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Original Research

Effects of Cycling-induced Fatigue on Lower Extremity Muscles Synergy in Novice Triathletes

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ABSTRACT

The study of muscle synergy is a new method to evaluate the function of the control system of the human body. Due to the physical demands of the nature of triathletes it appears that triathletes are affected by variety degrees of muscle fatigue. The aim of this study was to determine the effect of fatigue on lower limb muscles synergy in novice triathletes. Sixteen male novice triathletes participated in this semi-experimental study. Electromyography activity of rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius medial, soleus and tibialis anterior muscles were recorded before and after the cycling-induced fatigue protocol during running task. Non-negative matrix analysis algorithm approach was used to extract muscle synergies from electromyography signals. Pearson correlation method was emplyoed to measure the similarity of the extracted patterns. Paired-sample t-test was employed to compare the relative weight of muscles before and after the fatigue protocol ($P<0.05$). After muscle fatigue, the first and second synergy patterns showed high similarity and the third and fourth synergy patterns showed moderate similarity. The relative weight of vastus lateralis muscle ($P=0.012$) and tibialis anterior ($P=0.024$) decreased significantly after muscle fatigue. The relative weight of semitendinosus ($P=0.016$) and soleus ($P=0.031$) muscles increased significantly after muscle fatigue. The number of four muscle synergies were obtained by variance accounted for method from electromyography activity data of muscles before and after muscle fatigue. Cycling-induced fatigue can affect the organized cooperation of the central nervous system to create synergy

patterns in triathletes during running. It seems that disruption of synergy patterns and relative weight of lower limb muscles due to cycling-induced fatigue can change the mechanics of subsequent running in triathletes and increase the possibility of injury among these individuals.
Keywords: Muscle synergy, Fatigue, Electromyography, Triathletes

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INTRODUCTION

Muscle synergies provide a simple description of the control of the motor system of the human body. Despite years of research, it is still unclear how the central nervous system controls the activity of large numbers of muscles during coordinated exercise [1]. Various researches have been showed that the central nervous system uses the muscles in groups to reduce complexity required to control the muscles during the activity [2]. Understanding how muscle synergies are used may contribute to our greater understanding of the neural mechanisms that underlie many injury conditions [1].

The muscle synergy concept was first proposed by Bernstein (1966) and represents the strategy of the central nervous system to solve the problem of redundancy or uncertainty to control the degrees of freedom of the musculoskeletal system during physical activity. Thus, in order to select and perform the appropriate activity of a small set of muscles synergies, afferent messages and supraspinal descending movement control messages interact to control the desired activity [3]. In fact, muscle synergy expresses neuromuscular coordination to activate muscle avtivity patterns. Hence, it is believed that the nervous system selects strategies to reduce the complexity of controlling motor behavior during activity [4].

Triathletes compete to record better total times in swimming, cycling and running. Success in this sport depends on the athlete's ability to run with maximum efficiency, motor performance and the appropriate pattern of muscle activity [5]. Previous studies show that possibility of musculoskeletal injuries of triathletes during long distance running depends on the fact that muscle patterns for running do not change much after cycling phase [6, 7, 8]. Most triathlon athletes report a noticeable change in muscle coordination during running after cycling. Reasons for these inconsistent patterns are still unclear in the literature. Fatigue after cycling, probably causes this inconsistency in running [9].

