Journal of Research in Medical and Dental Sciences
2018, Volume 6, Issue 3, Page No: 258-267

Available Online at: www.jrmds.in
eISSN No. 2347-2367: pISSN No. 2347-2545

Fatigue Induced Effects after Concentric versus Eccentric Exercises on Sense of Force and Senses of Position among Young Normal Adults- A Controlled Single-Blinded Study

Parvin Shokri [1], Fariba Eslamian[1], Seyed Kazem Shakouri[1], Silva Ohanian [2], Fatemeh Jahanjoo[1]*

[1]Aging Research Institute, Physical Medicine and Rehabilitation Research Center, Tabriz University of Medical Sciences, Tabriz, Iran
[2] Providence Saint Joseph Medical Center. Epidemiology Department. 501 S Buena Vista St. Burbank, CA, USA

DOI: 10.24896/jrmds.20186340

ABSTRACT
Although knee joint proprioception could be affected by muscle contractions, knowledge on muscle fatigue during sports and work activities is limited. This study was aimed to identify the effect of the quadriceps muscle fatigue during concentric and eccentric contractions on knee joint proprioception. Twenty healthy women with mean age of 20.45 ± 1.36 years old performed concentric contractions at first set. One week later, eccentric training was carried out during fatigue protocol. Force Sense, position sense, and knee stability were measured before and after both concentric/eccentric contractions by feedback and non-feedback procedures utilizing Biodex Isokinetic Dynamometer, double-armed goniometer, and centimeter, respectively. There was a significant increase in force sense error and position sense error following eccentric contractions (p = 0.025, p = 0.038). However, concentric contractions only affected position sense (p = 0.028). Position sense improved after concentric contractions, while it was deteriorated following concentric contractions (p = 0.002). There was no evidence of a difference between protocols regarding knee stability. Eccentric contractions addresses lessen in the knee joint proprioception with regard to the sense of force and sense of position. Therefore, eccentric contractions deserve a lot more attention by the athletes because it can be a secret weapon for creating healthier joints.

Key words: Proprioception, Knee Joint, Sense Force, Sense Position, Stability.

HOW TO CITE THIS ARTICLE: Parvin Shokri, Fariba Eslamian, Seyed Kazem Shakouri, Silva Ohanian, Fatemeh Jahanjoo*, Fatigue Induced Effects after Concentric versus Eccentric Exercises on Sense of Force and Senses of Position among Young Normal Adults- A Controlled Single-Blinded Study, J Res Med Dent Sci, 2018, 6(3): 258-267, DOI: 10.24896/jrmds.20186340

Corresponding author: Fatemeh Jahanjoo
E-mail✉: f.jahanjou@yahoo.com
Received: 25/01/2018
Accepted: 15/04/2018

INTRODUCTION

The participation of women in intercollegiate sports and their interest in sports such as soccer and basketball which are more popular among men, has led the world to have a fresh perspective at this issue and provide the necessary accommodations for their better and healthier activities [1].
As it is widely believed musculoskeletal injuries are influenced more by the type of sport than gender-differences during sports competitions [2]. However, the differences in the incidence of injuries and the severity of knee injuries among men and women have recently been studied [3, 4].
Considering the special physical structure of female and the nature of sports competitions, it can be concluded that joint injuries are more common in female athletes, particularly the injuries involving the knee [5]. The rate of injuries for female athletes is reported to be 2 - 8 times higher than for their male counterparts [6]. Therefore, it is essential to develop sports injury prevention strategies, especially for women [7].
The Knee joint injuries are one of the most common injuries in sports competitions [8]. Nervous muscle control and knee dynamic stability are very important factors in preventing joint injury. The dynamic stability of the joint is a

complex phenomenon that is influenced by various factors such as joint mechanical inhibitors, muscular strength and endurance, proprioception, neural control, and extra.

The proprioception involves afferent information that is derived from sensory nerve endings in the skin, joint, and in particular the muscular mechanoreceptors, which are sent to the central nervous system and used for the sense of position, sense of movement and sense of force [9, 10].

