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Effects of experimental pain on elbow flexor muscles performance after eight weeks of strength training: a pilot study

Efeitos da dor experimental no desempenho dos músculos flexores do cotovelo após oito semanas de treinamento de força: um estudo piloto

Venício de Paula Silva¹

Valmor Tricoli²

Ulysses Fernandes Ervilha³

¹Corresponding author. Universidade de São Paulo (São Paulo). São Paulo, Brazil. veniciusesc@gmail.com

^{2,3}Universidade de São Paulo (São Paulo). São Paulo, Brazil.

ABSTRACT | INTRODUCTION: Strength training has been recommended in clinical rehabilitation, as well as in the physical conditioning of athletes. It is not uncommon, in both cases, the presence of pain during practice; however, to date, there is no consensual information about the effects of acute muscle pain on strength training adaptations. **OBJECTIVE:** The aim of this pilot study was to evaluate the effects of experimentally induced pain on muscle strength adaptation after an 8-week training period. **METHOD:** The study included five untrained, healthy male volunteers. Participants were submitted to a strength training protocol (3x/week for 8 weeks) for the elbow flexor muscles. Acute muscle pain was induced at the beginning of each training session through an intramuscular infusion of 2.5 ml of hypertonic saline (6%) into the biceps brachii muscle belly. Maximal dynamic strength (1RM) and maximal voluntary isometric contraction (MVIC) were measured at pre- and after four and eight weeks of training. **RESULTS:** Maximal dynamic strength increased, on average, 37.3% and 78.4% after four and eight weeks, respectively. However, little, if any, difference was found in MVIC (-1.7% and -3.0% after four and eight weeks, respectively). **CONCLUSION:** After 24 strength training sessions, with acute muscle pain induced every session, healthy volunteers increased their ability to produce maximal dynamic strength by more than 75%; however, isometric strength presented only small negative changes.

KEYWORDS: Muscle Pain. Exercise. Muscle Strength. Rehabilitation.

RESUMO | INTRODUÇÃO: O treinamento de força tem sido recomendado na reabilitação clínica, bem como no condicionamento físico de atletas. Não é incomum, em ambos os casos, a presença de dor durante a prática; no entanto, até o momento, não há informação consensual em relação aos efeitos da dor muscular aguda nas adaptações ao treinamento de força. **OBJETIVO:** O objetivo deste estudo piloto foi avaliar os efeitos da dor induzida experimentalmente na adaptação da força muscular após um período de treinamento de 8 semanas. **MÉTODO:** O estudo incluiu cinco voluntários saudáveis do sexo masculino e não treinados. Os participantes foram submetidos a um protocolo de treinamento de força (3x/semana durante 8 semanas) para os músculos flexores do cotovelo. A dor muscular aguda foi induzida no início de cada sessão de treinamento, por meio de infusão intramuscular de 2,5 ml de solução salina hipertônica (6%) no ventre do músculo bíceps braquial. A força dinâmica máxima (1RM) e a contração isométrica voluntária máxima (CIVM) foram medidas antes e após quatro e oito semanas de treinamento. **RESULTADOS:** A força dinâmica máxima aumentou, em média, 37,3% e 78,4% após quatro e oito semanas, respectivamente. Entretanto, pouca ou nenhuma diferença foi encontrada na CIVM (-1,7% e -3,0% após quatro e oito semanas, respectivamente). **CONCLUSÃO:** Após 24 sessões de treinamento de força, com dor muscular aguda induzida a cada sessão, voluntários saudáveis aumentaram sua capacidade de produzir força dinâmica máxima em mais de 75%; entretanto, a força isométrica apresentou apenas pequenas variações negativas.

PALAVRAS-CHAVE: Dor muscular. Exercício. Força Muscular. Reabilitação.

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1. Introduction

Strength training has been widely recommended for the treatment of various musculoskeletal disorders, as well as in the physical conditioning of athletes.¹⁻³ Despite strength training being sometimes performed in the presence of pain, either in rehabilitation or in sports conditioning programs, little is known about the added effects of acute pain on strength performance after a period of training.