Few studies have been done on the effect of fatigue on the biomechanical parameters of triathletes. Marino et al. (2008) studied on the speed and stride length over 40 km of cycling and running and reported that running after the cycling stage decreases the speed and stride length [10]. Chapman et al. (2008) investigated the effect of cycling on tibialis anterior muscle activity and running kinematic parameters. They reported no significant difference in the kinematic characteristics of running and the mean frequency of this muscle after cycling fatigue. Nonetheless, they observed a significant difference in the tibialis anterior muscle activity in running pattern after cycling [6]. Del Caso et al. (2012) measured the jump height and lower limb strength before and after the half distance of the Ironman Triathlon. They reported that the amount of jumping height and the output power of the lower limb decreased significantly after the competition [9]. Anbarian et al. (2015) investigated the effect of pedaling and fatigue on changes of knee muscles co-contraction during running in triathletes. Their results showed that fatigue changes muscle co-contraction in different phases of running of triathletes [11]. Fatigue caused by cycling may also affect muscles synergies, consequently, the mechanics of running can be changed and cause injuries to triathletes. According to our knowledge, no research was found in muscle synergy in novice triathletes. Therefore, the purpose of this study was to investigate the effect cycling-induced fatigue protocol on synergy of the lower limb muscles in novice triathletes during running in order for a better understanding of the risk factors of triathlon injuries.

MATERIAL AND METHODS

Participants

Sixteen male novice triathletes participated in this quasi-experimental study with pre-test and post-test design. The Sample size was selected using G*power software with an effect size of 0.8 and a power of 0.95. A novice triathlete was defined as an individual who had never taken part in a formal competition such skilled triathletes. However, they had trained between 1-2 years [11]. Demographic information for all subjects can be found in Table 1. All subjects were free of any cardiovascular pathology, neurological disorders, lower extremity injuries and not participating in other sports in the last 6 months. They also have been practicing triathlon at least three times a week [12]. All subjects received clarifications regarding the procedures and agreed to participate by signing a statement of informed consent. This study received approval from the ethics committee of Bu-Ali Sina University.

Table 1: Demographic information of subjects (Mean±standard deviation).

Age (year)	Height (cm)	Mass (Kg)
23.9±2.51	178.52±3.41	76.15±4.12

Procedure

Surface electromyography signals were collected using a 16-channel Megawin wireless device (Biomonitor ME6000, Kuopio, Finland). After abrasion and cleaning of the skin with alcohol, surface electromyography electrodes (Ag.AgCl; 10-mm diameter; bipolar arrangement; inter-electrode distance 2.5 cm) were attached over the target muscles of the dominant leg of the subjects identified by which leg the subject used to kick a ball [13]. Electromyography activity of rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF), semitendinosus (SM), gastrocnemius medial (GM), soleus (SO) and tibialis anterior (TA) muscles were recorded during running [16]. The position of the electrodes on each muscle was according to the SENIAM protocol [15]. The ground electrode was placed on the tibia tuberosity. The center-to-center distance of the electrodes were considered to be 20 mm. Electrodes and cables were fixed on the skin in order to prevent movement noises and disturbances in the subject's movement. Then, the maximal voluntary isometric contraction (MVIC) was recorded for the acquisition of normalization signals from the muscles. Subjects performed 3 repetitions of 5 seconds of maximum voluntary isometric contraction for each muscle or muscles group, and subjects were given a one-minute rest between each repetition [15]. Before the measurements, all subjects performed training trials to become familiarized with the test situation. After familiarization, electromyography signals of muscles were recorded during running before and after cycling-induced fatigue. In order to record a successful stride while running, two foot-switches; one on the most posterior plantar region of the heel and the other under the first metatarsophalangeal joint were attached under the foot. To prevent the possible change of the subject's running pattern as a result of focusing on the running speed, the subjects were asked to run at their self-selected speed. In the main test, the subjects were asked to run over a 15-meter runway. Each subject was required to complete six trials per condition (before and after fatigue protocol) with one minute rest between each trial. Three successful running trials out of six were averaged for data analyses [16, 17].