Consequently, the analysis of the reproduction of the force sense and the position sense is one of the most commonly used tests to assess proprioception. The accuracy of the reproduction of the joint force sense and position sense is measured by feedback and non-feedback procedures [11, 12]. Furthermore, reduced proprioception may lead joint instability and is associated with the occurrence of injuries during sports and exercise [13].

One of the major factors influencing the proprioception is muscles fatigue [14, 15]. Muscle fatigue is defined as physical performance impairment that increases the perception of effort necessary to exert a specific force [15]. All physical activities, depending on intensity and duration, can generate some degree of muscle fatigue [16]. It is widely believed that muscle fatigue is a limiting and intrusive factor that increases the risk of musculoskeletal injuries during the latter stages of athletic activity [17].

Up to now, many researchers have studied the effect of muscle fatigue on proprioception of the joints. Several studies reported that fatigue affects proprioception, and some reported no effect. Thus, conflicting effects have already been found in this field. Variety types of fatigue, their mechanisms and different effects on proprioception in previous studies provide the need for further researches [11]. On the other hand, there is a difference on joint proprioception following muscle fatigue induced by either concentric or eccentric exercise. Studies have shown that after severe eccentric exercise, the muscle is more vulnerable and also more inclined to be painful [15, 18, 19]. Therefore, this study aimed to evaluate the effect of quadriceps muscle fatigue during the concentric and eccentric contractions on the knee joint proprioception major components, called knee sense of force and sense of position, as well as knee joint stability.

MATERIALS AND METHODS

Study Design

In this quasi-experimental crossover study the effect of quadriceps muscle fatigue during the concentric and eccentric contractions was assessed on the sense of force, sense of position and stability of the knee in normal and healthy women. Since aging process and joint diseases have been shown to affect the sense of force and sense of position, a young healthy case group without joint disease was chosen [20]. Also due to the change in the type of women's favorite sports, and considering women physical structure that makes joint injuries to be more common in female [21], only women were enrolled in this study.
This was a randomized, cross-over study design in which all participants completed two exercise sessions. The two sessions were separated by one week. One session involved the use of traditional, concentrically focused resistance exercise machines (CON RX; MedX®) and the second session involved exercise with modified MedX® machine that enhances the eccentric phase of contraction (Figures 1a and 1b). This was the eccentrically focused resistance exercise (ECC RX). The testing order was balanced and randomized. Participants received sealed envelopes with the assigned testing order.

Research ethics

The study procedure was in accordance with the ethical standards of the local Committee on Human Experimentation and approved by the Research Ethics Committee of the Tabriz University of Medical Sciences. The study ethical code was IR. TBZMED.REC.1395.275. Before participating in the project, the aims of the study was explained to all of the participants and written informed consent was obtained. The participants were allowed to withdraw from the study at any stage.

Blinding

The physician who assessed the participants and data analysts were kept blinded to the participants' assigned group. To preserve the blinding of clinical outcome assessor, participants were requested not to disclose details about their treatment assignment to the blinded outcome assessor.

Sample size

According to the literature [19] and considering the sense of force as the primary outcome, for a power of 90%, α = 5% (2 sided), the sample size was estimated, 18 people. Considering 10% as last to follow up rate, the final sample size was determined, 20 people.

Participants

A convenience 20 healthy young women in the age range of 18 to 23, were recruited and evaluated in the physical medicine and rehabilitation research center of a university hospital between March 2015 and April 2016. All participants were right - leg dominant. The average body mass index (BMI) was 21.86 ± 2.24 (range 17.37-25.99). Each participant acted as his own control.

The inclusion and exclusion criteria consisted of the following: no surgical history in lower organs, no history of knee pain and neuromuscular complications, no fractured or broken bone or any neural injury in knee or thigh muscles, no insulin-dependent diabetes mellitus [22].

As the practice of regular muscle endurance activity clearly increases the sensitivity of the spindles and therefore proprioception [23], the type of physical activity of these women been taken into account. Also age control was an important element in this analysis because we know that this is an important risk of bias in the extent of proprioception [24].