Several studies have reported that pain reduces muscle's capacity to generate strength.⁴⁻⁶ This is evident in chronic pain conditions and experimental pain models as well, where the influence of pain on muscle strength production can be investigated specifically without the confounding effects of behavioral adaptations or modifications in musculoskeletal system integrity.⁷ When the effects of pain are verified by local hypertonic saline injection, some studies have reported alteration of agonist, antagonist, and synergist muscles' electrical activity and decreases in motor unit firing rate and joint range of motion, thus, reducing muscle's ability to generate maximal strength.⁸⁻¹⁰

Henriksen et al.⁶ and Flaxman et al.¹¹ evaluated the effects of induced muscle pain on the production of maximal strength of the knee extensor and flexor muscles. Their results showed an 8 to 15% reduction in muscle's ability to generate force. Similarly, for the upper limbs, some studies have reported a 7.6% reduction in shoulder external rotator muscles' strength, as well as a 5% decrease in the force-generating ability of the elbow flexors in the presence of pain.^{12,13}

Based on these findings, it may be concluded that acute muscle pain negatively affects muscles' ability to produce force and thereby may reduce the positive effects of strength training programs.^{14,15} Interestingly, most studies involving muscle pain and strength were developed with cross-over design, which hampers

the possibility of verifying pain effects on maximal strength production over time.^{5,6,11} Considering the aforementioned issues, it would be interesting to investigate the effects of pain on muscle strength adaptation after a period of training. Therefore, this pilot study aimed to assess the summed effects of acute induced muscle pain on strength adaptations after an 8-week training period. We hypothesized that the presence of acute muscle pain during training would reduce or inhibit muscle strength gains.

2. Materials and methods

2.1 Experimental procedures

A longitudinal pilot study with eight weeks of exercise intervention was conducted. Subjects were submitted to a unilateral strength training protocol. One week before the start of training sessions, all volunteers participated in two familiarization sessions to eliminate any learning effects on strength testing and to be informed about all experimental procedures.

2.2 Participants

Five untrained healthy male individuals (age 20.6 ± 2.6 years; height 1.72 ± 0.04 m; body mass 71.2 ± 12.1 kg) with no musculoskeletal disorders participated in this study. None of them had participated in any systematic strength training during the previous six months. They were not taking any medication for pain treatment, ergogenic aids or nutritional supplements and had no pain-related conditions. In addition, subjects were asked to maintain their sleeping, eating, and hydration habits during the study. All subjects received written and verbal information and signed an informed consent before participation. The study was conducted in accordance with the Declaration of Helsinki and approved by the local Ethics Committee (protocol n. 2.002.120).

2.3 Tests procedures

2.3.1 Maximum dynamic strength test (1RM)

The strength of the elbow flexor muscles was measured on the right arm of all subjects using the 1RM test. The test followed the guidelines of the American Society of Exercise Physiologists.¹⁶ The participants performed a general 5-minute warm-up running on a treadmill at 9 km/h. Then, they performed two specific warm-up sets using the unilateral elbow flexion exercise. In the first set, the subjects performed eight repetitions with an intensity corresponding to 50% of their estimated 1RM, which was obtained during the familiarization sessions. In the second set, they performed three repetitions with 70% of their estimated 1RM. A 2-minute rest interval was granted between warm-up sets. Three minutes after the specific warm-up, the 1RM test was initiated. Participants performed a complete and correct cycle of unilateral elbow flexion (initial position with full extension [180°] going up to 70° of flexion and returning to the starting position). The weight was progressively increased until the participant could not complete a correct movement cycle. The number of attempts did not exceed five, with an interval of three minutes between them. Verbal encouragement was provided during the attempts. The tests were conducted by the same examiner and were performed pre- (Week 0), after four (Week 4) and eight weeks (Week 8) of training.

2.3.2 Maximal voluntary isometric contraction (MVIC)

The MVIC test was performed on a dynamometer (Biodex System 3, Biomedical System, Newark, CA, USA). During the test, the subject was seated

comfortably on the device's chair, keeping the elbow of the right arm supported by an adjustable support to maintain the shoulder at 45° of flexion and abduction. The estimated elbow joint center of rotation was aligned with the dynamometer center of rotation. The thorax, pelvis, and right lower limb were fixed to the chair by belts to minimize undesired or compensatory movements. A specific warm-up (50, 60, and 70% 5-s MVIC trials separated by 60-s rest intervals) was performed. Then, the subject was oriented to perform two 3-s MVIC attempts with 60-s intervals aiming to reach peak torque with the elbow joint at 90°. The highest value obtained was considered for statistical analysis. Tests were conducted by the same examiner and were performed pre- (Week 0), after four (Week 4) and eight weeks (Week 8) of training.