The twelve-step protocol related to the study of Bonacci et al. (2013) and a stationary bicycle made in England were used for the cycling-induced fatigue protocol [8]. The subjects' pedaling speed were 90 to 100 revolutions per minute in all stages of the protocol. To ensure that fatigue is created at the end of each stage of the protocol, the 6-20 rank Borg index was used. The number 6 indicates lack of fatigue and rank 17 to 20 indicates fatigue. If the subjects expressed as a number higher than 17 in each stage, they were given more rest, and during the rest period, they were asked to express their level of fatigue again when this scale reached lower than 17, next the fatigue protocol was performed [18]. After the fatigue protocol, the subjects were asked to run over a 15-meter runway at their self-selected speed like before the fatigue protocol. According to the quality of the foot switch signals, the seventh or eighth step were selected for analysis. The sampling frequency was 1000 Hz and the signal-to-noise ratio was 90 dB .The data were smoothed with a 6 Hz Butterworth filter of order 4th to perform the linear envelope operation. Then to normalize the data during the running cycle, it was divided by the values of the maximum voluntary isometric contraction of the same muscle and multiplied by 100. At the end, each step was time-normalized through cubic interpolation and divided into 101 points.

Data analysis

Electromyography signals were factorized for obtaining the muscular synergy components including 1) NCs (neural commands) and 2) SVs (synergy vectors). Non-negative matrix decomposition algorithm methods were used to extract muscles synergies. The variance accounted for method was used to determine the number of synergies needed to reconstruct the input matrix. According to previous studies, at each level of synergy, if the variance accounted for value is higher than 0.9, there is no need to process information for the next synergy [1, 2, 4]. These data processing was done using Matlab software version 2016. Shapiro-Wilk test was used to check the normality of data distribution. Pearson correlation test was used to compare the similarity of synergy patterns (low synergy similarity (0.0-0.29), medium synergy similarity (0.3-0.69), high synergy similarity (0. 7-1) [1, 4]. Dependent t-test was used for detecting the relative weight of the muscles. All steps of statistical analysis were performed using SPSS software version 24. and the significance level was considered at $P<0.05$.

RESULTS

Figure 1 illustrates the patterns of muscle synergies before and after the cycling-induced fatigue protocol during running. Using Pearson's correlation between the first synergy pattern before and after the muscle fatigue protocol during running, the value of r=0.91 (high similarity) was obtained. The similarity of the second synergy pattern to r=0.95 (high similarity), the similarity of the third synergy pattern to the value of r=0.68 (average similarity), the degree of similarity of the fourth synergy pattern was obtained with the value of r=0.59 (medium similarity) between the synergy patterns before and after the fatigue protocol during running. Also, different onset times and peaks before and after muscle fatigue can be seen in the synergy patterns

