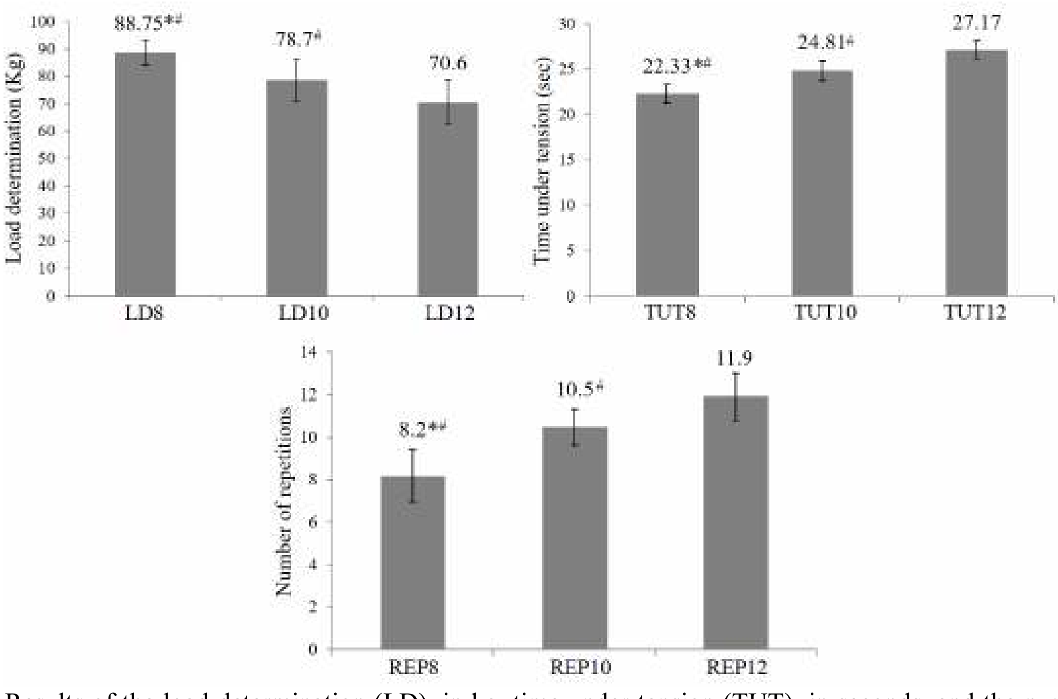

Fig. 1. Results of the load determination (LD), in kg, time under tension (TUT), in seconds, and the number of repetitions (REP) performed in the experimental protocol for 8, 10 and 12RM in the squat exercise.
* significant difference in comparison with LD10; # significant difference in comparison with LD12; * significant difference in comparison with TUT10; # significant difference in comparison with TUT12; * significant difference in comparison with REP10; # significant difference in comparison with REP12.

Higher levels of LAC were observed in the LACpos12 compared to the LACpos10 ($p = 0.005$) and the LACpost8 ($p < 0.001$). The LACpost10 protocol also presented higher levels of LAC compared to LACpost8 ($p = 0.012$) (Figure 2).

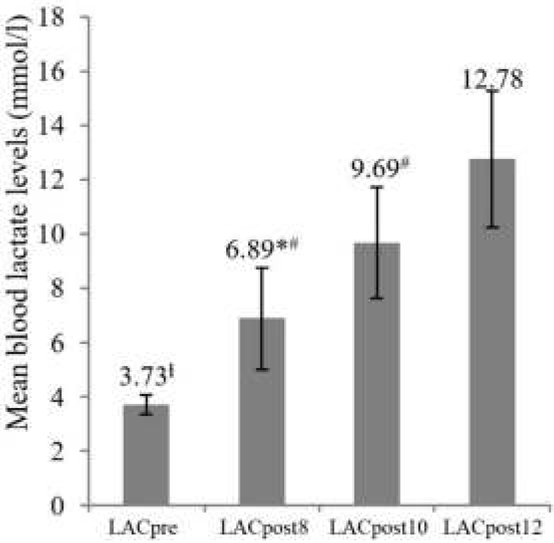

Fig. 2. Mean values of blood lactate levels pre and post-experimental protocol in mmol/l in the squat exercise.
ǂ significant difference for LACpre 8, 10 and 12; * significant difference for LACpost10; # significant difference for LACpost12.

Figure 3 presents the results of EMG for VM, VL, RF, and FB in the three RM protocols. Greater indices of the EMG recording was observed for the VL in the 8RM protocol compared to the 12RM protocol (p = 0.005), and higher RF activation in the 10RM protocol compared to the 12RM protocol (p = 0.007). No significant differences were found for VM and FB between the protocols.

