Journal of Exercise and Health Science, Vol. 02, No. 05, Winter 2022, page 17-26

Research Paper

Sex Differences in Neuromuscular Fatigability of the Vastus Medialis Oblique Muscle

Esmat Rashidi[1], Mahta Sardroodian[2], Sodabeh Mohamadian[3], Mohammad Shabani[4]

1. Kashmar Higher Education Institute, Kashmar, Iran,
2. Department of Sport Science, University of Bojnord, Bojnord, Iran
3. Department of Sport Science, University of Bojnord, Bojnord, Iran
4. Department of Sport Science, University of Bojnord, Bojnord, Iran (Corresponding Author)

Received: 2022/09/12 **Accepted: 2022/10/24**

Abstract

Background: An appropriate activity of the vastus medialis oblique (VMO) muscle is important to resist against lateral pull of the vastus lateralis (VL) muscle during knee extension. Females utilize different muscular activation patterns compared to males, and therefore their VMO adaptation to fatiguing exercise may be different from the male. The aim of this study was to investigate sex differences in neuromuscular fatigability of the VMO muscle during submaximal fatiguing sustained contraction. **Methods**: 24 subjects (12 female and 12 male) were recruited for this study. Maximal isometric voluntary contraction (MIVC), and electromyography (EMG) signals from the VMO muscle was recorded before and after fatiguing sustained contraction at the level of 50% MVIC. Root mean square (RMS) and mean power frequency (MPF) was computed from raw EMG signals. **Results**: In men, maximal isometric voluntary contraction of quadriceps muscle was significantly higher than women ($P > 0.05$). Besides, the female participants showed a longer time to task failure over fatiguing sustained contraction as compared to male ($P > 0.05$). Moreover, EMG RMS significantly increased and MPF decreased over fatiguing sustained contraction. Change in EMG RMS and EMG MPF for female was significantly larger than the male ($P > 0.05$). Women showed a greater change in EMG features for the VMO muscle as compared to men during fatiguing sustained contraction. **Conclusion**: The results indicate that VMO muscle in female is more susceptible to fatigue during a

1. Email: rashidi@ub.ac.ir
2. Email: m_sardroodian@yahoo
3. Email: mohamadian@ub.ac.ir
4. Email: rs_shabani@yahoo.com

fatiguing sustained contraction as compared to male. As a result, it may increase the risk of patellofemoral malalignment and knee injuries in females.

Keywords: Vastus Medialis Oblique, Surface EMG, Sustained Contraction, Sex Differences

Introduction

Deficits in neuromuscular activity of the vastus medialis oblique (VMO) have been reported to be associated with patellofemoral pain syndrome (PFPS) (Fagan & Delahunt, 2008). Although the causes of PFPS are not clearly understood, this syndrome is related to abnormal patellar arrangement and biomechanics, most probably due to an imbalance of VMO and VL activity (Petersen et al., 2014). A lower VMO: VL activity ratio leads to excessive lateral tracking of the patella and rubbing of the lateral femoral condyle, which causes articular surface erosion and degeneration and induces pain (Petersen et al., 2014). For example, the previous electromyographic (EMG) study reported that in healthy individuals, EMG activity for the VMO muscle was equal to EMG activity for the VL muscle (Souza & Gross, 1991), while in patients with PFPS, EMG activity for the VMO was less than VL muscle (Powers, 2000). Moreover, VMO muscle is more susceptible to fatigue, most likely due to higher percentage of fast twitch motor unit within this muscle (Hedayatpour, 2012, 2007; Nasrabadi et al., 2018). Muscle fatigue can reduce neural drive from higher motor centers to muscle fiber, as assessed by measuring balance and/ or by examining EMG activity of the skeletal muscle (Hedayatpour et al, 2008, 2014). After an exercise program designed to induce muscular fatigue, healthy individuals have demonstrated reduction in balance ability, suggesting that fatigue results in motor control deficits (Wright et al., 2013). EMG studies suggest that, additionally, to balance, muscle fatigue affects muscle activity by increasing the latency of muscle firing and by resulting in less efficient muscular processes (Hedayatpour et al, 2008, 2009). There are also sex differences in the fatigability of skeletal muscle (Miller et al., 1993). Therefore, it is expected that VMO muscle in female show different adaptation to fatiguing sustained contraction with respect to male. We were particularly interested in determining whether fatigue would be more pronounced in females than in males participating in fatiguing sustained contraction. This knowledge may be useful to understand the mechanisms underlying knee injuries in female after fatiguing exercise.

