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ORIGINAL ARTICLE

Electromyographic analyses of muscle pre-activation induced by single joint exercise

Análise eletromiográfica da pré-ativação muscular induzida por exercício monoarticular

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Abstract

Objective: To investigate whether performing a low-intensity, single-joint exercises for knee extensors was an efficient strategy for increasing the number of motor units recruited in the vastus lateralis muscle during a subsequent multi-joint exercises. **Methods:** Nine healthy male participants (23.33±3.46 yrs) underwent bouts of exercise in which knee extension and 45°, and leg press exercises were performed in sequence. In the low-intensity bout (R30), 15 unilateral knee extensions were performed, followed by 15 repetitions of the leg presses at 30% and 60% of one maximum repetition load (1-MR), respectively. In the high-intensity bout (R60), the same sequence was performed, but the applied load was 60% of 1-MR for both exercises. A single set of 15 repetitions of the leg press at 60% of 1-MR was performed as a control exercise (CR). The surface electromyographic signals of the vastus lateralis muscle were recorded by means of a linear electrode array. The root mean square (RMS) values were determined for each repetition of the leg press, and linear regressions were calculated from these results. The slopes of the straight lines obtained were then normalized using the linear coefficients of the regression equations and compared using one-way ANOVAs for repeated measures. **Results:** The slopes observed in the CR were significantly lower than those in the R30 and R60 ($p<0.05$). **Conclusions:** The results indicated that the recruitment of motor units was more effective when a single-joint exercise preceded the multi-joint exercise.
Article registered in the Australian New Zealand Clinical Trials Registry (ANZCTR) under the number ACTRN12609000413224.

Key words: resistance training; exercise order; electromyography.

Resumo

Objetivo: Verificar se a execução de um exercício monoarticular de baixa intensidade para os extensores do joelho é uma estratégia eficaz para aumentar o número de unidades motoras recrutadas no músculo vasto lateral durante a realização de um exercício multiarticular subsequente. **Métodos:** Nove sujeitos saudáveis do sexo masculino (23,33±3,46 anos) foram submetidos a rotinas de treinamento nas quais os exercícios cadeira extensora e *leg press 45°* eram realizados em sequência. Na rotina de baixa intensidade (R30), foram realizadas 15 extensões unilaterais de joelho, seguidas de 15 repetições de *leg press 45°* com cargas de 30% e 60% de uma repetição máxima (1-RM), respectivamente. Na rotina de alta intensidade (R60), a mesma sequência foi executada, porém a carga dos dois movimentos foi de 60% de 1-RM. Uma série simples de 15 repetições *leg press 45°* com carga de 60% de 1-RM foi utilizada como exercício controle (RC). A eletromiografia de superfície foi registrada no músculo vasto lateral por meio de um arranjo linear de eletrodos. O valor RMS foi calculado para cada repetição do *leg press 45°* e, a partir desses resultados, foram calculadas regressões lineares. As inclinações das retas obtidas foram então normalizadas pelos coeficientes lineares das equações de regressão e comparadas por meio da ANOVA de um fator para medidas repetidas. **Resultados:** As inclinações observadas na rotina RC foram significativamente inferiores às de R30 e às de R60 ($p<0,05$). **Conclusões:** Os resultados indicaram um recrutamento mais efetivo de unidades motoras nas rotinas de exercício multiarticular precedidas de exercício monoarticular.
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Palavras-chave: treinamento resistido; ordem de exercícios; eletromiografia.

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Introduction

The order in which physical exercises are performed is of extreme relevance to the prescription of resistance training[1-4]. To execute movements in a way that the stimulus sequence provides better responses of the muscles is the main goal of professionals who use resistance training for performance improvement and rehabilitation.

The execution of a single-joint exercises immediately followed by a multi-joint exercises, both applied to the same musculature, are common practices in resistance training[2,4-6]. The assumptions for the adoption of this sequence is that, during multi-joint exercises, small muscles suffer from fatigue sooner than muscles of large volume[5]. In this manner, the triceps brachialis, for instance, would lose its contractile capacity before the supine exercise could take the larger pectoral muscle to its maximum limit[7]. This could affect the benefits of the exercise applied to the largest muscle groups, due to the fact that exercising the musculature until fatigue has shown benefits for strength gains and muscular hypertrophy[8].