Intervention Protocol

Each participant carried out the warm-up to cool-down phases of the study in two stages: Stage1, before and after concentric contractions, and Stage2, before and after eccentric contractions.
These phases consisted of: warm-up (WU), eyes-open pre-treatment measurements (EO-Pr.TrM), eyes-closed pre-treatment measurements (EC-Pr.TrM), fatigue Protocol (FP), eyes-open post-treatment measurements (EO-Po.TrM), eyes-closed post-treatment measurements (EC-Po.TrM), and cool-down (CD). Testing took place on two separate days with at least 1 week between testing stages. Seven phases were performed utilizing concentric contractions at first set and one week later, eccentric training was carried out during the fatigue protocol. Participants performed an initial 10 minute warm up, and were instructed to do stationary cycling and strength exercises. Then, they were asked to sit on a chair and to prevent extra and unnecessary movements, the individual's body and thighs were fastened to the chair by resistance pad, which was placed on the intersection of 80% and 20% of the length of the participant's lower leg [19]. The eyes- closed phases was omitted in measuring knee stability.

Measuring Sense of force

The evaluation of the force sense was accomplished using the Biodex Isokinetic Dynamometer [Biodex Medical Systems, Shirley, New York]. Initially pre-determined random angle (45 °, 60°, or 75° of knee flexion), assigned to each individual.

Then the participants were requested to produce voluntary force using visual feedback from the monitor in three repetitions and the data were recorded (EO-Pr.TrM). The dynamometer presented the estimated force generated by the participants through a torque-time curve. Participants were requested to concentrate on the amount of the producing muscle force. With 60 seconds rest interval (to decrease the force matching errors), they were requested to reproduce the target force without the visual feedback from the monitor in three repetitions and the data were recorded (EC-Pr.TrM). The average of all force production in three repetitions at EO-Pr.TrM phase was recorded as feedback force data and that at EC-Pr.TrM phase was recorded as non-feedback force data. The absolute difference between the two values (| (non-feedback force data) – (feedback force data) |) was defined as the absolute force sense reproduction error in Newton-meters (N.m). All evaluations, before and after concentric and eccentric contractions, were measured as explained above [19, 22].

Measuring Sense of Position

The Sense of position data also was collected using the Biodex Isokinetic Dynamometer [Biodex Medical Systems, Shirley, New York]. Although it is well known that the sensitivity is much better in the prone position for repositioning test, but in order to be able to make feedback and non-feedback assessments, this test was performed in a sitting position [25].

Initially, each individual's dominant leg moved passively by the examiner to the pre-determined random angle (either 45°, 60°, or 75° of knee flexion) [26], verifying this measurement using the double-armed goniometer, and considering this angle as the anatomic joint reference. After holding the leg in this position for 2 to 4 minutes, the examiner moved back the leg to the starting position and the participant was then requested to return the leg to the position at which it had originally been placed by the examiner. After familiarization process in which the participant produced the target position three times, participants were requested to reposition the leg at the reference position with open eyes and inform the examiner if they thought they were at the reference position. The procedure was repeated three times (EO-Pr.TrM). With 60 seconds rest interval, participants were instructed to reposition the leg at the reference position with closed eyes for three trails (EC-Pr.TrM). Feedback position data and non-feedback position data was recorded as the average of three repetitions at EO-Pr.TrM and EC-Pr.TrM phases, respectively. The absolute difference between non-feedback position data and feedback position data (| (non-feedback position data) – (feedback position data) |) was defined as the absolute position sense reproduction error in degree. All evaluations, before and after concentric and eccentric fatigue protocols were measured as explained above [27].

Measuring Knee Stability

The stability of the knee was assessed during the single leg hope test. Each participant performed two practice trials for familiarization purposes. The practical performance was assessed by a single-leg hop test by which the participant must stay on a single leg and put her toes to a mark on the floor. Then the participant jumps ahead as far as possible and lands on the same leg.

The participant permitted to move her hands around freely as she jumped. The exact distance, in centimeters (cm), was measured from the toe in the starting position to the heel wherever the participant landed. A jump was just considered as successful jump if the participant was able to keep his foot in position while balancing on a single leg (i.e. no additional jump was permitted) until the investigator had documented where the participant had landed. Failure to do so resulted in a re-hop. The test was performed until three successful hops were obtained for each leg, with the dominant leg. The average of three functional repetitions was considered as final measurement. All evaluations, before and after concentric and eccentric exercises, were documented as explained above [28].