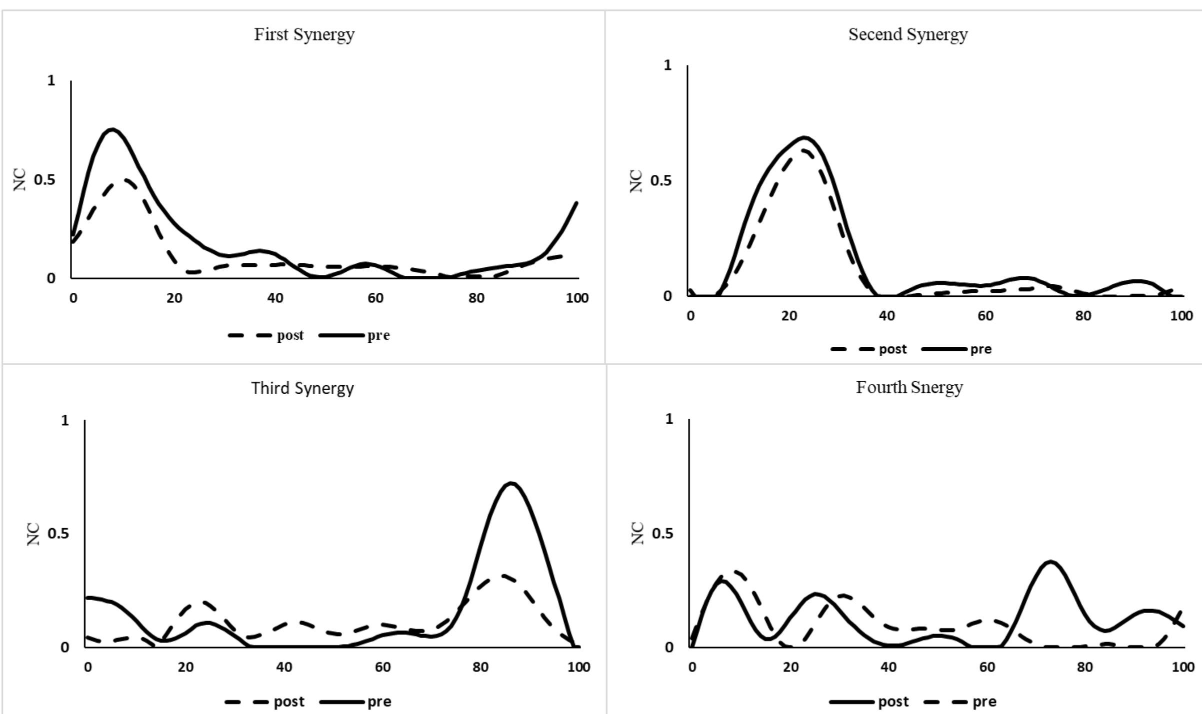

Figure 1: Synergy patterns before and after the muscle fatigue protocol during running

Figure 2 shows the relative weight of muscles before and after the fatigue protocol during running. The relative weight of vastus lateralis muscle (P=0.012) and tibialis anterior (P=0.024) decreased significantly after muscle fatigue. The relative weight of semitendinosus (P=0.016) and soleus (P=0.030) muscles increased significantly after muscle fatigue.

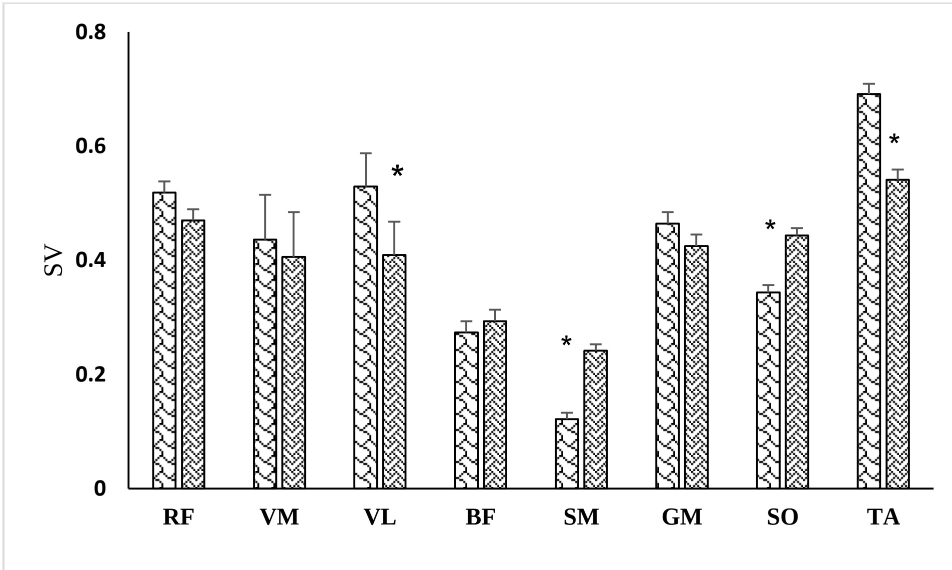

Figure 2: Relative muscle weight before and after the muscle fatigue protocol during running. Abreviations: RF stands for rectus femoris, VM stands for vectus medialis, VL stands for vectus lateralis, BF stands for biceps femoris, SM stands for semitendinosus, GM stands for gastrocnemius medial, SO stands for soleus and TA stands for tibialis anterior muscles

Figure 3 shows the variance accounted for values for extracting four muscle synergies before and after muscle fatigue. The variance accounted for method was used to determine the number of required synergies, which was higher than 0.9 for muscle activity data before and after muscle fatigue at the extraction level of four muscle synergies.