The few studies which evaluated the implications of the single-joint/multi-joint sequence of exercise suggested that this type of exercise sequencing might exhibit non-expressive and even counterproductive results in terms of motor unit recruitment[2,5]. However, the performed analyses of this exercise sequencing seem to have explored only combinations in which heavy loads are applied to both single and multi-joint exercises. In contractions using light loads, the recruitment of all the available motor units is not accomplished. Thus, as fatigue is increased, new motor units are recruited to compensate the failure of the ones initially required[9-14]. In this manner, it is plausible to think that the applications of moderate intensities of single-joint exercises may demand an additional recruitment of the motor units of pre-fatigued muscles during multi-joint exercises. This happens without, however, the activation of inhibitory mechanisms which limit the muscular activities during strenuous efforts. Although such strategies have not been evaluated in previous studies, they could be quite helpful in situations of rehabilitation and training of patients affected by pathological conditions or limitations which hinder the use of heavy loads. Therefore, the purpose of the present study was to investigate whether the previous performance of low-intensity single-joint exercises for knee extensors correspond to an efficient stimulus to increase the number of motor units recruited in the vastus lateralis muscle during subsequent multi-joint exercises.

Methods

Subjects

The sample was composed by nine healthy male subjects, with a mean age of 23.33±3.46 yrs, mean body mass of 75.68±8.10 kg, mean stature of 1.76±0.66 m and mean body mass index of 24.47±2.19 kg/m^2. All of them performed resistance exercises at a minimum frequency of three times a week for at least a year and did not report any interruptions in training for over six weeks over the last 12 months.

Before the test performance, the subjects responded to the Physical Activity Readiness Questionnaire-PAR-Q[15] of the Canadian Society for Exercise Physiology. In case the PAR-Q pointed out the need of medical evaluation for the practice of physical exercise, and the subjects was prevented from participating in the study.

The study was approved by the Ethics in Research Committee of the Faculdade de Ciências da Saúde of the Universidade de Brasília - FS/UnB (process nº. 131/2007), and the participants signed a free and clear consent form, in which were described the objectives, possible risks and discomforts and the methods used in the study.

Establishing the workloads

The loads of the experimental protocol were defined based upon the test of one maximum repetition load (1-MR)[16]. The goal of this test was to determine the maximum supported load in the performance of a single correct movement of a 45º-leg press (Vitally, Brazil) and knee extensor bench (Gervasport Fitness Equipment, Spain) exercises. As the equipment used in the experiment showed limitations of the loads available for the determination of 1-MR of the proposed exercises, the unilateral performance of the tests using the lower limb reported as dominant, by the Subject, was used.

In the leg press, the participants started the exercise with their knee in complete extension and performed eccentric quadriceps contractions until their joint reached a flexion of 80º. An elastic band held over the participant (Figure 1-A) was used to limit this angle. The subjects had the aim to flex their knee until their thigh touched the band, and then return to the initial position. A goniometer (Model T.K.K-1216, Greece) was used to calibrate the amplitude of movement in the leg press.

On the knee extensor bench, the participant started with their knees 80º flexed, in which the angle was determined by the equipment itself. Then, the subject performed a complete knee extension and returned to the initial position.

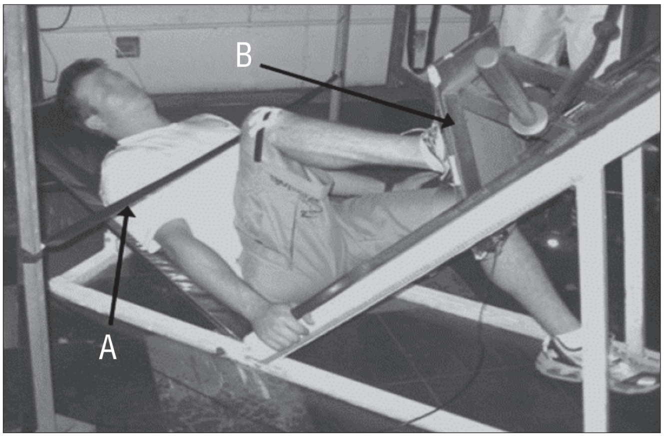


Figure 1. Elastic band limiting the knee amplitude in 80° during 45° leg press performance (A) Weight platform of 45° leg press equipment without extra load (B).