Measuring Muscle Fatigue

According to the literature, torque production was utilized to assess fatigue in the quadriceps muscle. This maximum amount of torque that is produced by the muscle group is defined as its peak torque. In the literature, peak torque was often measured by taking the average of a given number of maximal muscular contractions. Participants performed predetermined random knee flexion/extension repetitions with the dominant leg at a speed of 180 degrees per second (°/s) on an isokinetic dynamometer [29]. In this study, an isokinetic muscle fatigue was determined when there was a 50% decline in the peak torque from baseline to the end of the exercise protocol [20, 30].

Statistical analysis

Version 16 of SPSS software for Windows (Chicago, IL, USA) was used for all statistical tests. Data were checked for normal distribution using Shapiro-Wilk test and variance homogeneity using Levene’s test. The data were presented as frequencies and percentages for categorical data and mean and standard deviation for continues data. Nonparametric data were reported with median (25th percentile-75th percentile).

Mann-Whitney U Test was used for intergroup comparisons and Wilcoxon Signed Rank Test was used for intragroup comparisons.

The change for each variable was the difference between follow-up values and baseline values (follow-up – baseline). A p-value of <0.05 was considered statistically significant and the Graphpad Prism Software No. 6 was used to draw the graphs.

RESULTS

Twenty females were included in the study who had a mean age of 20.45 ± 1.36 years old (18 - 23 yrs) and mean body mass index of 21.86 ± 2.30 kg/m^2. Participants’ demographic and baseline information are shown in Table 1, where both groups were found to be similar with respect to baseline characteristics.

Table 2 shows measured parameters before and after intervention in each study group. At the baseline, the median absolute force sense reproduction error was 7.46 (1.40 – 13.11)-newton meter (N.m.) which changed to 7.23 (2.33 – 8.46)-N.m after concentric contractions.

However, such decrease was not statistically significant (p-value = 0.799). The median absolute force sense reproduction error in the eccentric group was 6.19 (3.36 – 14.37)-N.m. in pre-training assessment and increased to 13.89 (8.06 – 21.06) at post-training assessment.

Table 1:Participants' demographic characteristics at baseline

Group / Variables	Concentric (N=20)	Eccentric (N=20)	P-value
Age	20.45 ± 1.36		NA
BMI[a], kg/m²,	21.86 ± 2.30		NA
<25, n (%)	17 (85.0%)		
26-30, n (%)	3 (15.0%)		
Absolute force sense reproduction error (N.m)†	7.46 (1.40 – 13.11)	6.19 (3.36 – 14.37)	0.583 ‡
Absolute position sense reproduction error (degree)†	4.50 (4.00 – 7.33)	3.00 (1.33 – 7.00)	0.081 ‡
Stability (cm)	95.50 (70.58 – 123.50)	98.00 (72.28 – 122.50)	> 0.999 ‡

*The values are mean and standards of Error, frequency (percentage) or median (25th percentile-75th percentile); a BMI: body mass index; NA, not applicable; † The error term is calculated by subtracting feedback measurement from non-feedback measurement (| (non-feedback force data) – (feedback force data) |); ‡ Result from Mann-Whitney U Test.

Table 2: Force sense and position sense errors and knee stability during the study in Concentric and Eccentric Contractions

Group / Variables	Concentric (N=20)	P-value	Eccentric (N=20)	P-value
Absolute force sense reproduction error (N.m)				
Baseline	7.46 (1.40 – 13.11)	0.799 †	6.19 (3.36 – 14.37)	0.025 †
Follow-Up	7.23 (2.33 - 8.64)		13.89 (8.06 – 21.06)	
Absolute position sense reproduction error (degree)				
Baseline	4.50 (4.00 – 7.33)	0.028 †	3.00 (1.33 – 7.00)	0.038 †
Follow-Up	2.00 (1.08 – 6.25)		10.00 (3.00 – 15.72)	
Stability (cm)				
Baseline	95.50 (70.58 – 123.50)	0.911 †	98.00 (72.28 – 122.50)	0.433 †
Follow-Up	103.16 (79.33 – 119.50)		107.66 (83.08 – 120.83)	

* The values are median (25th percentile-75th percentile); ‡ Result from Wilcoxon Signed Rank Test; † The error term is calculated by subtracting feedback measurement from non-feedback measurement (| (non-feedback force data) – (feedback force data) |)

The force sense reproduction error significantly increased in eccentrically trained participants from 6.19 (3.36 – 14.37)-N.m. to 13.89 (8.06 – 21.06)-N.m. (p = 0.025, Fig. 1).