2.4 Strength training

Unilateral strength training was performed 3x/week, with at least 48 hours of rest between sessions, during eight weeks. The training began with a 5-minute warm-up running on a treadmill at 9km/h followed by 1x8 repetitions at approximately 50% 1RM. After the warm-up, the participant underwent acute muscle pain induced through an intramuscular infusion of 2.5 ml of hypertonic saline solution (6%) in the biceps brachii muscle belly. As soon as the pain reached a score of 2 on a visual analog scale (VAS) of 0 to 10 (where 0 indicated "no pain" and 10 "intolerable pain"), the training was started, as shown in Table 1. The exercise consisted of unilateral elbow flexion in a sitting position. Training intensity progressed across sessions based on the repetitions maximum, and if the participant could perform more or less than the established number of repetitions in a set, in the following set, the weight was adjusted. A 60-second rest period was granted between sets.

Table 1. Strength training protocol

Weeks	1	2	3	4	5	6	7	8
RM	10-12	10-12	8-10	8-10	8-10	8-10	6-8	6-8
Sets	3	3	4	4	5	5	6	6

RM = repetition maximum.
Source: the authors (2023)

2.5 Experimentally induced muscle pain

Muscle pain was induced by intramuscular injection of 2.5 ml sterile hypertonic saline solution (6% NaCl) into the biceps brachii over a 20-second period via a disposable stainless needle (30 mm, 8 mm). From the third week of training, participants received an additional infusion of 1.5 ml of hypertonic saline solution, immediately after the last repetition of the third set. Subjects were asked to rate the pain intensity from 0 to 10 according to a VAS.

2.6 Statistical analysis

Data are reported as means \pm standard deviations, when appropriate. Additionally, delta change (%) was calculated after four and eight weeks of training.

3. Results

The results showed that after the strength training period, there were increases in maximum dynamic strength (1RM). Increments of 37.3% and 78.4% were found after four and eight weeks, respectively. These results are presented in Table 2. On the other hand, MVIC values showed, on average, smaller changes after the same time periods (-1.7% and -3.0% after four and eight weeks, respectively) compared to the baseline measurements (Table 2).

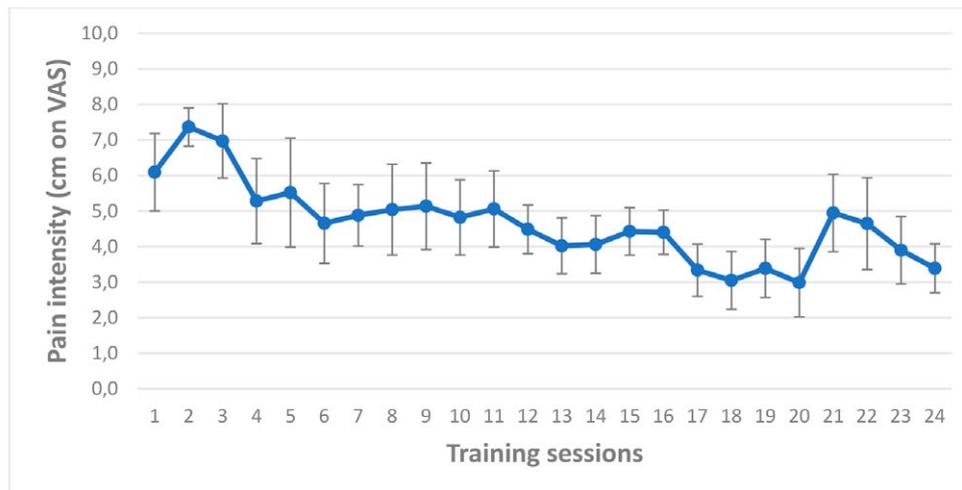
Table 2. Mean (\pm SD) and delta change values obtained in the 1RM and MVIC tests at pre (Week 0), after four (Week 4) and eight weeks (Week 8) of strength training (n=5)

Variables	Mean \pm SD	Difference (% from 0 week)
1 RM* (Kg)		
Week 0	10.2 \pm 1.6	
Week 4	14.0 \pm 1.7	37.3
Week 8	18.2 \pm 2.7	78.4
MVIC** (N·m)		
Week 0	591.2 \pm 118.0	
Week 4	581.0 \pm 159.0	-1.7
Week 8	573.6 \pm 120.1	-3.0

*1RM = 1 repetition maximum; **MVIC = maximal voluntary isometric contraction.
Source: the authors (2023).

