Electromyographic parameters in fatiguing exercises performed with different types of resistance

Parâmetros eletromiográficos em exercícios fatigantes realizados com diferentes tipos de resistência

Estándares electromiográficos en ejercicios extenuantes empleando distintos tipos de resistencia

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ABSTRACT | The present study sought to investigate the electromyographic parameters of muscle fatigue during dynamic exercise conducted with variable resistance (elastic) and fixed resistance (pulley). Ten trained men participated voluntarily in the study. Two maximum voluntary isometric contractions (MVIC) of the elbow flexors were performed for 5 seconds and a two minutes interval rest was given between reps. Then, the volunteers performed unilateral elbow flexion repetitions until the exhaustion using fixed and elastic resistance with a pre-established rhythm of two seconds for each phase of the movement. Constant resistance was carried out at the pulley at 30% of MVIC. For the elastic resistance, load control was based on the subjective perception of the participant's effort. The exercise order was randomized, and electromyography signal of the biceps brachii muscle was recorded during contractions. From the electromyographic signal related to every movement, linear regression lines were drawn for root mean square (RMS) variables and median power frequency (MPF). The inclination of the lines normalized by the linear coefficient of regression equations were compared using the paired t-test. No significant differences between the types of resistance (elastic and pulley) were found. During elbow flexion exercise performed with elastic resistance and pulley, electromyographic parameters of fatigue did not differ. Effort perception during the exercise with an elastic implement does not influence the electromyographic signal pattern (RMS and MPF).

Keywords | Electromyography; Muscle Fatigue

RESUMO | Buscou-se investigar os parâmetros eletromiográficos da fadiga muscular durante exercício dinâmico realizado com resistência variável (elástica) e resistência fixa (polia). Dez homens treinados participaram voluntariamente do estudo. Foram realizadas duas contrações voluntárias isométricas máximas (CVIM) de flexão do cotovelo com 5 segundos de duração cada e 2 minutos de intervalo entre as mesmas. Em seguida, os voluntários realizaram a flexão unilateral do cotovelo até a exaustão, utilizando resistência fixa e elástica com ritmo pré-estabelecido de 2 segundos para cada fase do movimento. A resistência constante foi realizada na polia a 30% da CVIM. Para a resistência elástica, o controle de carga era baseado na percepção subjetiva de esforço do participante. A ordem do exercício foi randomizada, e o sinal de eletromiografia do músculo bíceps braquial foi registrado durante as contrações. A partir do sinal eletromiográfico referente a cada execução de movimento, foram traçadas retas de regressão linear para as variáveis RMS e frequência de potência mediana (FPM). As inclinações das retas normalizadas pelo coeficiente linear das equações de regressão foram comparadas por meio do teste t pareado. Não foram observadas diferenças significativas entre os tipos de resistência (elástica e polia). Os parâmetros eletromiográficos de fadiga não foram diferentes durante o exercício de flexão do cotovelo realizado com resistência elástica e polia. A percepção de esforço durante o exercício com implemento elástico não influencia no padrão do sinal eletromiográfico (RMS e FPM).

Descritores | Eletromiografia; Fadiga Muscular.

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RESUMEN | En esta investigación se pretendió estudiar los estándares electromiográficos de fatiga muscular durante la realización de ejercicio dinámico con resistencia variable (elástico) y resistencia fija (polea). Han participado voluntariamente diez varones entrenados. Se llevó a cabo dos contracciones voluntarias máximas (CVIM) de flexión de codo, cada cual de cinco segundos de duración y dos minutos de intervalo entre las mismas. Después los voluntarios hicieron la flexión unilateral del codo hasta sentirse cansados, y emplearon la resistencia fija y elástica con ritmo prestablecido de dos segundos para cada fase del movimiento. Se llevó a cabo la resistencia constante en la polea a 30% de la CVIM. Relativo a la resistencia elástica, el control de carga se basaba en una percepción subjetiva del esfuerzo empleado por el participante. El orden del ejercicio fue aleatorio, y se registró la señal electromiográfica del músculo bíceps durante las contracciones. Desde la señal electromiográfica relativa a cada ejecución del movimiento se dibujó rectas de regresión lineal para las variables RMS y la frecuencia de potencia media (FPM). Se confirmó las inclinaciones de rectas normalizadas por el coeficiente lineal de las ecuaciones de regresión a través de la prueba t pareada. No se observaron diferencias significantes entre los tipos de resistencia (elástica y polea). Los estándares electromiográficas de fatiga durante la práctica de ejercicios de flexión de codo empleando resistencia elástica y polea no fueron distintos. La percepción del esfuerzo durante la práctica de ejercicio con elástico no trae consecuencias al estándar de señal electromiográfico (RMS y FPM).