Methods & Materials

Participants: 12 male (age, mean ± SD, 21.3 ± 2.3 yr, body mass 74.3 ±5.9 kg, height 1.75 ± 0.06 m) and 12 female subjects (age, mean ± SD, 20.4 ± 2.5 yr, body mass 65.3 ±4.9 kg, height 1.64 ± 0.05 m) were selected for this study. All subjects were right leg dominant and were not involved in regular exercise of their quadriceps muscle for at least one year before the experiment. The study was conducted in accordance with the Declaration of Helsinki, approved by the Local Ethics Committee at University of Bojnord, and written informed consent was obtained from all subjects prior to inclusion.

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 (Simens, 500 Kg.). 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 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.

Isometric fatiguing sustained contraction: Participants also performed submaximal isometric knee extension contraction at 50% MIVC sustained until task failure, with the participant at the same position as in the MIVCs. The submaximal force was defined relative to the highest MIVC measured on the same session of the test. Task failure was defined as a drop in force > 5% MIVC for > 5s after strong verbal encouragement to the subject to maintain the target force value.

Surface electromyography (EMG): Surface EMG signals was recorded from the VMO muscle of the right leg during fatiguing sustained contraction at 50% MIVC (Figure 1). Two pair electrodes (circular Ag–AgCl surface electrodes (Ambu Neuroline, conductive area 28 mm2) were carefully placed in bipolar configuration (2-cm interelectrode distance) on the VMO muscle. Muscle tissue for the VMO muscle was determined by palpating 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 10–500 Hz), sampled at 2048 Hz, and stored after 12-bit A/D conversion. A ground electrode was placed around the right ankle.

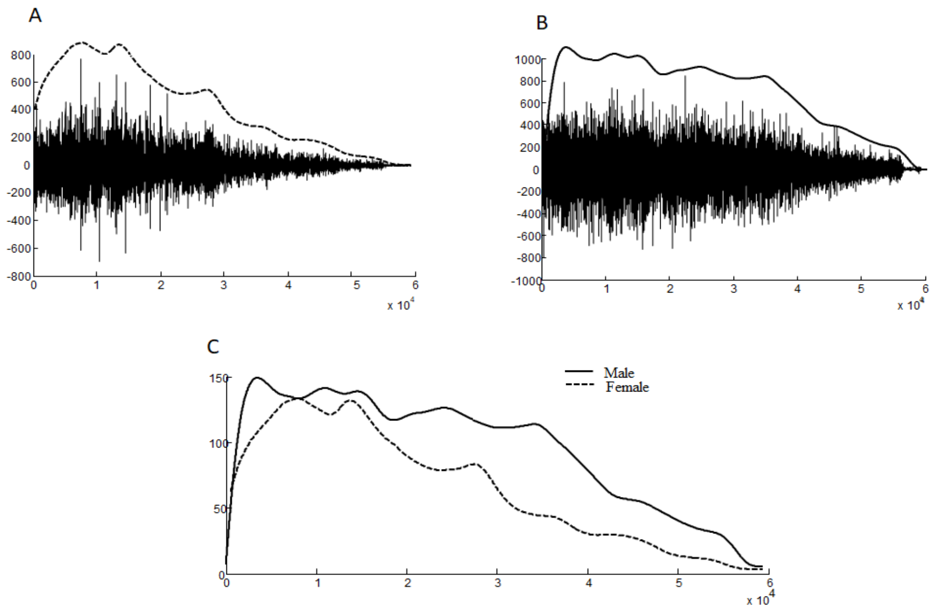

Figure 1. Bipolar surface EMG signals recorded from VMO muscle for one female subject (A) and one male subject (B). Dashed and solid lines show change in EMG envelop over time. Change in EMG envelop for male and female overlapped (C).