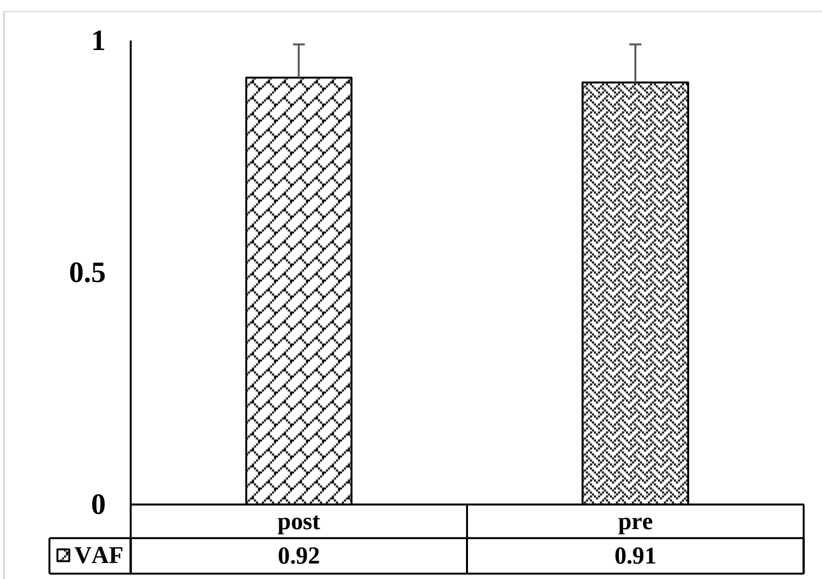

Figure 3: Variance accounted for values before and after the muscle fatigue protocol at the extraction level of four synergies.

DISCUSSION

The aim of this study was to determine the effect of cycling-induced fatigue on synergy of the selected lower limb muscles among novice triathletes. Our findings showed a high similarity between first and second synergy patterns while it was moderate for third and fourth synergy patterns. In muscular synergy levels after fatigue protocol and according to variance accounted for value, no difference was observed in the number of muscle synergies. This means that the central nervous system does not alter the number of muscle synergies after muscle fatigue in triathletes. Clark et al. (2020) investigated the synergy of lower limb muscles in individuals with stroke during walking. They extracted four synergies and reported different changes in the relative weight of muscles along with the synergy pattern in patients with stroke. Clark et al. were among the first to present the theory of "reduction of central nervous system organization for movement pattern". They pointed out that there is evidence to show that the central nervous system organizes muscle activation with small dimensions to perform tasks [19].

Undoubtedly, using this muscle organization for the coordination of movements, muscle and nerve injuries, diseases and biomechanical variables including muscle fatigue was unknown until then. Our results indicate that the tendency of synergy pattern and muscle weight were different in the groups examined in their study [19]. Oliveira et al. (2014) investigated the effect of electromyography data processing during walking, including averaging/concatenation and number of step cycles, on muscle synergies. Their results showed that the number of step cycles extracted for the analysis of electromyography data has no effect on determining the number of muscles synergies, but how to process the signal could have an effect on the final result [20]. Serrancolí et al. (2016) studied the effect of an anterior cruciate ligament injury on the synergy pattern and relative weight of muscles. Five synergies were extracted from both injured and healthy groups with variance accounted for above 0.9. They concluded that the central nervous system does not change the number of synergies used after injury. This means that the way the anterior cruciate ligament controls muscle synergy in individuals with anterior cruciate ligament injuries is not different compared to healthy individuals. However, the activation time of synergies and the relative weight of the muscles changed after injury to the anterior cruciate ligament. The change in synergy activation timing and relative weight were considered as the reason for the difference in the muscle activation pattern during walking in individuals with anterior cruciate ligament injuries, as well as the biomechanical outputs such as the kinematics of joints [1]. Smale et al. (2016) used muscle synergy to detect muscle fatigue during the squat movement. Their results showed that after muscle fatigue, the number of muscle synergies remains constant, but its activation occurs at different points of the movement cycle, and the relative weight of the muscles changes as well. They concluded that muscle fatigue by changing the neuromuscular characteristics causes a change in the tendency of muscle synergies and the relative weight of muscles, and as a result, by changing the tendency of muscle synergies and by activating them at different time points in the movement cycle, they can change the movement pattern. A change in the movement pattern causes a change in the biomechanical outputs such as the range of motion and the torque of the joints during movements, and ultimately it will cause changes in the intensity and pattern of muscle activity [21]. Hajilou et al. (2020) conducted a study on the effect of fatigue on the synergy of lower limb muscles of novice runners. The results of their study revealed that muscle fatigue changed the synergy pattern and the relative weight of muscles after muscle fatigue [22].