Following concentric contractions, a significant decrease in joint absolute position sense reproduction error was observed (p = 0.028), while participants were less accurate in their joint repositioning after eccentric contractions (p = 0.038, Fig. 3).

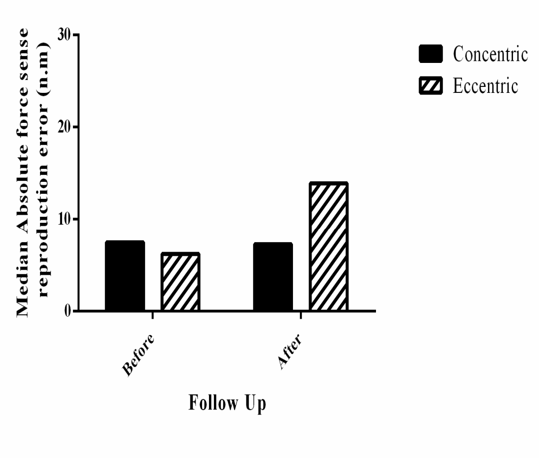

Figure 1: The comparison of median absolute force sense reproduction error before and after contraction in both study groups

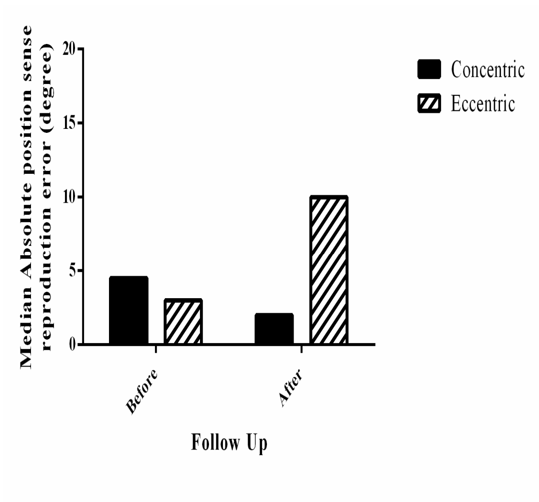

Figure 2. The comparison of median absolute position sense reproduction error before and after contraction in both study groups

These results indicated that both concentrically and eccentrically trained participants increased their jump height, however it was not statistically significant (p = 0.911 and p = 0.433, respectively). Table 3 presents the absolute changes in both groups after the intervention. The reported amount of force sense impairment in eccentrically trained participants was significantly greater than that of concentrically trained ones (p = 0.043). The absolute position sense reproduction error was considerably improved after concentric contractions, while it was deteriorated following concentric contractions (p = 0.002). In addition, the eccentric group recorded higher jump as compared to the concentric group, however, it was not statistically significant (-2.83 VS 5.83, p = 738). (Table 3).

Table 3: Comparison of the effect of Concentric Contraction vs. Eccentric Contraction on the force sense and position sense errors and knee stability

Group / Variables	Concentric (N=20)	Eccentric (N=20)	P-value
Absolute force sense reproduction error Changes† (N.m**)**	-0.06 (-7.41, 8.97)	5.56 (-.16, 18.73)	0.043 ‡
Absolute position sense reproduction error Changes† (degree**)**	-200 (-5.16, – 0.33)	6.10 (-1.92, 13.33)	0.002 ‡
Stability Changes† (cm**)**	-2.83 (-8.25, 12.67)	5.83 (-9.67, 16.50)	0.738 ‡

*The values are median (25_{th} percentile, 75_{th} percentile); † The changes term for each variable is the difference between follow-up values and baseline values (follow-up – baseline); ‡ Result from U-Mann Whitney test

DISCUSSION

This study was designed to determine whether quadriceps muscle fatigue impairs sense of force and position reproduction and stability of knee joint, or not. The ultimate aim was to test whether produced effects of concentric exercises differ from eccentric exercises, or not.