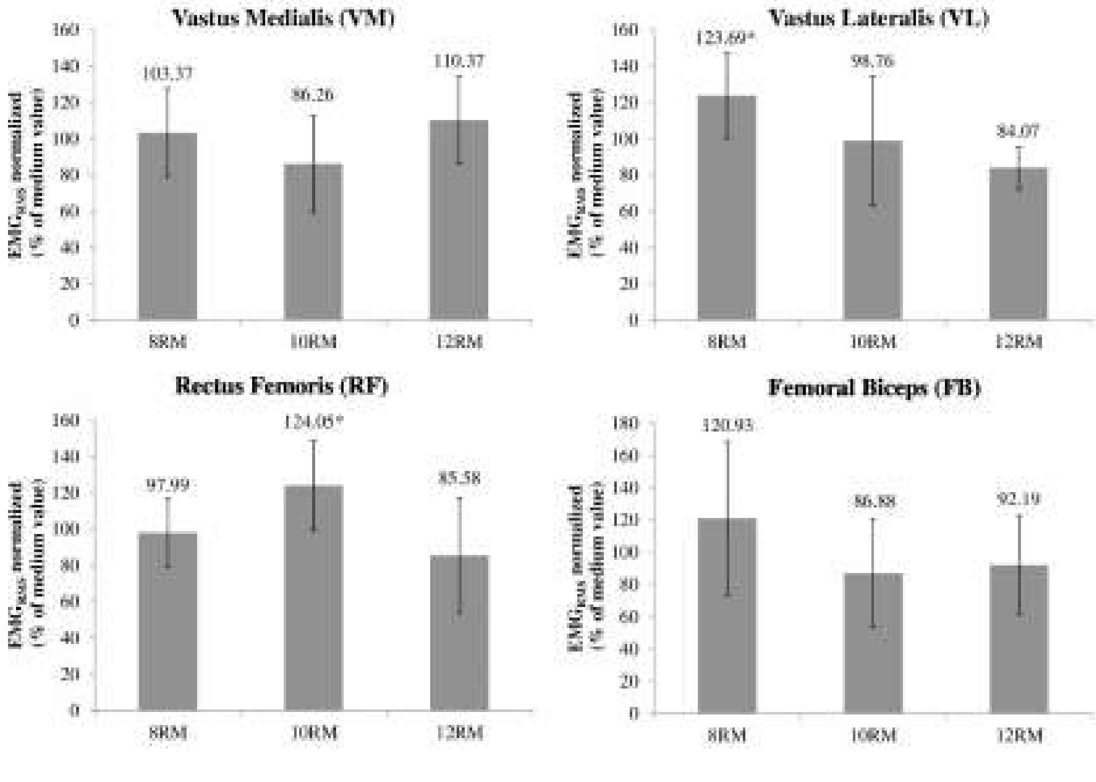

Fig. 3. Normalized values of electromyographic activity of VM, VL, RF, and FB in the squat exercise.
* significant difference for this protocol compared to 12RM

Discussion

The results of the present study demonstrated that the TUT of 12RM was significantly higher than the TUT of 8RM and 10RM as well as the TUT of 10RM was higher than the TUT of 8RM. The LAC of 12RM was significantly higher than the LAC of 8RM and 10RM as well as the LAC of 10RM was higher than the LAC of

8RM. As the number of repetitions increased, the TUT also increased, since the 8, 10 and 12RM protocols were performed at the highest possible speed. Thus, higher blood levels of LAC were found in the longer TUT (12 > 10 > 8RM). These results demonstrate that the higher volume of training influenced the metabolic responses of lactate corroborating with other studies (Fink et al., 2018; Henselmans & Schoenfeld, 2014; Schoenfeld, 2013). There was a significant reduction in the EMG activity of the RF for the 10 and 12RM protocols, as well as in the activation of the VL for the 8 and 12RM protocols, corroborating the findings of Tran et al. (2006).

Santiago et al. (2012) verified the TUT in the leg press exercise and found a TUT for 10RM of 25.7 ± 6s in trained women with the load of 175.4 ± 65.4 kg. This result presented similarities with the TUT found in the present study for this range of repetitions, which utilized the squat exercise in physically active men. Although they are distinct, the exercises resemble the joint movements, suggesting a pattern found in the TUT. However, Haua et al. (2013) verified the TUT of 18.67 ± 2.05s for 10RM in the wide grip seated row exercise in 18 men with experience in RT. These results suggest that the TUT can vary both due to the number of repetitions performed in the same exercise, as well as the type of exercise. The size of the body segment can influence the displacement and, consequently, the velocity and TUT during the execution of the exercise (Silva et al., 2016). Thus, this result highlights the necessity to verify the TUT for each exercise and for each muscle group.