The order in which the 1-MR tests were carried out was alternated among the participants to guarantee the randomness in the performance of the experiment. The tests always started with a five-minute warm-up using an ergometer bicycle (Ergo-Fit-Ergo Cycle, Germany). The intensity of this warm-up was defined by each participant, which was guided to maintain a comfortable cadence. After the warm-up on the ergometer, the participants complemented the test preparation with a set of eight repetitions of the first drawn exercise during the randomization procedure. Kraemer and Fry[16] suggested that this specific warm-up be performed with loads from 40% to 50% of the 1-MR load established by the subject. However, the participants did not have references about the supported weight for the unilateral performance of the proposed exercises. Thus, based on preliminary tests, the intensity of 10% of the weight reported by the subject was chosen for the bilateral performance of the exercises in their training bout.

After the warm-up procedures were concluded, the subjects rested during a minute and the equipment load was increased to 1-MR[16]. In case the participant could not manage to complete a repetition correctly or support the performance of two repetitions in the first attempt, the load was adjusted and a new opportunity was granted after a five-minute rest[16]. In a single day, up to five attempts were allowed for each exercise. After a 20 min. interval, the participant performed a new set of preparations for the execution of the test on the second apparatus. As in the first exercise, this set consisted in the performance of eight repetitions with the intensity of 10% of the bilateral load reported by the subject. Again, the participant rested for a minute and the load was increased to the measurement of 1-MR.

Training to control the exercise velocity was performed after the load tests. During this practice session, the subjects performed a set of 10 repetitions on each apparatus, in which two secs. were spent on the concentric phase and two secs.. were spent on the eccentric phase of movement. A digital metronome (Seiko - D20-440, China), with a rhythm of 30 beats per minute was used to set the performance speed. The participants were guided so they could synchronize the beep of the metronome with the beginning and end of each phase. The load used in this training was equivalent to 60% of the weight obtained in the load test[1,7]. The interval between the usage of the two apparatus varied from six to eight minutes[1,7], according to the participants' need for a satisfactory performance of the set.

A second round of strength tests (test and retest) was performed in order to confirm the loads established on the first day. Then, a minimum period of 48 hours and maximum of 72 hours between the sessions was provided. During this second occasion, the order of performance of the exercises was inverted. In the case of any discrepancies between the results obtained from the observed load tests of the first two days, the largest value was considered for the performance of the experiment.

Experimental procedures

The experimental procedures consisted of two exercise bouts, in which the knee extensor bench and the 45º leg press exercises were combined at different intensities. The pre-activation bouts with low-intensity single-joint exercises (R30) were composed by a set of 15 repetitions of knee extensor bench exercise, at 30% of 1-MR, immediately followed by a set of 15 repetitions of leg presses, at 60% of 1-MR. The pre-activation bouts with high-intensity single-joint exercises (R60) were similar to the previously mentioned bouts, however the 15 knee extensor bench exercise repetitions were performed at 60% of 1-MR. A third bout, called the Control Bout (CR), was also performed and aimed to record the muscular activity during the multi-joint exercises without previous performance of the single-joint exercise. In this manner, the CR was composed only of a set of 15 leg press repetitions, at 60% of 1-MR.

The intensity of 60% of 1-MR was applied to the experimental procedures due to the fact that it is the minimum load suggested in the literature for strength gains and hypertrophy[1,7,17]. In addition, this moderated load allowed the participants to have better control of the movement technique and performance speed. In the R30, the load of 30% of 1-MR for the single-joint exercise was adopted because it was associated with low metabolic production[18]. In theory, this would lead to a lower performance of the inhibition mechanisms of the muscular activity during the subsequent multi-joint exercises. The number of 15 repetitions was determined based upon preliminary tests in which were observed that this volume could provide a satisfactory quantity of data for the linear regression analyses used in the data processing.