In the present study, after cycling-induced fatigue protocol, the tendency of the third and fourth synergies and the relative weight of the muscles in triathletes changed during the running task. According to the results of the present study, the high similarity in the first and second synergy (Figure 1) indicates that the central nervous system activates the muscle groups synergistically. In the third and fourth synergy levels, we observed a moderate similarity. In other words, the central nervous system does not synergistically activate the muscle groups after fatigue caused by cycling at this level of synergy. These changes could be seen in the relative weight of the muscles (Figure 2). The relative weight of the vastus lateralis muscle and tibialis anterior decreased significantly after muscle fatigue protocol, while the relative weight of the semitendinosus and soleus muscles increased significantly after cycling-induced fatigue protocol. Moreover, we can see that in the third and fourth synergy, the peak of synergy activity has occurred at different points of the movement, consequently causing a change in the third and fourth synergies. Rozumalski et al. (2017) examined the effect of walking slope and speed on muscle synergy. They were interested in finding out whether muscle synergy would change due to mechanical changes or not. Their results demonstrated that mechanical variables such as the slope and speed of walking would not change the number of synergies required for walking, but the time points of the activation of synergies and the relative weight of muscles in each synergy would be changed. These changes cause various biomechanical outputs, including changes in joint angles and muscle activity levels [23]. According to Rozumalski et al., it can be stated that cycling-induced fatigue can change the mechanics of movement in triathletes during running. It results in changes in muscle activity and kinetics and kinematics of movement. These changes at the level of the central nervous system did not cause a change in the number of muscle synergies required during running, but caused a change in the pattern of the third and fourth synergies and the relative weight of the muscles. The change of the synergy pattern is an influential factor in coordination of the muscles in the basic time events during the movement, which may increase the traumatic mechanisms after muscle fatigue. By examining muscle synergy, more insight can be gained into changes and cause and effect relationships in muscle activity after the presence of biomechanical variables such as muscle fatigue, injury, change in environmental conditions, and the use of sports equipment. According to the previous studies, it can be stated that muscle fatigue with changes in synergy tendencies and changes in weight of muscle can disrupt the coordination of muscles to perform movement and this causes injuries in triathletes. When the tendency of synergy changes after a variable such as fatigue, the pattern of using and cooperation between the muscles and calling them into action will change in the movement, and as a result, the mechanics of the movement will change.

CONCLUSION

According to our findings, it could be concluded that cycling-induced fatigue can affect the organized cooperation of the central nervous system to create synergy patterns in triathletes during running task. Consequently, disruption in synergy patterns and relative weight of muscles during running due to muscle fatigue can change the mechanics of running in triathletes and may increase injury risk.

Author Contributions: Mostafa Sepehrian has done the initial idea of reading and writing the article and laboratory work. Mehrdad Anbarian has written and prepared the initial and final draft, supervised the data collection and submitted and revised the article. Hassan Khotanlou has done coding process of the data. Behrouz Hajilou has been in charge of laboratory work and data collection.

Institutional Review Board Statement: The study protocol was approved by the ethics committee of the Bu-Ali Sina University, Hamedans, Iran (IR.BASU.REC.1400.051).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available at request.