Pain intensity scores reported by the subjects after 2.5 ml and 1.5 ml hypertonic saline injections are presented in Figure 1. The mean peak pain intensity was 4.7 ± 0.5 cm on VAS.

Figure 1. Mean (\pm SD) pain intensity scores (VAS) recorded after each exercise set, averaged across subjects and by training session. Error bars show the standard deviation



Source: the authors (2023).

4. Discussion

To the best of our knowledge, this is the first pilot study to investigate the accumulated effects of acute muscle pain on strength adaptations after an 8-week training period. The novel finding of the study was that after 24 strength training sessions, with acute muscle pain induced every session, there was a marked increase in maximum dynamic strength (78.4%), while maximal isometric strength presented only a small negative change (-3.0%).

Our findings demonstrated that even though muscle pain was present in all training sessions, the subjects increased their dynamic strength. This result was unexpected, considering the findings of acute studies involving muscle strength production in the presence of pain.⁴⁻⁶ These studies showed an impairment in the force-generating capacity in the presence of pain, which, in theory, would prevent the chronic increase in 1RM values found in the present study since all training sessions were performed with experimentally induced pain (Figure 1). It appears that if muscle pain had an inhibitory role during training, the inhibition was not strong enough to negatively affect the adaptations caused by the strength training, at least in the 1RM tests. Furthermore, studies have reported that after a few training sessions, there may be an increase in pain tolerance through the excitation of endogenous opioid systems and harmful descending inhibitory mechanisms.^{17,18} Therefore, this phenomenon may explain the increases in 1RM observed in the present study. It should be emphasized that in the above-mentioned studies⁴⁻⁶, strength was measured by applying isometric and dynamic tests.

Our results agree with Sørensen et al.¹⁹, who also evaluated the effects of experimental muscle pain on maximal strength production. Their results showed significant increases in 1RM (24.6%) after eight weeks of training. According to the authors, neuromuscular reorganization during pain may account for the observed changes. Several possible mechanisms may be proposed to explain the strength gains in the presence of pain. Pain may selectively inhibit low-threshold (predominantly type I muscle fibers) while simultaneously favoring the recruitment of high-threshold motor units (predominantly type II muscle fibers)^{19,20}, which are responsible for greater muscle strength production.²¹ Thus, the present study suggests that this phenomenon may have been responsible for the observed increase in 1RM in the presence of pain.

Ervilha et al.¹⁰ reported that another mechanism responsible for increasing the ability to generate muscle strength during painful conditions is the greater activation of synergistic muscles to the movement. However, in the study performed by Hodges et al.²⁰, this mechanism was not sustained. The researchers investigated the motor units firing rate of the plantar flexor muscles of the ankle joint. Single motor unit (MU) potentials were recorded in the medial gastrocnemius and soleus muscles. During the experimental protocol, the subjects performed ankle plantar flexion in order to recruit 1 to 4 MU, performing 3 contractions of 20-s to a targeted force before, during, and after experimental pain in the lateral gastrocnemius. Interestingly, a decrease in the firing rate was found in the triceps surae muscle during pain. The authors reported that the effect of pain is not restricted to the painful muscles and may reduce the MU firing rate in the synergistic muscles. Additionally, according to Hodges and Tucker⁹, the maintenance of strength during painful contractions occurs through redistribution of activity within and between muscles that are involved in a specific motor task.

Another finding of our investigation was the small changes in the ability to generate isometric strength, even after 24 training sessions. Curiously, the increase in 1RM was not followed by a similar change in isometric strength. However, the most likely explanation for this result would be related to the specificity phenomenon. Maybe subjects needed more familiarization sessions with the MVIC test to optimize the specific neuromuscular activation during the task, as described by Sampson et al.²² In addition, Morrissey et al.²³ showed that adaptations to strength training are specific to the modality in which muscles are trained. Previous investigation has shown that increasing of isometric torque production is specific to the joint angles at which the muscle actions occurred during training.²⁴ Furthermore, changes in muscle activation are contraction-specific, which means that muscle activation increases but only during the muscle action utilized during training.²⁵ These reasons may justify the increases in performance in the 1RM tests but not in the MVIC tests.

