Journal of Kerman University of Medical Sciences
2021; 28(5): 478-485

10.22062/JKMU.2021.91765

Original Article

http://jkmu.kmu.ac.ir/

Effects of Concentric and Eccentric Strength Training on Electromyography Activity of the Knee Agonist-Antagonist Muscles

Mahdi Zeigham Jahani[1], Ali Yaghoubi[1*], Mohamad Amin Younessi Heravi[2]

1. Department of Physical Education and Sport Sciences, Islamic Azad University, Bojnourd Branch, Bojnourd, Iran
2. Department of Medical Physics and Radiology, School of Medicine, North Khorasan University of Medical Sciences, Bojnurd, Iran

Open Access
Publish Free

ABSTRACT

Background: The appropriate activity of the knee agonist-antagonist muscles is important to resist against abnormal abduction-adduction moments loads around knee joint and reduce the risk of knee injuries. Exercise training has been commonly used as an intervention to improve neuromuscular activity of the synergic and/or agonist-antagonist muscles. However, maximizing the effectiveness of exercise interventions for improving neuromuscular activity between muscle groups has been less investigated. The aim of this study was to investigate the improvement in neuromuscular activity of quadriceps and hamstrings muscles after resistance eccentric training versus concentric training.

Methods: 26 male subjects randomly recruited for this controlled laboratory study. Subjects were randomly divided into two groups, eccentric training group (No = 13), and concentric training group (No = 13). Maximal knee extension force and bipolar surface electromyography (EMG) signals from quadriceps and hamstrings muscles were recorded before and after concentric and eccentric strength training. Root mean square (RMS) was computed from raw EMG signals.

Results: Percent increase in maximal voluntary isometric contraction (MIVC) of quadriceps muscle after eccentric training was significantly higher than that after concentric training ($P < 0.05$). Moreover, eccentric training resulted in a greater increase in RMS of EMG for quadriceps and hamstrings muscles compared to concentric exercise training ($P < 0.05$).

Conclusion: The higher increase in neuromuscular activities within the quadriceps and hamstring muscles observed after eccentric exercise may indicate that resistance training using eccentric contraction is more effective in improving neuromuscular activity of the agonist and antagonist muscles.

Keywords: Agonist-antagonist muscle, Surface EMG, Eccentric exercise

---

Citation: Zeigham Janani M, Yaghoubi A, Younessi Heravi MA. Effects of Concentric and Eccentric Strength Training on Electromyography Activity of the Knee Agonist–Antagonist Muscles. *Journal of Kerman University of Medical Sciences* 2021; 28(5): 478-485. doi: 10.22062/JKMU.2021.91765

Received: 02.04. 2021
Accepted: 17.07. 2021

*Correspondence: Ali Yaghoubi; Emai l: yaghoubiali65@gmail.com

Published by Kerman University of Medical Sciences

Introduction

A greater knee abduction-adduction moment during sport activities has been reported to be the major cause of knee injury (1). The quadriceps and hamstrings muscles have the potential to provide dynamic frontal-plane knee stability because of their abduction and/or adduction moment arms (2). Using a neuromuscular biomechanical model, Lloyd et al. (2003) noted that the quadriceps and hamstrings not only have the potential to support frontal-plane moments but also actually provide support to abduction-adduction moments. Therefore, the appropriate activity of the knee agonist-antagonist muscles is necessary to reduce the risk of knee injuries (2). The researchers suggested that quadriceps muscle plays a primary role in ACL injury prevention, as it is much stronger than the hamstrings and it has a favorable vector with regard to the ACL during closed kinetic chain activities (3). Other researchers reported that in patients with ACL deficient, quadriceps muscle activation has strongly contributed to the functional stability as it increased medial stiffness of the knee by 48%. Because, quadriceps-hamstrings co-activation plays a critical role in ACL prevention, optimizing exercise training to improve hamstring/quadriceps activation, received considerable attention from scientists and clinicians (4). Although all forms of exercise may induce a significant improvement in neuromuscular activity, it is not always clear which method is the best one for maximizing neuromuscular activity.