Signal analysis: Surface EMG signals were divided into epochs of duration 10% of the time to task failure. Root mean square (RMS) and mean power spectral frequency (MPF) were estimated from raw EMG signals for epochs of 250ms. The values obtained from 250ms-long epochs in intervals of 10% of the time to task failure were averaged to obtain one representative value for each 10% interval. This was done to compare subjects that had different times to task failure. To compare changes among subjects, the percentage change calculated as follow:
Statistical analysis: One-way analysis of variance (ANOVA) was applied to compare maximal isometric voluntary contraction and time to task failure between male and female. Moreover, one-way ANOVA was used to assess percent change in EMG RMS and EMG MPF (percent change from the initial to the last interval) with sex as independent factor.

$$\text{Percent change} = \frac{\text{Last Interval} - \text{Initial Interval}}{\text{Initial Interval}} \text{ X } 100$$

Results

A significant difference was observed for both maximum force ($F=8.5$, $p < 0.001$) and time to task failure ($F=12.0$, $p < 0.0001$) between female and male, in which male produced a higher maximum knee extension force and female showed a longer time to task failure ($p < 0.05$). Moreover, for both male and female, maximum knee extension force significantly decreased after fatiguing sustained contraction ($p < 0.05$). Additionally, EMG RMS for the VMO muscle measured from both male and female significantly increased over time during fatiguing sustained contraction. The percentage of increase in RMS (in the final epoch with respect to the initial epoch) for female was significantly higher than the male ($F=3.2$, $p < 0.05$, Figure 1).

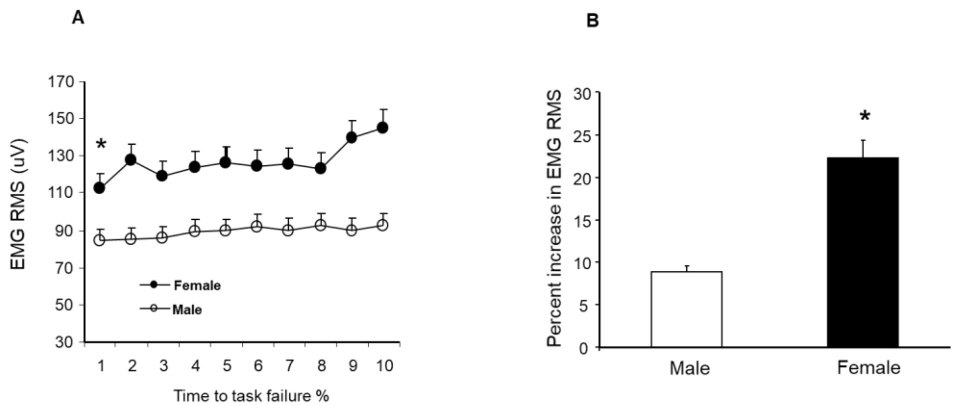

Figure 2: Change in root mean square (RMS) of EMG over 10 intervals (10% of the time to task failure; A), and associated percent change (percent change from the first to the last interval, B) over fatiguing sustained contraction. Asterisk (*) indicates differences in EMG RMS changes from the first to the last interval between female and male (P <0.05).

Mean power frequency of EMG measured from both male and female decreased significantly over time during fatiguing sustained contraction. The percentage of decrease in MPF (in the final epoch with respect to the initial epoch) for female was significantly larger than the male ($F=3.7$, $p < 0.05$, Figure 2)