The studies that evaluated the effects of pain on muscle strength performance were developed with a cross-over design, which makes comparisons with our findings difficult. On the other hand, we present an unprecedented pilot study in the literature. There is not a single study involving experimentally induced muscle pain in humans with the number of training sessions for upper limbs performed in the present study. Our results show that despite the presence of acute pain, it is possible to increase muscles' capacity to generate maximum dynamic strength. If we consider that most rehabilitation protocols use dynamic and isometric muscle actions, our findings show that the presence of pain during training may be an obstacle to improve isometric strength.

The present pilot study is not without limitations. First, the small sample size due to the difficulty in recruiting participants willing to perform 24 sessions of strength training in the presence of pain. Second, the absence of a control group submitted to isotonic saline solution injections for comparison with the results obtained in this study. Third, the study was performed in healthy, untrained men free from any pain. Thus, our results cannot be generalized to other populations, including women, elderly, and/or resistance-trained individuals. Finally, angle-specific isometric strength training was not provided to the subjects, limiting our consideration of the small changes observed in the MVIC test. Therefore, future studies are needed to confirm our results and better understand the adaptations generated by strength training in the presence of experimentally induced muscle pain.

5. Conclusions

The present pilot study showed that acute muscle pain induced in every one of 24 strength training sessions did not inhibit maximum dynamic strength development. On the other hand, the pain caused small negative changes in maximal isometric strength performance.

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Authors' contributions

Silva V worked on the search and statistical analysis of research data. All authors participated in the conception of the research question, methodological design, interpretation of the results, and writing of the scientific article. All authors reviewed and approved the final version and are in agreement with its publication.

Conflicts of interest

No financial, legal, or political conflicts involving third parties (government, private companies, and foundations, etc.) were declared for any aspect of the submitted work (including but not limited to grants and funding, advisory board participation, study design, manuscript preparation, statistical analysis, etc.).

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References

1. Kristensen J, Franklyn-Miller A. Resistance training in musculoskeletal rehabilitation: a systematic review. *Br J Sports Med.* 2012;46(10):719-26. <https://doi.org/10.1136/bjism.2010.079376>
2. Turner MN, Hernandez DO, Cade W, Emerson CP, Reynolds JM, Best TM. The role of resistance training dosing on pain and physical function in individuals with knee osteoarthritis: A Systematic Review. *Sports Health.* 2019;18;12(2):200-6. <https://doi.org/10.1177/1941738119887183>
3. Pareja-Blanco F, Asián-Clemente JA, Villarreal ES. Combined squat and light-load resisted sprint training for improving athletic performance. *J Strength Cond Res.* 2021;35(9):2457-63. <https://doi.org/10.1519/JSC.0000000000003171>

4. Graven-Nielsen T, Svensson P, Arendt-Nielsen L. Effects of experimental muscle pain on muscle activity and co-ordination during static and dynamic motor function. *Electroencephalogr Clin Neurophysiol.* 1997;105(2):156-64. [https://doi.org/10.1016/S0924-980X\(96\)96554-6](https://doi.org/10.1016/S0924-980X(96)96554-6)
5. Salomoni S, Tucker K, Hug F, McPhee M, Hodges P. Reduced maximal force during acute anterior knee pain is associated with deficits in voluntary muscle activation. *PLoS One.* 2016;11(8):0161487. <https://doi.org/10.1371/journal.pone.0161487>
6. Henriksen M, Rosager S, Aaboe J, Graven-Nielsen T, Bliddal H. Experimental knee pain reduces muscle strength. *J Pain.* 2011;12(4):460-7. <https://doi.org/10.1016/j.jpain.2010.10.004>
7. Rice DA, Mannion J, Lewis GN, McNair PJ, Fort L. Experimental knee pain impairs joint torque and rate of force development in isometric and isokinetic muscle activation. *Eur J Appl Physiol.* 2019;119(9):2065-73. <https://doi.org/10.1007/s00421-019-04195-6>
8. Farina D, Arendt-Nielsen L, Merletti R, Graven-Nielsen T. Effect of experimental muscle pain on motor unit firing rate and conduction velocity. *J Neurophysiol.* 2004;91(3):1250-9. <https://doi.org/10.1152/jn.00620.2003>
9. Hodges PW, Tucker K. Moving differently in pain: A new theory to explain the adaptation to pain. *Pain.* 2011;152(3):S90-S98. <https://doi.org/10.1016/j.pain.2010.10.020>
10. Ervilha UF, Farina D, Arendt-Nielsen L, Graven-Nielsen T. Experimental muscle pain changes motor control strategies in dynamic contractions. *Exp Brain Res.* 2005;164(2):215-24. <https://doi.org/10.1007/s00221-005-2244-7>
11. Flaxman T, Shourijeh MS, Alkjaer T, Krogsgaard MR, Simonsen EB, Bigham H et al. Experimental muscle pain of the vastus medialis reduces knee joint extensor torque and alters quadriceps muscle contributions as revealed through musculoskeletal modeling. *Clin Biomech.* 2019;67:27-33. <https://doi.org/10.1016/j.clinbiomech.2019.04.005>
12. Stackhouse SK, Sweitzer BA, McClure PW. The effect of experimental shoulder pain on contralateral muscle force and activation. *Physiother Theory Pract.* 2019;37(11):1227-34. <https://doi.org/10.1080/09593985.2019.1686670>
13. Khan SI, McNeil CJ, Gandevia SC, Taylor JL. Effect of experimental muscle pain on maximal voluntary activation of human biceps brachii muscle. *J Appl Physiol.* 2011;111(3):743-50. <https://doi.org/10.1152/jappphysiol.00603.2011>
14. Graven-Nielsen T, Arendt-Nielsen L. Impact of clinical and experimental pain on muscle strength and activity. *Curr Rheumatol Rep.* 2008;10(6):475-81. <https://doi.org/10.1007/s11926-008-0078-6>