The muscle adaptions to resistance training is also dependent on the type of muscle contractions performed (5, 6), and the neuromuscular adaptations and improvement in muscle force vary depending on whether eccentric, concentric, or isometric contractions are executed (7, 8). Of the three types of muscle contractions that can be utilized during exercise (concentric, isometric, and eccentric), eccentric exercises are those actions in which the muscle lengthened and induces muscle fiber damage (9, 10). Given that the central nervous system also employs a different neural strategy to control skeletal muscle during eccentric contractions versus isometric or concentric muscle contraction. For example, eccentric contraction characterized by different activation levels among synergistic muscles (11), different modulation of monosynaptic reflex excitability (12), or carrying out a different control strategy (e.g., motor unit recruitment) as compared to concentric contraction (13). Therefore, knee agonist and antagonist muscles are expected to show different adaptation to eccentric exercise compared to concentric exercise. The aim of this study was to examine neuromuscular adaptations within quadriceps and hamstrings muscle after concentric and eccentric strength training.

Materials and Methods

Subjects

This is an experimental study with a between-group comparison design. 26 male subjects (age, mean ± SD, 21.6 ± 2.1 years, body mass: 73.3 ± 6.9 kg, height: 1.76 ± 0.05 m) randomly recruited for the study. By taking the effect size of previous studies (9, 10) and a confidence interval of 95%, the sample size was determined to be 13 for each group, using the sample size formula.

$$n = \frac{\left(\sigma_1^2 + \sigma_2^2\right)\left(Z_{1-\alpha/2} + Z_{1-\beta}\right)^2}{\delta^2}$$

$\alpha = 0.05 \Rightarrow Z_{1-\alpha/1} = 1.96$ $1-\beta = 0.90 \Rightarrow Z_{1-\beta} = 1.28$

$\sigma_1 = 13.6$ $\sigma_2 = 12.4$ $\delta = (110\text{-}87) = 27$

$n \approx 12$

However, the sample size was evaluated to be 12 (for each group: totally 24), which was raised to 13 (for each group: totally 26) for possible participant dropout. All subjects were volunteered to participate in the study and were right leg dominant and were not involved in regular exercise of their knee extensor muscles for at least one year before the experiment. Subjects were randomly divided into two groups, eccentric training group (No = 13), and concentric training group (No = 13). The study was conducted in accordance with the Declaration of Helsinki, approved by the Local Ethics Committee; and written informed consent was obtained from all subjects prior to inclusion.

Exercise training protocols

Subjects performed eccentric exercise of their quadriceps using a weight-training machine (Universal Gym, the USA) in supine position. The subject lowered the load in an eccentric mode from the starting position (180º knee extension) to the finish position (90º knee flexion) in a controlled manoeuvre. Two assistants help subject to bring the leg to the starting position. This allowed the subjects to perform multiple repetitions using eccentric contraction against relatively high loads and delayed the onset of fatigue by eliminating the concentric contraction. Concentric group also performed concentric exercise from starting position (90º knee flexion) to the finish position (180º knee extension) on weight-training machine (Universal Gym, the USA) in the same position as eccentric training group. Moreover, one-repetition maximum (1-RM) was determined for each subjects using concentric contraction. Subjects in eccentric and concentric training groups performed 3 sets of 12 repetitions with 80% of the 1-RM with three minutes of rest between sets. 1-RM was evaluated for each subject every week and the weights were adjusted accordingly.

Maximal isometric voluntary contraction (MIVC)

The subject sat comfortably on a chair fixed with a belt at the hip and with the right knee in 90º of flexion. Maximal isometric voluntary contraction of quadriceps muscle was measured using a load cell. A strap, connected by a chain to a load cell, was attached to the ankle to measure knee extension isometric force. Force was provided to the subject as visual feedback on an oscilloscope. The subject performed a total of three 5-second maximal isometric voluntary contractions (MIVC) of knee extension each separated by a 2-min rest. During each MIVC, verbal encouragement was provided to exceed the previous force level. The highest MIVC value was considered as the reference value.