Palabras clave | Electromiografía; Fadiga Muscular.

INTRODUCTION

Resistance training (RT) is commonly used as a strategy to develop and improve physical capabilities. Nowadays, there are many implements that allow its practice varying according to the purpose intended[1].

Exercises performed with free weights or machines have constant resistance. On the other hand, exercises practiced with variable resistance, such as elastic tubing, have load variations during the movement[1]. Although resistance bands have unique features such as convenience, portability and low cost, studies that compare elastic load with constant load implements are scarce.

Besides the scarcity of studies on elastic resistance, the difficulty in obtaining a methodological procedure to compare the types of resistance, as well as physiological consequences for each intervention, makes elastic resistance use restricted and focused on articular or clinical rehabilitation programs, in which the exercises are usually carried out with submaximal intensity. According to Andersen et al.[3] few studies have analyzed physiological adaptations induced by exercises with elastic resistance compared to other contraction modalities. Moreover, previous studies found that elastic resistance used in an adequate intensity provides significant improvements in functional tests and changes the body composition – reduction of abdominal perimetry and body fat percentage[4,5].

Surface electromyography (SEMG) allows the researcher to analyze the lower and upper limbs muscular actions during exercises. It is known that SEMG may provide relevant information about the activity of motor units and recruitment of different muscle fiber types[6]. For example, some authors verified an association between the amplitude and the electromyographic signal frequency and the pattern of motor units activity[7,8]. Moreover, a connection was identified between the conduction velocity obtained by SEMG and the recruitment of different muscle fibers. Several authors use SEMG to analyze the behavior of localized muscular fatigue[9-11] and many of them have used this tool, adding value to the discussion about neuromuscular behavior during exercises with different types of resistance[12,13,15]. However, there is no consensus on the effectiveness using different resistance methods and their neuromuscular adaptations, since most of these studies assess various types of populations.

The study of Melchiorri et al.[13] investigated the neuromuscular modifications induced by exercises until fatigue with two types of resistance (elastic *versus* constant). However, the constant resistance used in this study was provided by a machine developed by the researchers. Also, it is not the kind of equipment commonly found in fitness centers, which limits the research reproducibility.

Therefore, the aim of this study was to compare electromyographic parameters during fatiguing

exercises performed using pulley at a conventional weight machine to elastic resistance.

METHODOLOGY

Participants

Ten male volunteers (age 27.7±6.0; 79.8±5.5kg; 175.7±4.9cm) participated in the present study – they had at least six months of resistance training experience. Volunteers could not have any physical problems and/or osteomioarticular injuries that could be aggravated by the elbow flexion movement. Before taking part of the study, all volunteers signed a written informed consent form (ICF) that explained all research procedures. This study was carried out after approval by the Ethics and Research Committee of the Faculty of Health Sciences at the University of Brasília (UnB) –16303013.0.0000.0030.

Experimental procedures

Firstly, body weight (Líder Balanças®, model PM180, Araçatuba, SP) and height (Sanny®) were measured for the sample description. Then, individuals performed two maximum isometric voluntary contractions (MVIC) during five seconds with a two-minute rest between them. During the MVIC execution, volunteers remained seated with their right elbow forming a 90° angle between upper arm and forearm. A load cell, model TS (AEPH do Brasil Indústria e Comércio Ltda., 50kg±10%), was fixed on the chair by an inextensible chain, and a hilt attached to it was used to perform the exercise. Verbal encouragement was given throughout the MVIC by the same investigator.

After that, the volunteers were requested to perform elbow flexion repetitions with their right limb until exhaustion. This exercise protocol was repeated in two situations: with pulley at a conventional weight machine (Gervasport fitness equipment) (P) and with elastic tubing (E) as displayed in Figure 1. The order of tasks was counterbalanced with a 10-minute rest between them. The P task load corresponded to 30% of the MVIC, and the rhythm of contractions was two seconds for each phase of the movement, all controlled by a digital metronome (Seiko). The E task followed the same rhythm. However, the load adjustment of 30% of the MVIC was determined by a scale of subjective

perception effort used with elastic implements and validated by Colado et al.[14] (OMNI-RES), which intensity (in kilos) was informed to the evaluator. The volunteers, through their effort perception, were instructed to move enough to extend the elastic resistance until the perception corresponded to 30% of the MVIC, in order to make as many repetitions as possible of elbow flexion until exhaustion or until they were unable to keep the requested cadence. The OMNI-RES scale is currently the most widely used method to determine the load for variable resistance.