15. Schomburg ED. Spinal sensorimotor systems and their supraspinal control. *Neurosci Res.* 1990;7(4):265-340. [https://doi.org/10.1016/0168-0102\(90\)90008-3](https://doi.org/10.1016/0168-0102(90)90008-3)
16. Brown L, Weir J. ASEP procedures recommendation I: accurate assessment of muscular strength and power. *J Exerc Physiol* [Internet]. 2001;4(3). Available from: https://www.researchgate.net/publication/235782389_ASEP_Procedures_recommendation_I_Accurate_assessment_of_muscular_strength_and_power
17. Koltyn KF. Exercise-Induced hypoalgesia and intensity of exercise. *Sports Med.* 2002;32(8):477-87. <https://doi.org/10.2165/00007256-200232080-00001>
18. Newcomb LW, Morgan KF, Morgan WP, Cook DB. Influence of preferred versus prescribed exercise on pain in fibromyalgia. *Med Sci Sports Exerc.* 2011;43(6):1106-13. <https://doi.org/10.1249/MSS.0b013e3182061b49>
19. Sørensen TJ, Langberg H, Hodges PW, Bliddal H, Henriksen M. Experimental knee joint pain during strength training and muscle strength gain in healthy subjects: A randomized controlled trial. *Arthritis Care Res.* 2012;64(1):108-16. <https://doi.org/10.1002/acr.20618>
20. Hodges PW, Ervilha UF, Graven-Nielsen T. Changes in motor unit firing rate in synergist muscles cannot explain the maintenance of force during constant force painful contractions. *J Pain.* 2008;9(12):1169-74. <https://doi.org/10.1016/j.jpain.2008.06.012>
21. Nilwik R, Snijders T, Leenders M, Groen BBL, van Kranenburg J, Verdijk LB, et al. The decline in skeletal muscle mass with aging is mainly attributed to a reduction in type II muscle fiber size. *Exper Gerontol.* 2013;48(5):492-8. <https://doi.org/10.1016/j.exger.2013.02.012>
22. Sampson JA, McAndrew D, Donohoe A, Jenkins A, Groeller H. The effect of a familiarization period on subsequent strength gain. *J Sports Sci.* 2013;31(2):204-11. <https://doi.org/10.1080/02640414.2012.725134>
23. Morrissey MC, Harman EA, Johnson MJ. Resistance training modes: specificity and effectiveness. *Med Sci Sports Exerc.* 1995;27(5):648-60. <https://doi.org/10.1249/00005768-199505000-00006>
24. Ebersole KT, Housh TJ, Johnson GO, Evetovich TK, Smith DB, Perry SR. The effects of leg flexion angle on the mechanomyographic responses to isometric muscle actions. *Eur J Appl Physiol Occup Physiol.* 1998;78(3):264-9. <https://doi.org/10.1007/s004210050418>
25. Hortobágyi T, Lambert NJ, Hill JP. Great cross education following training with muscle lengthening than shorting. *Med Sci Sports Exerc.* 1997;29(1):107-12. <https://doi.org/10.1097/00005768-199701000-00015>