Surface electromyography (EMG)

Surface EMG signals were simultaneously recorded from quadriceps and hamstring muscles of the right leg during maximal isometric voluntary contraction of quadriceps muscle. Four pair electrodes (circular Ag–AgCl surface electrodes (Ambu Neuroline, conductive area 28 mm^2) were carefully placed in bipolar configuration (2-cm interelectrode distance) on quadriceps (vastus medialis, VM; vastus lateralis, VL) and hamstrings (semitendinosus, SM; biceps femoris, BF) of the right leg (Figure 1). Muscle tissue for the VM, VL, ST, and BF muscles was determined by palpating the muscle. Before electrode placement, the skin was shaved and lightly abraded in the selected locations. Surface EMG signals were amplified (EMG amplifier, EMG-16, LISiN-OT Bioelettronica, Torino, Italy, bandwidth of 10–500 Hz), sampled at 2048 Hz, and stored after 12-bit A/D conversion. A ground electrode was placed around the right ankle.

Signals analysis

Root mean square of (RMS) of EMG was estimated for epochs of 250 ms. the average of values obtained from 250 ms were calculated within the 5-second maximal isometric voluntary contractions. To compare changes across testing sessions, the percentage change between pre-exercise value and post-exercise value (Percentage change = Post-exercise value - Pre-exercise value/Post-exercise value × 100), was calculated.

Statistical analysis

One-way analysis of variance (ANOVA) with repeated-measures was applied to evaluate the change in maximal isometric voluntary contraction from pre-training to post-training condition with training group (concentric and eccentric). Three-way ANOVA with repeated-measures was used to assess percent change in EMG RMS (percent change from pre-training to post-training session) for the VL, VM, BF, and ST muscles with training group and testing session as an independent factor. Pairwise comparisons were performed with the Student-Newman-Keuls post-hoc test when ANOVA was significant. The significance level was set at $P < 0.05$ for all statistical procedures. Results are reported as the mean ± SD in the text and SE in the figures.

Results

No significant differences were found between the groups in terms of age and weight.

Maximal isometric voluntary contraction of quadriceps increased significantly for the concentric and eccentric training groups from pre- to post-training condition ($F = 65.6$ .34, $P < 0.0001$). A significant interaction was also observed between training group and testing session. Percent increase in a maximal isometric voluntary contraction of quadriceps after eccentric training was significantly larger than that after concentric training ($F = 17.1$, $P < 0.002$; Figure 2).