All tests were conducted in the Laboratory of Biological Signal Processing and Motor Control of the Faculty of Physical Education at University of Brasília (UnB) after prior calibration of the equipment and preparation of all complementary materials for data collection: adhesive plasters, razor blades, cotton, scotch tape, and so on.
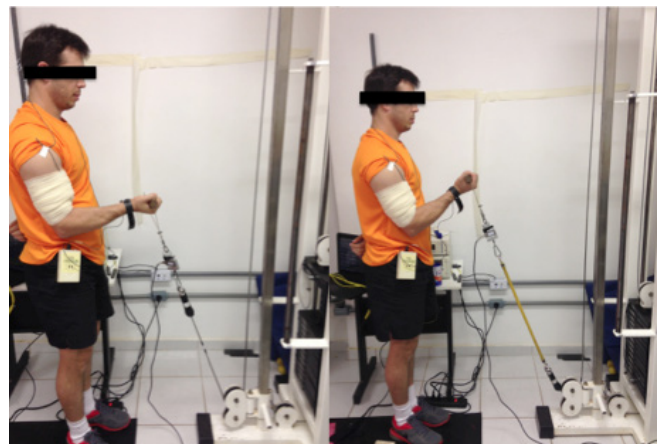

Figure 1. A volunteer exemplifying the experimental protocol with different resistances: pulley (P) and elastic (E), respectively

Electromyography

SEMG signals from the biceps brachii muscle were recorded by an electromyography (Bagnoli-2, Delsys, Boston, USA) with a 2,000 Hz sampling frequency. Bipolar electrodes (Ag/AgCl) pre-amplified with a 1,000V/V gain, a 20Hz-450Hz band pass-filter and 1-centimeter inter-electrode distance were used. The electromyography signal obtained was transferred to the computer through a 12-bit analog-to-digital board (National Instruments, PCI-6024E model, Austin, USA). SENIAM[16] recommendations for the electrode placement and skin asepsis were observed during the

test preparation. An electrogoniometer was positioned with its axis at the elbow lateral epicondyle and its stems affixed on the upper and forearm.

The SEMG signal was originally filtered by a 4th-order Butterworth filter with a 20Hz-500Hz bandwidth and correction on phase delay[17]. A low pass filter with the same characteristics and a 15 Hz cutoff frequency was used to filter the power signal[18].

The electrogoniometer signal was used as a reference for the burst cutting of the electromyographic signal in each repetition. From the angular position peak, which was represented by the largest extension angle of the elbow, 500 samples were covered and a window of 2,000 samples were cut. This methodology was adopted because even with the cadence control with a metronome, there was a slight variation in the movement speed of the most acute angles of elbow flexion. With this procedure, it was possible to obtain more reliable data concerning the imposed cadence to the volunteers during the entire experiment. This procedure also provided more uniformed windowing between the bursts of the two experimental situations.

The root mean square (RMS) and median power frequency (MPF) were calculated for the bursts of each repetition. From these amplitude and frequency parameters, linear regressions were drawn to indicate the electromyographic signal behavior during the exercise. The inclinations of regression lines (angular coefficients) were normalized by their initial values (linear coefficients) to help the comparison between volunteers and experimental situations. Digital signal processing was performed using specific routines written in Matlab 6.5 software (Mathworks software; Natick, MA, USA).

Statistical Analyses

All statistical procedures were performed using the statistical software package SPSS 20 (SPSS Inc., Chicago, IL). To verify the data normality, Shapiro-Wilk test was used. After confirming the normal distribution, comparisons between the types of resistance were made using paired t-test for each electromyographic parameter. Significance level adopted was 5%.

RESULTS

The reported data with mean values ± standard deviation related to electromyographic variables are shown in Table 1. Considering linear regression curves for the RMS and MPF variables, there are no significant differences for line inclinations between the types of resistance (P and E) (Table 2).

Table 1. Mean values and standard deviation of regression line inclinations of electromyographic variables with different types of resistance used (n=8)

Exercises	RMS	MPF
Pulley (P)	1.77±3.26	-2.14±1.62
Elastic (E)	0.90±2.20	-1.71±1.35

$p<0.05$; RMS: root mean square, normalized by the maximum voluntary contraction; MPF: median power frequency

Table 2. Paired t-test values for each variable with different types of electromyographic resistance (elastic and pulley)

Variables	Paired t-test
RMS	0.38
MPF	0.45

$p<0.05$; RMS: root mean square, normalized by the maximum voluntary contraction; MPF: median power frequency

DISCUSSION

The study results show that there was no significant difference between the inclination of the regression lines of the RMS and MPF recorded during the elbow flexions performed with elastic and constant resistance for the variables studied. Despite having unique characteristics, elastic resistance has not caused greater muscle activation and fatigue, even with a varying intensity throughout all the movement extent when compared to pulley, which has a measurable load control.