All subjects performed the experimental procedure bouts (R30, R60 and RC) on different days and with a 48 to 96 hour interval between them. As in the load tests, the exercises were performed using the dominant lower limb, and the order of execution of the routines was alternated between the participants to guarantee randomness in the performance of the experiment. The determined range of motion and the exercise performance were the same as described for the 1-MR tests, and the previously established cadence was also respected. During the experiment, two evaluators with experience in resistance training checked the fulfillment of these criteria. The violation of any aspect established in the test protocol determined the interruption of the experiment. In the R30 and R60 conditions, the period of transition between the knee extension and the leg press did not exceed 40 secs. for any participant.

Electromyography

The electromyographic signals were recorded for the vastus lateralis muscle during the performance of the 45º leg press exercise in the R30, R60 and CR conditions. The instrument used for the electromyographic data collection was the EMG-16 (Ot Bioelettonica, Italy).. This equipment had a gain of up to 50000 V/V, noise level of 1 μV (with reference to the input), analog bandpass filtering from 10 Hz to 500 Hz and common rejection mode of 96 dB. The sampling rate adopted was 2048 Hz and the tension gain was adjusted to 2000 V/V. The electromyographer was connected to a laptop (Toshiba Satellite - A105-S4114, China) by means of a PCMCIA A/D board of 12 bits (National Instruments - DAQ6045E, EUA).

After hair shaving and skin asepsis with cotton soaked with alcohol, a linear array of 16 rigid electrodes (LISiN - Ot Bioelettronica, Italy) with chlorinated silver bars of 5 x 1 mm and an inter electrode distance of 5 mm was placed over the participant's vastus lateralis. This was done to map the area of largest muscle bulk and locate the regions of the best propagation of action potentials, as described in previous studies[19-21]. In experimental protocols which addressed dynamic contractions, changes in the position of the joints corresponded to a critical element during the mapping, because innervation zones and tendinous regions shifted beneath the skin and generated low quality signals[22]. In this manner, the regions of acceptable conductivity were located during isometric contractions of 10 secs., during which the participants would remain with their knee flexed in an angle of 100º. This angle was measured with a goniometer (T.K.K - 1216, Greece) and the subjects sustained a load of 11.56 kg, equivalent to the weight platform of the 45º leg press equipment, without an extra load (Figure 1 - B).

The muscular mapping was performed only on the first day of testing. The electrode location was marked on the subject's thigh with a permanent marker (Faber Castel - Pilot 2.0 mm Az, Brazil), to guarantee the same positioning in the subsequent tests. In the marked area on the vastus lateralis muscle, a flexible linear array with eight electrodes (LISiN-Ot Bioelettronica, Italy) was placed for signal registration during the dynamic contractions. This array had the same dimensions as the rigid electrode and its adherence to the skin was guaranteed by a double-sided adhesive tape that contained holes for the insertion of conductive gel, which made the electrode placement less sensitive to movement artefacts[23]. Thirty micro-liters of gel were put in each electrode opening by a micropipette (High Tech Lab - HTL Monocanal, Brazil).

Signal processing

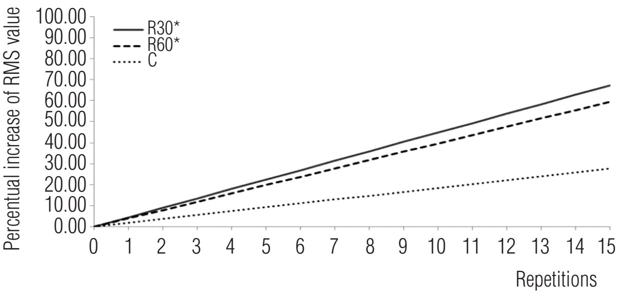
Among the seven differential eletromyographic signals obtained for each leg press set (in the R30, R60 and CR conditions), one differential channel was selected for the calculation of the root mean square (RMS). This channel was analyzed in the three experimental situations to provide more reliability of the signal analysis.