Due to the critical role of proprioception in daily activities such as waking up the sitting position and going up and down the stairs, particular attention was paid to effects of quadriceps muscle fatigue during concentric and eccentric contractions on proprioception.

Effect of concentric and eccentric fatigue on sense of force

Obtained results showed that fatigue exacerbates force sense reconstruction error. This response was expected because muscle fatigue has been shown to adversely alter joint proprioception [31]. In this study, sense of force reproduction error was significantly higher in eccentric contractions compared to the concentric contractions. Studies on different authors also verified that fatigue reduced the ability to reproduce sense of force, especially in eccentric quadriceps-muscle exercises [22, 32].

It should be noted that the ability to reproduce force is directly related to motor unit recruitment and firing frequency [33] and obviously if loads increase, the difficulty of the task also increases. The decreased force following eccentric exercise apparently leads to more effort required to maintain the same target force. This sensation probably explains the increase in error in the force sense. It is still unknown how exercise-induced muscle damage affects the function of the Golgi tendon organs and their ability to perceive the generated force.

In fact, the sensation of force arises from the sense of the tendon which generated by afferent feedback from the muscle. Indeed the receptors responsible for providing the peripheral information necessary to sense force are involved. However, the importance of the central mechanism in the sense of effort cannot be disregarded [32].

In similar studies, it had been discovered that the lengthening of a muscle during an eccentric contraction is spread heterogeneously so that some, weaker sarcomeres within the contracting muscle fibers take up a large portion of the length and become overextended. If sarcomere disruption following overextension is not too severe, reinter digitation and normal recovery function is possible. Some sarcomeres, however, cannot recover their regular banding structure, particularly after severe eccentric contractions. This procedure causes developing areas of irreversible injury which increase as the exercise continues [34]. As mentioned above, these results suggest that muscle fatigue after eccentric contractions seem to have a larger effect on impairment of proprioception compared to concentric ones.

Effect of concentric and eccentric fatigue on sense of Position

The results indicate that muscle fatigue that continuously contracts has a statistically significant effect on knee joint repositioning error in healthy participants.

This would support the view that the increased concentrations of metabolites and inflammatory elements, which often have a direct effect on the discharge structure of muscle spindles and alpha-gamma coactivation, might lead to decreasing in joint position proprioception within the fatigued muscles [35]. It is important to note that the size of the error in the reconstruction of knee position was reduced after concentric contractions, while it was increased after eccentric ones. This means the participants were more accurate in repositioning the targeted angle during concentric contractions.
The results of this study support the findings of Skinner and colleagues, [27]. Their results indicated that the fatigued participants showed a statistically significant decrease in the ability to reproduce knee joint angles. Voight et al, (1996) also found a statistically significant decrease in proprioceptive ability following a bout of eccentric fatigue. However, this study was performed on the glenohumeral joint [36].

In this regard, some authors hypothesized that the participants in the eccentric group would have had a larger decline in shoulder joint proprioception than the participants in the concentric group. The authors also suggested that this was a result of the "dysfunctional mechanoreceptors" theory whereby muscle fatigue desensitizes muscle spindles, decreasing afferent feedback to the central nervous system that leads to deterioration of proprioception [15, 37].

However, the results of the recent study [15] indicate that shoulder muscle fatigue induced by eccentric exercise does not affect shoulder joint proprioception to a larger extent than fatigue induced by concentric exercise.

In essence, there are differences between eccentric and concentric exercises. Studies have shown that after severe eccentric exercise, it is more prone to inflict pain and harm to the muscles. Torres *et al,* (2010) demonstrated that the exercise protocols included eccentric contractions could induce muscle damage and leads to a change in proprioception and it is suggestive of this fact that there may be disruptions in inner muscle fibers to happen [32].

Effect of concentric and eccentric fatigue on Knee stability

The result indicates that the jump distance increased following both concentric and eccentric muscle contractions. The higher jump distance in eccentrically trained participants as compared to concentrically trained one, suggests an enhanced capacity for energy storage and recovery [38].

A study by Ortiz *et al.,* regarding fatigue effects on knee joint stability showed that the fatigue created by the Wingate anaerobic test did not affect neuromuscular activation and dynamic knee joint stability in these young women to the level expected [39].