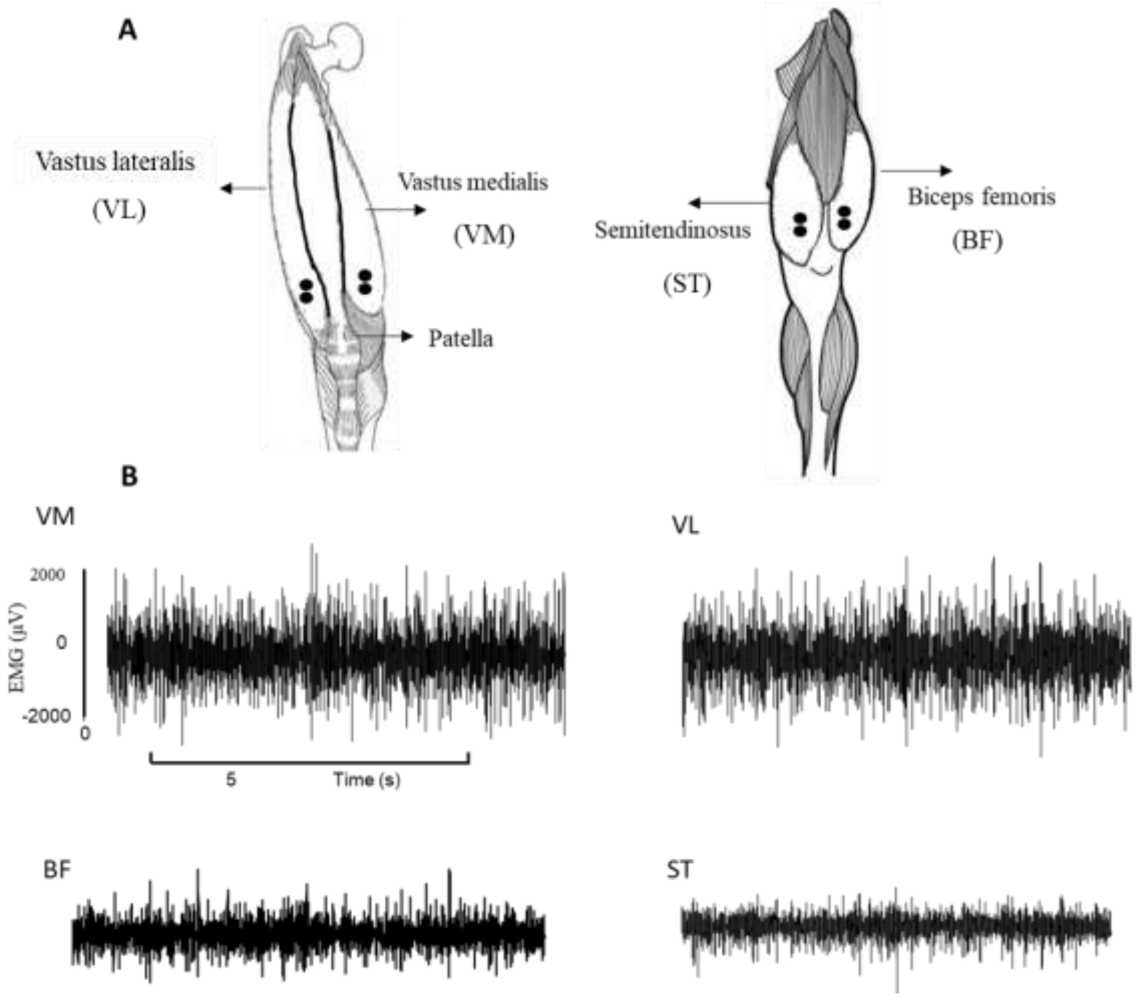

Figure 1. Schematic representation of electrode position on the quadriceps and hamstring muscles (A), and associated surface EMG signal (B), recorded during maximal isometric voluntary contraction. Surface electrodes were carefully placed in bipolar configuration on the distal regions of the quadriceps and hamstrings muscles.

Electromyography RMS measured during maximal isometric voluntary contraction of quadriceps was significantly increased for four muscles (VM, VL, ST, and BF) after eccentric and concentric training (F = 71.5, $P < 0.0001$). However, percent increase in EMG RMS depended on the interaction between training group, muscles and testing session (F = 16.4, $P < 0.002$). Percent increase in EMG RMS for four muscles at post-eccentric training session in eccentric group was significantly higher than that in the concentric group ($P < 0.05$; Figure 3).

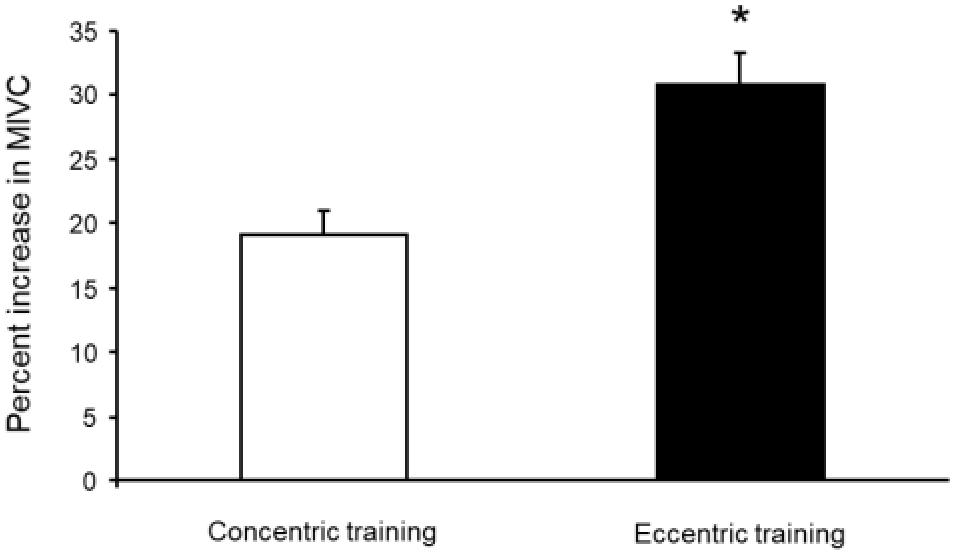

Figure 2. Percentage increase in maximal isometric voluntary contraction (MIVC) of quadriceps muscle (mean ± SE, %,) after 12 weeks concentric (white) and eccentric (black) resistance training. Asterisk (*) indicates that eccentric training resulted in a greater MIVC compared to concentric training (P<0.05).