A synchronizing trigger, developed at the Biological Signal Processing Laboratory, was adapted to the 45º leg press to indicate, during the dynamic contractions, the instant in which the knee reached a flexion angle of 100º. The electromyographic signal with the greatest amplitude and best quality for the vastus lateralis muscle was found at this joint angle. This trigger generated an electric amplitude pulse of approximately 1.5 V, which was simultaneously digitalized with the signals captured by the electrodes. Rectangular windows of 512 samples (250 ms) were cut around the pulses generated by the trigger, which indicated the concentric phases of each leg press repetition. As the beginning and end of the sets were the periods most likely to have exercise performance errors and possible violations of the movement cadence, the windows of the first and last concentric movement of all sets were discarded from the analysis. Windowing and all the other signal processing procedures were done by specific bouts developed by the computer application Matlab 6.5 (Mathworks - Natick, EUA).

Table 1. Comparison between percentage increase of RMS value during 45° leg press repetitions.

	Normalized slopes* of regression lines calculated from RMS value (%)
R30	4.49±3.44†
R60	3.96±2.60†
RC	1.84±1.31

*Angular coefficients normalized by the linear coefficients of regression equations; R30=bout with pre-activation induced by low intensity single-joint exercise; R60=bout with pre-activation induced by high intensity single-joint exercise; control exercise with no pre-activation; † one-way ANOVA for repeated measures – R30 and R60 vs. RC (p<0.05).



R30=bout with pre-activation induced by low intensity single-joint exercise; R60=bout with pre-activation induced by high intensity single-joint exercise; control exercise with no pre-activation; * one-way ANO.

Figure 2. Regression lines calculated from RMS value recorded in the 45° leg press, representing the percentage increase in the amplitude of the electromyographic signal during the bouts (R30, R60 and RC). Lines normalized by the linear coefficients of regression equations.

Based upon the RMS values estimated for each repetition window, linear regressions were calculated to verify the behaviors of the amplitude of the electromyographic signals in the performance of the 45º leg press in the R30, R60 and CR conditions. The slopes of the regression lines (angular coefficients of the determined equation) were normalized using their initial values (linear coefficients of the equations). In other words, the slopes were divided by the lines' intercepts[24]. After normalization, the slopes were expressed in percentage terms to represent the growth rate of the RMS values during the evaluated bouts.

Statistical analyses

Inter-class correlation coefficients (ICC) were used to verify the reproducibility of the 1-MR test performed on the leg press and the knee extension apparatus. As only some participants could complete the 15 repetitions initially proposed for the evaluated exercises, one-way ANOVAs for repeated measures and the *post hoc* Least Significant Difference (LSD) were applied to verify if there were any differences in the number of repetitions performed using the leg press in the R30, R60 and CR. The comparisons between the number of repetitions using knee extension in the R30 and R60 conditions were done by means of the Student *t*-test paired test.

The normalized slopes of the regression lines of the R30, R60 and CR conditions were also compared by means of the one-way ANOVAs for repeated measures. In case of significant differences, the *post hoc* of Least Significant Differences (LSD) was applied again to indicate the divergent values. Before the use of the Student *t*-test paired tests and the one-way ANOVAs for repeated measures, the data normality were verified by means of the Kolmogorov-Smirnov test. In all the analysis, a significance level of p<0.05 was adopted. The statistical treatment was performed by the *Statistical Package for the Social Sciences* (*SPSS* 13.0 - *LEAD Technologies*, EUA) software.

Results

The 1-MR loads measured on the first day of tests on the 45º leg press (120.67±29.80 kg) did not exhibit significant difference (r=0.96) regarding the loads obtained in the retest (120.00±27.85 kg). Similarly, there were not found significant differences (r=0.90) between the test and the retest on the knee extensor bench exercise (90.00±10.97 kg vs. 87.31±10.50 kg).

After the high-intensity knee extensions in the R60, the quantity of repetitions performed on the leg press (12.33±1.94) was inferior to the quantity recorded in the CR (14.89±0.33; p=0.01). However, there was not detected any significant difference related to the number of repetitions in the R30 (13.89±1.45; p=0.09). The comparison between the number of repetitions of the leg press exercise in the R30 and CR also did not show any significant difference (p=0.07). In the knee extensor bench exercise, the subjects supported a larger number of knee extensions in the R30 (14.89±0.33) than in the R60 (12.89±1.83; p=0.01).