Although it appears that women reached a high level of fatigue according to the fatigue index estimation, the rapid recovery might have played a factor preventing differences between non-fatigued and fatigued sessions.

There are additional factors that may have prevented significant biomechanical knee injury–predisposing factors from being observed during the fatigued session. Greater muscle control during the fatigued condition, greater eccentric control of the knee joint [40] and compensatory neuromuscular strategies [41] are all possible compensations to prevent dynamic instability of the lower limbs.

Neuromuscular factors that might help explain this behavior are the recruitment of additional motor units, increased firing synchronization, and the "common drive" (movement pattern generator) theory [41]. The recruitment of additional motor neurons and increased synchronization of gluteal and thigh muscles might be an attempt of the nervous system to activate, more intensively, the muscles to maintain the ability to jump after a landing, generating greater eccentric control [42]. The common drive theory states that force-generating properties of agonist and antagonist muscles are controlled by single reflexive actions indicating that agonists and antagonists muscle groups are activated simultaneously as a functional unit, regardless of fatigue level of specific muscle groups [41]. Given that the jumping tasks used in this investigation required a jump after landing and repetitive continuous jumps, these explanations seem credible.

It is apparent that the human body might be able to protect the lower extremities against unstable conditions through neuromuscular compensations, such as an increase in muscular activation during the onset of fatigue. However, this is not always the case because certain evidence exists in which fatigue may exacerbate predisposing factors for lower-extremity injuries. It is for this reason that strength and conditioning specialists should not underestimate training endurance and strength-endurance components in all athletes as means to reduce injuries and maximize performance.

CONCLUSION

Muscle fatigues, particularly after eccentric contractions, addresses lessen in the knee joint proprioception with regard to the sense of force and sense of position. Therefore, eccentric contractions deserve more attention by the athletes because it can be a secret weapon for creating healthier joints and can reinforce athletes against proprioception inflict.

Acknowledgements
This research was supported by Physical Medicine and Rehabilitation Research Center of Tabriz University of Medical Sciences. The authors are especially grateful to the participants for participation and cooperation in this research. The authors take responsibility for the integrity and accuracy of the data.

REFERENCES

1. Schepsis AA, Busconi B. Sports Medicine Edition n, editor: Lippincott Williams and Wilkins; 2005. 578 p.
2. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. The American journal of sports medicine. 1995;23(6):694-701.
3. Peck KY, Johnston DA, Owens BD, Cameron KL. The incidence of injury among male and female intercollegiate rugby players. Sports health. 2013;5(4):327-33.
4. Fulstone D, Chandran A, Barron M, DiPietro L. Continued Sex-Differences in the Rate and Severity of Knee Injuries among Collegiate Soccer Players: The NCAA Injury Surveillance System, 2004–2009. International journal of sports medicine. 2016;37(14):1150-3.
5. Voskanian N. ACL Injury prevention in female athletes: review of the literature and practical considerations in implementing an ACL prevention program. Current reviews in musculoskeletal medicine. 2013;6(2):158-63.
6. Donnell-Fink LA, Klara K, Collins JE, Yang HY, Goczalk MG, Katz JN, et al. Effectiveness of knee injury and anterior cruciate ligament tear prevention programs: A meta-analysis. PloS one. 2015;10(12):e0144063.
7. Wojtys EM. Sports injury prevention. Sports health. 2017;9(2):106.
8. Logerstedt D, Arundale A, Lynch A, Snyder-Mackler L. A conceptual framework for a sports knee injury performance profile (SKIPP) and return to activity criteria (RTAC). Brazilian journal of physical therapy. 2015;19(5):340-59.
9. Williams GN, Chmielewski T, Rudolph KS, Buchanan TS, Snyder-Mackler L. Dynamic knee stability: current theory and implications for clinicians and scientists. Journal of orthopaedic & sports physical therapy. 2001;31(10):546-66.
10. Hagert E, Lluch A, Rein S. The role of proprioception and neuromuscular stability in carpal instabilities. Journal of Hand Surgery (European Volume). 2016;41(1):94-101.
11. Mohammadi Bazneshin M, Amiri A, Jamshidi AA, Vasaghi-Gharamaleki B. Quadriceps muscle fatigue and knee joint position sense in healthy men. Physical Treatments-Specific Physical Therapy Journal. 2015;5(2):109-14.
12. Smith MP, Sizer PS, James CR. Effects of fatigue on frontal plane knee motion, muscle activity, and ground reaction forces in men and women during landing. Journal of sports science & medicine. 2009;8(3):419.
13. van der Esch M, Knoop J, Hunter DJ, Klein J-P, van der Leeden M, Knol DL, et al. The association between reduced knee joint proprioception and medial meniscal abnormalities using MRI in knee osteoarthritis: results from the Amsterdam osteoarthritis cohort.