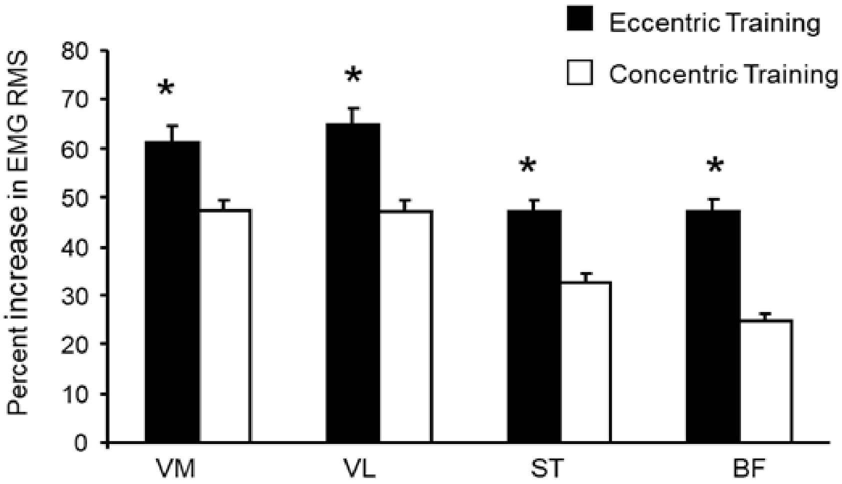

Figure 3. Percentage increase in root mean square (RMS) of EMG (mean ± SE, %,) after 12 weeks concentric (white) and eccentric (black) resistance training. Asterisk (*) indicates that eccentric training resulted in a greater increase in EMG RMS for all muscles (VM, VL, ST, and BF) compared to concentric training (P<0.05).

Discussion

The main finding of this study is that strength training using eccentric action resulted in a greater improvement in quadriceps strength as compared to concentric exercise. Moreover, EMG RMS of quadriceps (VM and VL) and hamstrings (ST and BF) muscle measured after eccentric strength training was significantly larger than those observed after strength concentric training. The result indicates that eccentric strength training is more effective than the strength concentric training to improve neuromuscular activity of the agonist and antagonist muscles.

Muscle function

Both strength eccentric and concentric exercise training resulted in a significant increase in maximal isometric quadriceps strength, which is consistent with the results of previous studies (14, 15). However, the increased isometric quadriceps strength after eccentric training was significantly greater than those observed after concentric exercise. Previous studies also showed a higher increase in muscle strength after dynamic stretching exercises. For example, Carvalho et al. (2014) showed that strength-training combined with stretching plyometric exercises could be an effective way to improve muscle strength (15). Likewise, a significant increase in muscle strength of the lower and upper limbs observed after strength training, and eccentric training was more effective than the concentric training to increase muscle strength (16-18). These results indicate that improvement in muscle strength depended on muscle contraction type, most probably due to differences in neural strategies among muscle contraction type required to control skeletal muscle.

Electromyography

RMS of EMG for quadriceps (VM and VL) and hamstring muscles (ST and BF) significantly increased after eccentric and concentric strength training. The increased EMG RMS after strength training can be attributed to the increased neural signals to muscle fibers, which in turn, results in a greater motor unit recruitment and muscle tension (19, 20). However, eccentric training resulted in a greater increase in RMS of EMG compared to concentric training. A higher increase in RMS of EMG after eccentric exercise may be explained by neural mechanisms underlying eccentric contraction to control skeletal muscle. For example, differences in recruitment order of motor units and cortical activation level was observed between eccentric and concentric contractions (13, 21). It has been reported that eccentric contraction is associated with a greater cortical activation (21) and preferential recruitment of fast-twitch motor units (13) compared to eccentric contraction. Therefore, strength training using eccentric action can result in a greater cortical activation, and as a consequence increase neural drive from central nervous system to the muscle fiber, this factor can produce larger EMG activity within the skeletal muscle during maximal task (22). Previous studies have also demonstrated an enhance in evoked V-wave and H-reflex amplitude during maximal voluntary contraction after high-intensity strength exercise, indicating a higher transmission of neural signals in the corticospinal pathways and increased excitability of motor neurons (23). Additionally, preferential recruitment of fast-twitch motor units has been reported during eccentric contraction as compared to isometric and concentric contraction (13). Fast-twitch motor unit is characterized by higher recruitment threshold, higher firing rate and conduction velocity, and is considered to produce a higher EMG activity (20). A higher increase in EMG activity within the knee antagonist muscles after eccentric exercise, may also be related to a reduction in reciprocal inhibition for the antagonist muscle, most likely due to unique neural strategies to control synergic and/or antagonist muscle during eccentric action (11). In summary, a greater increase in EMG activity of qudericpe and hamstring muscles was observed after eccentric strength training. This may indicates that strength training using eccentric contraction is more effective to trigger neuromuscular activity within the agonist and antagonist muscles simultaneously.