The slopes of the regression lines of the RMS values are shown in percentage terms in Table 1. The normalized slope values of the CR were inferior to the R30 (p=0.049) and R60 (p=0.04) ones. This difference suggests a more effective recruitment of motor units in the bouts where the single-joint exercise preceded the multi-joint. Significant differences between the slopes recorded in the R30 and R60 were not observed.

Figure 2 illustrates the normalized percentage increase in the RMS value recorded in the studied bouts. There was a percentage increase of 67.36% and 59.46% in the RMS values recorded in the R30 and R60, respectively. The percentage increase observed along the CR was of only 27.61%.

Discussion

The positive slopes values observed in the regression analysis of the RMS indicate a progressive increase in the number of motor units recruited in the vastus lateralis muscle in all the analyzed leg press sets. This increasing pattern in the intensity of the electromyographic signal diverges from the results of Augustsson et al.[5], which evaluated the response of the lower limb musculature in an exercise combination similar to the one applied in the present investigation. Due to the pre-fatigue of the quadriceps by the performance of the knee extensions, Augustsson et al.[5] reported a decrease in the amplitude of the electromyographic signal of the rectus femoris and the vastus lateralis during the execution of leg press exercises. In spite of the gluteus maximus not having shown an increase in the amplitude of the electromyographic signal in this study, the authors speculate that other muscles such as adductor and gastrocnemius, which activities were not monitored, may have compensated the performance decay of the anterior thigh muscles.

Recently, our group investigated the influence of a set of single-joint exercises before a set of multi-joint exercises of upper limbs[2]. In this study, 13 participants underwent a set of supine exercises (multi-joint) with and without the previous performance of crucifix weightlifting exercises using equipments (single-joint). Differently from the results obtained in the present investigation, a greater electrical activity of the pectoralis major and the anterior deltoid (muscles exhausted from the single-joint movement) was not recorded. On the other hand, the triceps brachialis, which was not requested in the single-joint exercise, showed an increase in the amplitude of the electromyographic signal during the bench exercise after the fatigue of the other primary muscles.

The divergence between the results of the present investigation and the results observed in the previous studies may be due to the intensity applied in the exercises. The 10-MR sets evaluated in experiments of Augustsson et al.[5] and Gentil et al.[5] represented intensities significantly superior to sets performed at 30% and 60% of 1-MR[25]. This heavy overload induces a larger production of metabolites[18,26] and, therefore, causes a greater activation of muscular receptors sensible to biochemical disturbances, such as the afferent groups III and IV, the muscle spindles and the Golgi tendon organ[27-29]. Taking into account that these structures generate a sensorial feedback that reduces the recruitment capacity of the motor units[30], it is possible that the low amplitude values of the electromyographic signal recorded during the multi-joint exercises analyzed by Augustsson et al.[5] and Gentil et al.[5] were due to inhibitory mechanisms initiated in the single-joint exercises. Differing from these results, the moderated loads applied in the single-joint exercise of this experiment seem not to jeopardize the recruitment of motor units in the multi-joint exercise. In spite of this moderate intensity not having demanded more participation of accessory muscles, as observed in the Gentil et al.[2] experiment, the evaluation of only one of the knee extensors precludes this type of conclusion.

The initial definition of 15 repetitions for all knee extensor bench exercise and leg press sets had the purpose of making more robust the data processing and the statistical analysis. Previous investigations about the sequence of exercises[2,3,5] observed an expressive reduction in the quantity of repetitions performed in the multi-joint exercises. This caused the comparison of a different number of samples collected in the experimental situations proposed. Although some participants could not stand the 15 repetitions proposed in the experimental protocol, a mean difference of three repetitions did not invalidate, statistically speaking, linear regression analysis or the normalization procedure applied.

The higher variation rates in the amplitude of the RMS value in the R30 and R60 than in the CR indicate that leg press repetitions, after the performance of the knee extensor bench exercise using the intensities evaluated in this study, start to recruit more muscle fibers than repetitions of the same exercise during a simple set. Even though there was a tendency of greater recruitment with low-intensity loads, the lack of any difference detected between the R30 and R60 indicated that the efficiency of the single-joint exercise was the same when performed at 30 and 60% of 1-MR for later activation of the vastus lateralis muscle in the multi-joint exercise.