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REFERENCES

1. Serrancolí G, Monllau JC, Font-Llagunes JM. Analysis of muscle synergies and activation–deactivation patterns in subjects with anterior cruciate ligament deficiency during walking. Clin Biomech. 2016; 31:65–73.
2. Rozumalski A, Steele KM, Schwartz MH. Muscle synergies are similar when typically developing children walk on a treadmill at different speeds and slopes. J Biomech. 2017; 64:112–9.
3. Bernstein N. The co-ordination and regulation of movements. Pergamon Press publisher, 1966.
4. Koohestani A, Kobravi HR, Koohestani M. Identifying the muscle synergy pattern during human grasping. J Biomed Eng Med Imaging. 2015;1(6).
5. Bentley DJ, Vleck VE. Pacing strategy and performance in elite world cup triathlon: a preliminary study. Med Sci Sport Exerc. 2004;36(5):S122.
6. Chapman AR, Vicenzino B, Blanch P, Dowlan S, Hodges PW. Does cycling effect motor coordination of the leg during running in elite triathletes? J Sci Med Sport. 2008;11(4):371–80.
7. Silder A, Gleason K, Thelen DG. Infeluence of bycicle seat tube angle and hand position on lower extremity kinematics and neuromuscular control: Implications for triathlon running performance. J Appl Biomech, 2011; 27: 297-305.
8. Bonacci J, Vleck V, Saunders PU, Blanch P, Vicenzino B. Rating of perceived exertion during cycling is associated with subsequent running economy in triathletes. J Sci Med Sport. 2013;16(1):49–53.
9. Coso J Del, Gonzalez-Millan C, Salinero JJ, Abian-Vicen J, Soriano L, Garde S, et al. Muscle damage and its relationship with muscle fatigue during a half-iron triathlon. PLOS, 2012; 7(8): e43280.
10. Marino GW, Goegan J. Work-energy analysis of triathletes running under bike/run and run only conditions. In: ISBS-Conference Proceedings Archive. 1993.
11. Chapman AR, Vicentzino B, Blanch P, Hodges PW. Leg muscle recruitment during cycling is less developed in triathletes than cyclists despite matched cycling training loads. Exp Brain Res, 2007; 181(3) 503-18.
12. Anbarian M, Sepehrian M, Nazem F, Hajiloo B. The Effect of Pedaling and Fatigue on Changes of Knee Muscles Co-contraction During Running in Triathletes. J Sport Biomech. 2015;1(1):5–13. (In Persian)
13. Hajiloo behrouz, Anbarian M, Jalalvand A, Mirzapour M. The effect of fatigue on Electromyography activity pattern and Co-contraction of lower limb muscle during running. Razi J Med Sci. 2018; 25(1):83–91. (In Persian)
14. Hajilou B, Anbarian M, Esmaili H, Sadeghi S. The effect of quadriceps fatigue on electromyographic activity of some knee joint muscles during stance phase of walking. 2014; 6:73-88. [In Persian]
15. Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, et al. European recommendations for surface electromyography. Roessingh research and development. 1999;8(2):13-54.
16. Anbarian M, Hajiloo B, Sepehrian M, Sadeghi S, Esmaieli H. The Effect of Quadriceps Fatigue on Co-Activation of Knee Muscles during Walking. Jundishapur Sci Med J.