Another study (Gentil et al., 2006) with trained men verified the effect of four RT execution rates using the same load in a knee extension machine. In the method with the traditional protocol of 10RM (cadence of 2s for the concentric phase and 2s for the eccentric phase), it was verified the total TUT of 42.08 ± 3.18s and LAC of 4.48 ± 1.57 mlmol. The study also found that the different execution speeds of the protocols modify the number of repetitions performed, interfering directly the TUT, maintaining the number of repetitions and, consequently, the obtained results. The results contrast with the present study, which found lower TUT for squat exercise in this range of repetitions and higher concentrations of lactate. This difference is probably due to the distinct exercise since knee extension involves less muscle mass than the squat exercise. However, differing from the present study, Gentil et al. (2006) did not find significant differences in LAC in the different TUT. The distinct results can be explained by the fact that the study (Gentil et al., 2006) have used trained individuals and cadenced speed.

Lacerda et al. (2016) verified higher concentrations of blood lactate in the protocol with the highest number of repetitions performed at a higher velocity when TUT and intensity were equalized. These acute effects suggest that the mechanical work of contractions is also important for muscle adaptations (Headley et al., 2011). However, without equalized TUT, Martins-Costa et al. (2016) verified higher lactate levels in the protocol with slower repetitions. The disagreement of these results supports the need presented by the present study to verify the average TUT of the proposed exercises and their muscular responses.

As in the present study, EMG also served as an analytical tool for Lacerda et al. (2016) and Martins-Costa et al. (2016) to verify the influence of TUT as a training variable. Both studies observed that the protocols with the higher number of repetitions presented greater amplitudes of the electromyographic signal for the pectoralis major and triceps brachii muscles ($p < 0.05$). However, in the present study, smaller values of muscle activation were verified in VL and RF. Associated with lactate levels, such results may suggest the beginning of the process of peripheral fatigue.

Sampson et al. (2014) verified the number of repetitions performed and the EMG in 12 trained men with the presumed load of 6RM. The participants performed elbow flexion exercise in three protocols: A) 2/2s cadence (control); B) maximum acceleration in the concentric phase and 2s in the eccentric phase; c) maximum acceleration in the concentric and eccentric phases. Although there was no difference in the number of repetitions, TUT presented a reduction of 40% and 30%, respectively, for protocol B and C, compared to control. However, higher activation was verified in the brachial biceps muscle in the highest TUT protocol ($p < 0.05$). These results do not corroborate with the findings of the present study, which observed different data to VL, RF, and FB. However, the findings of Sampson et al. (2014) suggest that the transition from the eccentric to the concentric phases at maximum velocity would stimulate the action of the stretching-shortening cycle. This evidences that this cycle would be responsible for the greater muscular activation by transforming the elastic energy into mechanics (Suchomel et al., 2016).

Some limitations can be mentioned in the present study. There was no use of another blood marker of muscle stress, such as Creatine Kinase (CK), or another instrument for detection of muscle damage, such as ultrasound. The protocols differ not only for TUT but also for load, being this a limitation of the present study. In addition, the participants performed only one session of familiarization with the proposed exercise, which can also be considered a limitation of the study design.

Conclusions

The present study showed significant differences between the TUT and LAC variables for all protocols in ascending order to the number of repetitions. However, the only significant difference in EMG for VL and RF muscles was verified. The VM and FB muscles presented no significant difference.

The number of repetitions performed in the experimental protocol of the present study with the TUT reflected the desired RM range. Thus, the TUT verified seems to reproduce the reality of the maximum effort when performed with maximum loads. Therefore, doing the squat exercise in the TUT verified by the present study seems to induce the same results as performing 8, 10 and 12RM in physically active individuals. Accordingly, depending on the purpose of the training, the control of the volume/intensity ratio and the control of training results can also be evaluated and re-evaluated based on the TUT. Strength gains can be related to decreasing TUT or increasing the number of repetitions in the same TUT in the squat exercise.

Future studies with the same thematic should use other exercises and trained individuals. Additionally, other biochemical markers of muscular work and other instruments of the neuromuscular response evaluation are also suggested.

Conflicts of interest

The authors have no conflicts of interest to declare.

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