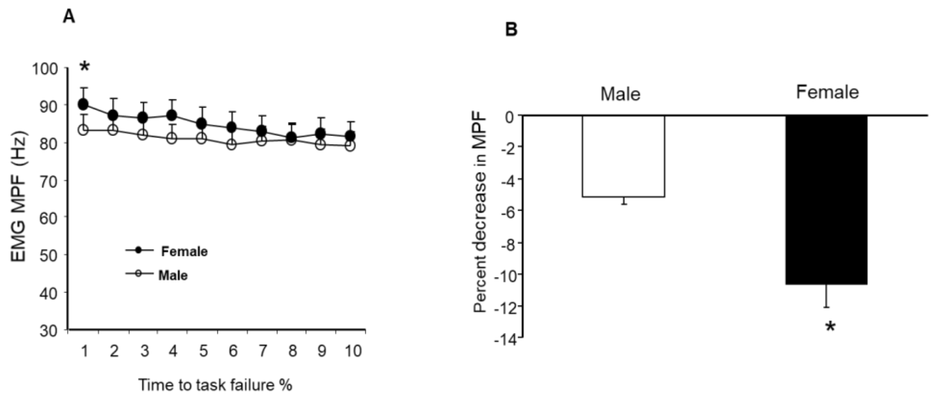

Figure 3: Change in mean power frequency (MPF) of EMG over 10 intervals (10% of the time to task failure; A), and associated percent change (percent change from the first to the last interval, B) over fatiguing sustained contraction. Asterisk (*) indicates differences in EMG MPF changes from the first to the last interval between female and male (P <0.05).

Discussion

The purpose of this study was to determine whether females and males demonstrate differences in VMO muscle activity during fatiguing sustained contraction. The main finding of the present study showed that the VMO muscle in female reflected a larger increase in EMG RMS and greater reduction in EMG MPF as compared to male during fatiguing sustained contraction. The results indicates that, VMO muscle in female is more susceptible to fatigue during a fatiguing sustained contraction than male. As a result, it may increase the risk of knee injuries in females.

Muscle Function: in male generated a greater isometric knee extension force during maximal isometric contraction than the female. However, female reflected a long time to task failure during submaximal sustained contraction with respect to male (Hunter et al., 2001). The previous studies also reported a greater voluntary force production (absolute units) in males than females, confirming the findings of the present study (Miller et al., 1993). Maximal isometric voluntary contraction of quadriceps measured after fatiguing sustained contraction reduced significantly for both female and male, indirectly indicating the decreased capacity of quadriceps muscle to generate force (Hedayatpour et al., 2014). Muscle force-generating ability depends upon many factors, such as muscle mass, muscle fiber type, and muscle activation characteristics (Miller et al., 1993,). This ability has been shown to be significantly higher in males than females (Hedayatpour & Falla, 2015), and is considered to be a reflection of greater muscle mass, a higher percentage of fast-twitch muscle fibers (Hedayatpour & Falla, 2015) and a sex-specific pattern of muscle recruitment (Simoneau & Bouchard, 1989).

Electromyography*:* The results showed that MPF decreases and RMS increases along with time for both sexes during the fatiguing sustained knee extension contraction. However, female reflected a higher increase in EMG RMS and a greater reduction in MPF for the VMO muscle during fatiguing sustained contraction as compared to the male. A higher increase in EMG RMS over fatiguing sustained contraction can be explained by increasing motor unit recruitment and/or discharge rate required to compensate for contractile failure caused by fatigue (Cioni et al., 1994). However, reduction in MPF over fatiguing sustained contraction is attributed to a reduction in muscle fiber conduction velocity and muscle fiber membrane excitability. This shift of the frequency spectrum of the myoelectric signal during sustained contractions, together with an increase in EMG amplitude, has been reported in several other studies (Kirsch & Rymer, 1992). Therefore, change in mean power frequency (MPF) has been confirmed as reliable indicators of muscle fatigue during sustained contractions.