Application

The appropriate activity of knee agonist-antagonist muscles is important for the performance of rapid movements. There is evidence of knee antagonist activity during explosive movement and/or heavy workload activity. Stronger agonists could increase the acceleration of the limb being moved, while stronger antagonists could facilitate inhibition of the limb movement in a shorter time, providing a longer time for acceleration. Moreover, a strong co-activation of knee agonist-antagonist muscles is necessary to provide resistance to abnormal moments loads around knee joint during daily and/or sport activities, which in turn reduces the risk of knee injuries.

Conclusion

The results of this study showed a higher increase in neuromuscular activity of the knee agonist-antagonist muscle after eccentric training. A higher increase in neuromuscular activity of the agonist-antagonist muscles observed after eccentric exercise may indicate that tension combined with stretching exercises is an effective stimulus for improving neuromuscular activities of the agonist and antagonist muscles. The results of this study may be relevant to designing exercise and/or rehabilitation training program to improve muscle performance and reduce the risk of knee injuries.

References

1. Thorstensson CA, Henriksson M, von Porat A, Sjödahl C, Roos EM. The effect of eight weeks of exercise on knee adduction moment in early knee osteoarthritis--a pilot study. Osteoarthritis Cartilage 2007; 15(10):1163-70. doi: 10.1016/j.joca.2007.03.012.
2. Lloyd DG, Besier TF. An EMG-driven musculoskeletal model to estimate muscle forces and knee joint moments in vivo. J Biomech 2003; 36(6):765-76. doi: 10.1016/s0021-9290(03)00010-1.
3. Heijne A, Werner S. Early versus late start of open kinetic chain quadriceps exercises after ACL reconstruction with patellar tendon or hamstring grafts: a prospective randomized outcome study. Knee Surg Sports Traumatol Arthrosc 2007; 15(4):402-14. doi: 10.1007/s00167-006-0246-z.
4. Thomas AC, Wojtys EM, Brandon C, Palmieri-Smith RM. Muscle atrophy contributes to quadriceps weakness after anterior cruciate ligament reconstruction. J Sci Med Sport 2016; 19(1):7-11. doi: 10.1016/j.jsams.2014.12.009.
5. Hedayatpour N, Falla D, Arendt-Nielsen L, Vila-Chã C, Farina D. Motor unit conduction velocity during sustained contraction after eccentric exercise. Med Sci Sports Exerc 2009; 41(10):1927-33. doi: 10.1249/MSS.0b013e3181a3a505.
6. Hedayatpour N, Falla D, Arendt-Nielsen L, Farina D. Effect of delayed-onset muscle soreness on muscle recovery after a fatiguing isometric contraction. Scand J Med Sci Sports 2010; 20(1):145-53. doi: 10.1111/j.1600-0838.2008.00866.x.
7. Hedayatpour N, Falla D. Physiological and neural adaptations to eccentric exercise: mechanisms and considerations for training. Biomed Res Int 2015; 2015:193741. doi: 10.1155/2015/193741.
8. Hedayatpour N, Falla D. Non-uniform muscle adaptations to eccentric exercise and the implications for training and sport. J Electromyogr Kinesiol 2012; 22(3):329-33. doi: 10.1016/j.jelekin.2011.11.010.
9. Hedayatpour N, Falla D, Arendt-Nielsen L, Farina D. Sensory and electromyographic mapping during delayed-onset muscle soreness. Med Sci Sports Exerc 2008; 40(2):326-34. doi: 10.1249/mss.0b013e31815b0dcb.