Kukulka and Clamann[31] and Masakado[32] reported that small muscles are capable of recruiting the majority of their motor units in intensities of 50% of the maximum voluntary isometric contraction. In addition, when this threshold is exceeded, the modulation of the strength production by the firing frequency of the action potentials occurs. However, in large muscle groups, the main mechanism for tension variation is the recruitment of motor units. The recruitment of the majority of the large muscle fibers such as the lower limb ones is only observed with loads superior to 90% of the maximum voluntary isometric contraction[32]. In this manner, it is possible that a considerable quantity of fibers from the vastus lateralis muscle, for instance, does not suffer from any type of stimulus during the performance of the 45º leg press, even though relatively heavy loads are applied in this movement.

As only the fibers recruited during training are subjected to the physiological adaptations[7], the previous performance of single-joint exercises with loads of 30% and 60% of 1-MR can make the multi-joint exercises more profitable for strength gain and muscular hypertrophy. This happens because a larger quantity of motor units starts to be stimulated with the implementation of this strategy.

In situations such as rehabilitation and training of muscle groups that require special care, the previous performance of single-joint exercises at 30% of 1-MR might be recommended. This intensity has proved itself as efficient as the load of 60% of 1-MR to increase the quantity of recruited motor units in the multi-joint movement and provides better control to performance the proper exercise technique. This procedure may reduce the probability of injury and overtraining in impaired muscle groups[33].

Conclusions

The performance of the knee extensor bench exercise with loads of 30% and 60% of 1-MR caused an increase in the amplitude of the electromyografic signal recorded in the 45º leg press exercise performed in sequence. This result points to an effectiveness of the pre-activation performed by means of a single-joint exercise with intensity from low to moderate in the increase in the number of recruited motor units during a subsequent multi-joint exercise.

References

1. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, et al. American college of sports medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2002;34(2):364-80.
2. Gentil P, Oliveira E, de Araújo Júnior V, do Carmo J, Bottaro M. Effects of exercise order on upper-body muscle activation and exercise performance. J Strength Cond Res. 2007;21(4):1082-6.
3. Sforzo GA, Touey PR. Manipulating exercise order affects muscular performance during a resistance exercise training session. J Strength Cond Res. 1996;10(1):20-4.
4. Tan B. Manipulating resistance training program variables to optimize maximum strength in men: a review. J Strength Cond Res. 1999;13(3): 289-304.
5. Augustsson J, Thomeé R, Hörnstedt P, Lindblom J, Karlsson J, Grimby G. Effect of pre-exhaustion exercise on lower-extremity muscle activation during a leg press exercise. J Strength Cond Res. 2003;17(2): 411-6.
6. Salles BF, Oliveira N, Ribeiro FM, Simão R, Novaes JS. Comparação do método pré-exaustão e da ordem inversa em exercícios para membros inferiores. Rev Educ Fis. 2008;19(1):85-92.
7. Fleck SJ, Kraemer WJ. Designing resistance training programs. 3ª ed. Champaign: Human Kinetics; 2004.
8. Rooney KJ, Herbert RD, Balnave RJ. Fatigue contributes to the strength training stimulus. Med Sci Sports Exerc. 1994;26(9):1160-4.
9. Henneman E, Somjen G, Carpenter DO. Excitability and inhibitability of motoneurons of different sizes. J Neurophysiol. 1965;28(3):599-620.
10. Van der Hoeven JH, Lange F. Supernormal muscle fiber conduction velocity during intermittent isometric exercise in human muscle. J Appl Physiol. 1994;77(2):802-6.
11. Moritani T, Muro M, Nagata A. Intramuscular and surface electromyogram changes during muscle fatigue. J Appl Physiol. 1986;60(4):1179-85.
12. Houtman CJ, Heerschap A, Zwarts MJ, Stegeman DF. pH heterogeneity in tibial anterior muscle during isometric activity studied by (31)P-NMR spectroscopy. J Appl Physiol. 2001;91(1):191-200.
13. Houtman CJ, Stegeman DF, Van Dijk JP, Zwarts MJ. Changes in muscle fiber conduction velocity indicate recruitment of distinct motor unit populations. J Appl Physiol. 2003;95(3):1045-54.
14. Bilodeau M, Schindler-Ivens S, Williams DM, Chandran R, Sharma SS. EMG frequency content changes with increasing force and during fatigue in the quadriceps femoris muscle of men and women. J Electromyogr Kinesiol. 2003;13(1):83-92.
15. American College of Sports Medicine. Manual do ACSM para: teste de esforço e prescrição de exercício. 5ª ed. Rio de Janeiro: Revinter; 2000.
16. Kraemer WJ, Fry AC. Strength testing: development and evaluation of methodology. Champaign: Human Kinetics; 1995.
17. McDonagh MJ, Davies CT. Adaptive response of mammalian skeletal muscle to exercise with high loads. Eur J Appl Physiol Occup Physiol. 1984;52(2):139-55.
18. Lagally KM, Robertson RJ, Gallagher KI, Goss FL, Jakicic JM, Lephart SM, et al. Perceived exertion, electromyography, and blood lactate during acute bouts of resistance exercise. Med Sci Sports Exerc. 2002;34(3):552-9.
19. Farina D, Pozzo M, Merlo E, Bottin A, Merletti R. Assessment of average muscle fiber conduction velocity from surface EMG signals during fatiguing dynamic contractions. IEEE Trans Biomed Eng. 2004;51(8): 1383-93.
20. Veneziano WH. Estudo do comportamento do sinal eletromiográfico de superfície em atividades subaquáticas (tese). Brasília (DF): Universidade de Brasília; 2006.