Sex Differences in VMO Fatigability

EMG manifestation of the VMO muscle showed a greater neuromuscular fatigue in female as reflected by a higher increase in EMG amplitude and a greater reduction in MPF over fatiguing sustained contraction. A higher VMO fatigability in female may be explained by sex differences in synergic muscle activity. It has been reported that females utilize different muscular activation patterns compared to males. For example, the previous studies reported sex differences in hip muscle activity during single-leg landing (DeVries et al., 1968). Similarly, Clark et al (21) reported females achieve an overall greater relative activation of the quadriceps femoris at task failure than men. The Previous studies also revealed that knee pain occurs in female more than twice as frequently as in men, most probably due to differences in the modulation of muscles which control patellar tracking (Boling et al., 2010). Additionally, it has been shown that, motor unit recruitment and motor unit discharge patterns of the VM and VMO are different between sexes (Tenan et al., 2013). The observed differences in VMO activation between men and women indicate that cortical control of vastus medialis complex sub-sections may allow for differential activation of the VM and VMO. The sexual dimorphism of vastus medialis complex neuroanatomy may predispose women to higher activation and injury.

In female, a higher increase in VMO activity during fatiguing sustained contraction results in high accumulation of metabolites and as a result, increases neuromuscular fatigue. The increased neuromuscular fatigue within the VMO muscle may abolish the ability of VMO to counteract the lateral pull of the VL muscle during knee extension (24), thereby leaving the knee complex more vulnerable to injuries (Hedayatpour et al, 2011, 2014).

The previous investigations have reported the prevalence of PFPS in females to be as high as two times that of males (Taunton et al., 2002). Fulkerson and Arendt (27) reported that patellofemoral pain is the most common chronic injury in athletic populations and female athletes are considered to be at much greater risk from this pathology. Therefore, it may be important to decrease the risk of patellofemoral pain syndrome in females via strengthening the VMO muscle.

Conclusion

EMG manifestation of the VMO muscle showed a higher neuromuscular fatigue in female than male. A higher neuromuscular fatigue of the VMO muscles can reduce the ability of this muscle to counteract the lateral pull of the VL, and consequently, increase the risk of patellofemoral malalignment. Therefore, strengthening the VMO muscle may be important to prevent from patellofemoral malalignment and as a result, decrease the risk of patellofemoral pain syndrome among females.

Conflict of Interest

There is no conflict of interest concerning this article.

Funding: No funding was received for this study

Author contributions: All authors discussed the results and contributed to the final manuscript.

Acknowledgement: I would like to thank all the participants that contributed to this research.

References

1. Boling, M., Padua, D., Marshall, S., Guskiewicz, K., Pyne, S., Beutler, A. (2010). Sex differences in the incidence and prevalence of patellofemoral pain syndrome. Scand J Med Sci Sports, 20(5):725-30.
2. Cioni, R., Giannini, F., Paradiso, C., Battistini, N., Navona, C., Starita, A. (1994). Sex differences in surface EMG interference pattern power spectrum. J Appl Physiol, 77(5):2163-8.