10. Nasrabadi R, Izanloo Z, Sharifnezad A, Hamedinia MR, Hedayatpour N. Muscle fiber conduction velocity of the vastus medilais and lateralis muscle after eccentric exercise induced-muscle damage. J Electromyogr Kinesiol 2018; 43:118-26. doi: 10.1016/j.jelekin.2018.06.008.
11. Hody S, Croisier JL, Bury T, Rogister B, Leprince P. Eccentric muscle contractions: risks and benefits. Front Physiol 2019; 10:536. doi: 10.3389/fphys.2019.00536.
12. Bautista W, Aguilar J, Loeza-Alcocer JE, Delgado-Lezama R. Pre- and postsynaptic modulation of monosynaptic reflex by GABAA receptors on turtle spinal cord. J Physiol 2010; 588(Pt 14):2621-31. doi: 10.1113/jphysiol.2010.188979.
13. Del Vecchio A, Casolo A, Negro F, Scorcelletti M, Bazzucchi I, Enoka R, et al. The increase in muscle force after 4 weeks of strength training is mediated by adaptations in motor unit recruitment and rate coding. J Physiol 2019; 597(7):1873-87. doi: 10.1113/JP277250.
14. Abdi N, Hamedinia MR, Izanloo Z, Hedayatpour N. The effect of linear and daily undulating periodized resistance training on the neuromuscular function and the maximal quadriceps strength. Balt J Health Phys Act 2019; 11(1):45-53. doi: 10.29359/BJHPA.11.1.05.
15. Carvalho A, Mourão P, Abade E. Effects of strength training combined with specific plyometric exercises on body composition, vertical jump height and lower limb strength development in elite male handball players: a case study. J Hum Kinet 2014; 41:125-32. doi: 10.2478/hukin-2014-0040.
16. Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. Med Sci Sports Exerc 2003; 35(3):456-64. doi: 10.1249/01.MSS.0000053727.63505.D4.
17. Prestes J, da Cunha Nascimento D, Tibana RA, Teixeira TG, Vieira DC, Tajra V, et al. Understanding the individual responsiveness to resistance training periodization. Age (Dordr) 2015; 37(3):9793. doi: 10.1007/s11357-015-9793-x.
18. Mazani AA, Hamedinia MR, Haghighi AH, Hedayatpour N. The effect of high speed strength training with heavy and low workloads on neuromuscular function and maximal concentric quadriceps strength. J Sports Med Phys Fitness 2018; 58(4):428-34. doi: 10.23736/S0022-4707.17.06655-5.

19. De Luca CJ, Gonzalez-Cueto JA, Bonato P, Adam A. Motor unit recruitment and proprioceptive feedback decrease the common drive. J Neurophysiol 2009; 101(3):1620-8. doi: 10.1152/jn.90245.2008.

20. Hedayatpour N, Arendt-Nielsen L, Farina D. Motor unit conduction velocity during sustained contraction of the vastus medialis muscle. Exp Brain Res 2007; 180(3):509-16. doi: 10.1007/s00221-007-0877-4.

21. Younessi Heravi MA, Maghooli K, Nowshiravan Rahatabad F, Rezaee R. Application of a neural interface for restoration of leg movements: intra-spinal stimulation using brain electrical activity in spinally injured rabbits. Journal of Applied Biomedicine 2020; 18(2-3):33-40. doi: 10.32725/jab.2020.009.

22. Hedayatpour N, Arendt-Nielsen L, Farina D. Non-uniform electromyographic activity during fatigue and recovery of the vastus medialis and lateralis muscles. J Electromyogr Kinesiol 2008; 18(3):390-6. doi: 10.1016/j.jelekin.2006.12.004.

23. Vieira A, Blazevich A, Souza N, Celes R, Alex S, Tufano JJ, et al. Acute changes in muscle thickness and pennation angle in response to work-matched concentric and eccentric isokinetic exercise. Appl Physiol Nutr Metab 2018; 43(10):1069-74. doi: 10.1139/apnm-2018-0055.