2015;14(3):309–21. [In Persian]
17. Esmaeili H, Anbarian M, Salari Esker F, Hajiloo B, Sanjari MA. Long-term effects of foot orthoseson leg muscles activity in individuals with pesplanus during walking. Sci J Kurdistan Univ Med Sci. 2014;19(1):88–98. [In Persian]
18. Parijat P, Lockhart TE. Effects of quadriceps fatigue on the biomechanics of gait and slip propensity. Gait Posture. 2008;28(4):568–73.
19. Clark DJ, Ting LH, Zajac FE, Neptune RR, Kautz SA. Merging of Healthy Motor Modules Predicts Reduced Locomotor Performance and Muscle Coordination Complexity Post-Stroke. J Neurophysiol. 2010;103(2):844–57.
20. Oliveira AS, Gizzi L, Farina D, Kersting UG. Motor modules of human locomotion: influence of EMG averaging, concatenation, and number of step cycles. Front Hum Neurosci. 2014;8:335.
21. Smale KB, Shourijeh MS, Benoit DL. Use of muscle synergies and wavelet transforms to identify fatigue during squatting. J Electromyogr Kinesiol. 2016;28:158–66.
22. Hajiloo B, Anbarian M, Esmaeili H, Mirzapour M. The effects of fatigue on synergy of selected lower limb muscles during running. J Biomech. 2020;103: 109692.
23. Rozumalski A, Steele KM, Schwartz MH. Muscle synergies are similar when typically developing children walk on a treadmill at different speeds and slopes. J Biomech. 2017; 64: 112-119.

تأثیر خستگی ناشی از دوچرخه‌سواری بر سینرژی عضلات اندام تحتانی در ورزشکاران مبتدی سه‌گانه

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چکیده:

مطالعه سینرژی عضلانی روشی نوین جهت بررسی عملکرد سیستم کنترلی بدن انسان است. با توجه به نیازهای فیزیکی رشته سه‌گانه، ورزشکاران این رشته تحت تاثیر درجات مختلفی از خستگی عضلانی قرار می‌گیرند. هدف از این مطالعه تاثیر خستگی بر سینرژی عضلات اندام تحتانی ورزشکاران سه گانه مبتدی بود. شانزده دونده مرد ورزشکار سه گانه در این مطالعه نیمه تجربی شرکت کردند. فعالیت الکترومایوگرافی عضلات دوقلو، نعلی، درشت نی قدامی، راست رانی، پهن خارجی، پهن داخلی، نیم وتری و دوسر رانی قبل و پس از خستگی ناشی از رکاب زدن روی دوچرخه ثابت طی دویدن ثبت شد. جهت استخراج سینرژی عضلانی از روش‌های الگوریتم تجزیه ماتریس نامنفی استفاده شد. از روش آماری همبستگی پیرسون جهت میزان شباهت الگوهای استخراج شده و از تست تی وابسته برای مقایسه وزن نسبی عضلات قبل و بعد از پروتکل خستگی استفاده شد (P<۰/۰۵). بعد از خستگی عضلانی الگوی سینرژی اول و دوم شباهت بالا و الگوی سینرژی سوم و چهارم شباهت متوسط را نشان دادند. وزن نسبی عضله پهن خارجی (P=۰,۰۱۲) و درشت نی قدامی(P=۰,۰۲۴) بعد از خستگی عضلانی کاهش معنی داری داشت. وزن نسبی عضلات نیم وتری (P=۰,۰۱۶) و نعلی (P=۰,۰۳) بعد از خستگی عضلانی افزایش معنی داری پیدا کرد. تعداد چهار سینرژی عضلانی توسط روش شمول واریانس از داده‌های فعالیت الکتریکی عضلات قبل و بعد از خستگی عضلانی بدست آمد. خستگی عضلانی می‌تواند همکاری سازمان دهی شده دستگاه عصبی مرکزی برای ایجاد الگوهای سینرژی را در ورزشکاران سه گانه بعد از خستگی ناشی از دوچرخه سواری طی دویدن تحت تأثیر خود قرار دهد. اختلال الگوهای سینرژی و وزن نسبی عضلات طی دویدن با شرایطی نظیر خستگی عضلانی می‌تواند مکانیک دویدن را در ورزشکاران سه گانه دچار تغییر کرده و احتمال آسیب دیدگی را در این افراد افزایش دهد.

واژه های کلیدی: سینرژی عضلانی، خستگی، الکترومایوگرافی، ورزشکاران سه‌گانه