3. Clark, B.C, Collier, S.R., Manini, T.M., Ploutz-Snyder, L.L. (2005). Sex differences in muscle fatigability and activation patterns of the human quadriceps femoris. Eur J Appl Physiol, 94(1-2):196-206.
4. DeVries, H.A. (1968). "Efficiency of electrical activity" as a physiological measure of the functional state of muscle tissue. Am J Phys Med, 47(1):10-22.
5. Fagan, V., Delahunt, E. (2008). Patellofemoral pain syndrome: a review on the associated neuromuscular deficits and current treatment options. Br J Sports Med, 42(10):789-95.
6. Fulkerson, J.P., Arendt, E.A. (2000). Anterior knee pain in females. Clin Orthop Relat Res, (372):69-73
7. Hedayatpour, N., Arendt-Nielsen, L., Falla, D. (2014). Facilitation of quadriceps activation is impaired following eccentric exercise. Scand J Med Sci Sports, 24(2):355-62.
8. Hedayatpour, N., Arendt-Nielsen, L., Farina, D. (2007). Motor unit conduction velocity during sustained contraction of the vastus medialis muscle. Exp Brain Res, 180(3):509-16.
9. Hedayatpour, N., Arendt-Nielsen, L., Farina, D. (2008). Non-uniform electromyographic activity during fatigue and recovery of the vastus medialis and lateralis muscles. J Electromyogr Kinesiol, 18(3):390-6.
10. Hedayatpour N., Falla D. (2014) Delayed onset of vastii muscle activity in response to rapid postural perturbations following eccentric exercise: a mechanism that underpins knee pain after eccentric exercise? Br J Sports Med, 48(6):429-34.
11. Hedayatpour, N., Falla, D. (2012). Non-uniform muscle adaptations to eccentric exercise and the implications for training and sport. J Electromyogr Kinesiol. 22(3):329-33.
12. Hedayatpour, N., Falla, D. (2015). Physiological and Neural Adaptations to Eccentric Exercise: Mechanisms and Considerations for Training. Biomed Res Int, 2015:193741.
13. Hedayatpour, N., Falla, D., Arendt-Nielsen, L., Farina, D. (2008). Sensory and electromyographic mapping during delayed-onset muscle soreness. Med Sci Sports Exerc, 40(2):326-34.
14. Hedayatpour, N., Falla,D., Arendt-Nielsen, L., Vila-Chã, C., Farina, D. (2009). Motor unit conduction velocity during sustained contraction after eccentric exercise. Med Sci Sports Exerc, 41(10):1927-33.
15. Hedayatpour, N., Hassanlouei, H., Arendt-Nielsen, L., Kersting, U.G., Falla, D. (2011). Delayed-onset muscle soreness alters the response to postural perturbations. Med Sci Sports Exerc, 43(6):1010-6.
16. Hunter, S.K., Evoke, R.M. (2001). Sex differences in the fatigability of arm muscles depends on absolute force during isometric contractions. J Appl Physiol, 91(6): 2686-94.

17. Kirsch, R.F., Rymer, W.Z. (1992). Neural compensation for fatigue-induced changes in muscle stiffness during perturbations of elbow angle in human. J Neurophysiol, 68(2):449-70.
18. Miller, A.E, MacDougall, J.D., Tarnopolsky, M.A., Sale, D.G. (1993). Sex differences in strength and muscle fiber characteristics. Eur J Appl Physiol Occup Physiol, 66(3):254-62.
19. Nasrabadi, R., Izanloo, Z., Sharifnezad, A., Hamedinia, M.R., Hedayatpour, N. (2018). Muscle fiber conduction velocity of the vastus medilais and lateralis muscle after eccentric exercise induced-muscle damage. J Electromyogr Kinesiol, 43: 118-126.
20. Petersen, W., Ellermann, A., Gösele-Koppenburg, A., Best, R., Rembitzki, I.V., Brüggemann, G.P., Liebau, C. (2104). Patellofemoral pain syndrome. Knee Surg Sports Traumatol Arthrosc, 22(10):2264-74.
21. Powers, C.M. (2000). Patellar kinematics, part I: the influence of vastus muscle activity in subjects with and without patellofemoral pain. Phys Ther, 80(10):956-64. PMID: 11002431.
22. Simoneau, J.A., Bouchard, C. (1989). Human variation in skeletal muscle fiber-type proportion and enzyme activities. Am J Physiol, 257(4 Pt 1): E567-72.
23. Souza, D.R., Gross, M.T. (1991). Comparison of vastus medialis obliquus: vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. Phys Ther, 71(4):310-6.
24. Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R., Zumbo, B.D. (2002). A retrospective case-control analysis of 2002 running injuries. Br J Sports Med, 36(2):95-101.
25. Tenan, M.S., Peng, Y.L., Hackney, A.C., Griffin. L. (2013). Menstrual cycle mediates vastus medialis and vastus medialis oblique muscle activity. Med Sci Sports Exerc, 45(11):2151-7.
26. Wright, K.E., Lyons, T.S, Navalta, J.W. (2013). Effects of exercise-induced fatigue on postural balance: a comparison of treadmill versus cycle fatiguing protocols. Eur J Appl Physiol, 113(5):1303-9.
27. Zazulak, B.T., Ponce, P.L., Straub, S.J., Medvecky, M.J., Avedisian, L., Hewett, T.E. (2005). Sex comparison of hip muscle activity during single-leg landing. J Orthop Sports Phys Ther, 35(5):292-9.