21. Saitou K, Masuda T, Michikami D, Kojima R, Okada M. Innervation zones of the upper and lower limb muscles estimated by using multichannel surface EMG. J Hum Ergol (Tokyo). 2000;29(1-2):35-52.

22. Martin S, MacIsaac D. Innervation zone shift with changes in joint angle in the brachial biceps. J Electromyogr Kinesiol. 2005;16(2): 144-8.

23. Clancy EA, Morin EL, Merletti R. Sampling, noise-reduction and amplitude estimation issues in surface electromyography. J Electromyogr Kinesiol. 2002;12(1):1-16.

24. Falla D, Farina D. Muscle fiber conduction velocity of the upper trapezius muscle during dynamic contraction of the upper limb in patients with chronic neck pain. Pain. 2005;116(1-2):138-45.

25. Hoeger WWK, Hopkins DR, Barette SL, Hale DF. Relashionship between repetitions and selected percentages of one repetition: a comparison between untrained and trained males and females. The Journal of Applied Sport Science Research (JASSR). 1990;4(2):47-54.

26. Gentil P, Oliveira E, Bottaro M. Time under tension and blood lactate response during four different resistance training methods. J Physiol Anthropol. 2006;25(5):339-44.

27. Gandevia SC. Spinal and supraspinal factors in human muscle fatigue. Physiol Rev. 2001;81(4):1725-89.

28. Hunter SK, Duchateau J, Enoka RM. Muscle fatigue and the mechanisms of task failure. Exerc Sport Sci Rev. 2004;32(2):44-9.

29. Gandevia SC. Neural control in human muscle fatigue: changes in muscle afferents, motoneurones and motor cortical drive. Acta Physiol Scand. 1998;162(3):275-83.

30. Ascenção A, Magalhães J, Oliveira. J, Duarte J, Soares J. Fisiologia da fadiga muscular. Delimitação conceptual, modelos de estudo e mecanismos de fadiga de origem central e periférica. Rev Port Cien Desporto. 2003;3(1):108-23.

31. Kukulka CG, Clamann HP. Comparison of the recruitment and discharge properties of motor units in human brachial biceps and adductor pollicis during isometric contractions. Brain Res. 1981;219(1):45-55.

32. Masakado Y. Motor unit firing behavior in man. Keio J Med. 1994;43(3): 137-42.

33. Stone M, Chandeler J, Conley MS, Kraemer JB, Stone ME. Training to muscular failure: is it necessary? J Strength Cond J. 1996;18(3):44-8.