In both cases, the RMS value increased and the median power frequency (MPF) decreased. This pattern is well described in the literature as an indicative of Localized Muscle Fatigue (LMF) and is justified by an increasing recruitment due to the sum of motor units, which consequently increases the signal amplitude over time[17]. We also observed an increase in the electromyographic signal power at low frequencies, when compared to the high ones, which represents a spectral signature associated with LMF respectively[19,20].

Previous studies that compared elastic resistance and constant resistance intended to adapt the variables of training for these different resistances and assess physiological and functional aspects that result in gains of strength and resistance to muscular fatigue.

Sundstrup et al.[21] investigated the recruitment strategies of the medial deltoid, upper trapezius, splenius and infraspinatus muscles by using SEMG during shoulder lateral raise exercise, performed with maximum and submaximal loads using elastic implement. The results found showed that elastic overload use in submaximal intensity exercise conducted until muscle exhaustion promotes quite satisfactory muscle activation levels of the muscle motor units exercised. This reinforces the usability and portability of elastic implement and corroborates the RMS value increase during the task carried out with elastic in the study. In addition, regardless of the method of load determination, the use of elastic implement until exhaustion with submaximal loads is enough to increase muscle activation.

Calatayud et al.[15] aimed to compare strength levels with different resistances and found similar gains of strength in push-ups performed with elastic resistance and bench press, using the Smith equipment, a bar and barbells. Their result contributes to the use of elastic implements in biomechanically similar movements, i.e., individuals – who are trained and familiar with the bench press and push-ups – can use both resistance modalities for strength gains. In addition, push-ups with elastic resistance are versatile and can be carried out in multiple locations with different intensity settings. Adding strength to electromyographic signals can be an important inferential tool to evaluate physiological aspects of muscular system and its implications on strenght improvements[12,13]. Thus, future studies should include the analysis of muscle strength in results.

In the case of lower limbs, Jakobsen et al.[22] analyzed the electromyographic signal of the primary motor muscles and the stabilizers muscles of hamstring knee performed with dumbbells and elastic. The authors determined 33%, 66% and 100% intensities for 10 repetition maximum. They concluded that the greatest recruitment of the hip and knee muscles occurred with elastic resistance with mean intensity (66% of 10RM) when compared with low (33% of 10RM) and maximal intensities (100% of 10RM). Such finding suggests that when lunges are performed with the elastic band using a medium load, it can be a good alternative to inducing high levels of neuromuscular activation during muscle contractions.

However, our study has not found a pattern or a specific behavior for the elbow flexion exercise performed with elastic implement and pulley. Our findings are in accordance with the results of the Melchiorri et al.[13] study which investigated neuromuscular changes induced by fatiguing exercise performed with elastic resistance compared to constant load. The constant load equipment used was built by the authors themselves to perform the elbow flexion exercise. Despite being a common movement of resistance training, all results are based in an equipment that is not available in the fitness market.

The present study innovates by making the comparison between an exercise performed with variable resistance and the same exercise performed in a pulley machine. In addition, the study of Melchiorri et al.[13] presented an exhaustion protocol with isometric contraction of elbow flexion. Moreover, when comparing electromyographic variables before and after exhaustion, they have found no significant differences as well.

Our experimental protocol consisted in dynamic elbow flexion contractions. Despite dynamic muscle contractions present more vulnerability to movement artifacts from the electrode on the skin and muscles during a SEMG acquisition, our results of fatigue and muscle activation for both tasks (E and P) were consistent and are in accordance with those described in the literature[9,19,20] – decrease of the MPF and increase of the muscle recruitment.

Therefore, considering that the studied tasks have the same indicative of muscle fatigue with distinct load curves – constant and elastic resistance –, the results suggest that the adoption of intercalated exercises between these two modalities, during the process of physical training, can become an alternative to avoid a training plateau[23]. An exercise practiced with a single modality of resistance tends to achieve this plateau[1] and to minimize the results[23]. Based on the results, the non-significance between tasks suggests that, intercalating practices that cause muscle fatigue in the same muscle group, with different load curves, can avoid training plateau by achieving a more effective result.

CONCLUSION

During an elbow flexion exercise performed with constant and variable resistance, the electromyographic parameters of muscle fatigue did not differ. These results indicate that the effort perception during the exercise with elastic band does not influence the standard electromyographic pattern of muscle fatigue.

We suggest additional studies that associate these parameters of fatigue for both resistances and the force level generated during execution. The variable resistance, besides depending on the individual's perception of intensity, also lacks quantitative load control, unlike the pulley, which has a constant and known load.

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