Osteoarthritis and cartilage. 2013;21(5):676-81.
14. Abd-Elfattah HM, Abdelazeim FH, Elshennawy S. Physical and cognitive consequences of fatigue: A review. Journal of advanced research. 2015;6(3):351-8.
15. Spargoli G. The acute effects of concentric versus eccentric muscle fatigue on shoulder active repositioning sense. International journal of sports physical therapy. 2017;12(2):219.
16. Bogdanis GC. Effects of physical activity and inactivity on muscle fatigue. Frontiers in physiology. 2012;3.
17. Ascensão A, Leite M, Rebelo AN, Magalhäes S, Magalhäes J. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. Journal of sports sciences. 2011;29(3):217-25.
18. Jones D, Newham D, Torgan C. Mechanical influences on long-lasting human muscle fatigue and delayed-onset pain. The Journal of Physiology. 1989;412(1):415-27.
19. Sari Sarraf V, Hamidi H, Talebi Q-A. The Effect of Quadriceps' Fatigue Following Eccentric and Concentric Contractions on Force Perception in Knee Joint. Indian Journal of Fundamental and Applied Life Sciences. 2014;4(4):641-6.
20. Skinner H, Wyatt M, Hodgdon J, Conard D, Barrack R. Effect of fatigue on joint position sense of the knee. Journal of Orthopaedic Research. 1986;4(1):112-8.
21. Abbott K. Injuries in women's ice hockey: special considerations. Current sports medicine reports. 2014;13(6):377-82.
22. Salahzadeh Z, Maroufi N, Salavati M, Aslezaker F, Morteza N, Rezaei Hachesu P. Proprioception in subjects with patellofemoral pain syndrome: using the sense of force accuracy. Journal of Musculoskeletal Pain. 2013;21(4):341-9.
23. Lin D-H, Lin C-HJ, Lin Y-F, Jan M-H. Efficacy of 2 non-weight-bearing interventions, proprioception training versus strength training, for patients with knee osteoarthritis: a randomized clinical trial. Journal of orthopaedic & sports physical therapy. 2009;39(6):450-7.
24. Collier MB, McAuley JP, Szuszczewicz ES, Engh GA. Proprioceptive deficits are comparable before unicondylar and total knee arthroplasties, but greater in the more symptomatic knee of the patient. Clinical Orthopaedics and Related Research®. 2004;423:138-43.
25. Batra V, Sharma VP, Batra M, Agarwal GG, Sharma V. Influence of sitting and prone lying positions on proprioceptive knee assessment score in early knee osteoarthritis. The Malaysian journal of medical sciences: MJMS. 2011;18(2):40.
26. Pincivero DM, Bachmeier B, Coelho AJ. The effects of joint angle and reliability on knee proprioception. Medicine and science in sports and exercise. 2001;33(10):1708-12.
27. Skinner HB, Barrack RL. Joint position sense in the normal and pathologic knee joint. Journal of Electromyography and Kinesiology. 1991;1(3):180-90.
28. Augustsson J, Thomeé R, Linden C, Folkesson M, Tranberg R, Karlsson J. Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis. Scandinavian journal of medicine & science in sports. 2006;16(2):111-20.
29. Lord C, Ma'ayah F, Blazevich AJ. Change in knee flexor torque after fatiguing exercise identifies previous hamstring injury in football players. Scandinavian journal of medicine & science in sports. 2018;28(3):1235-43.
30. Arends KM, Miller ST, VanderMaas JT. The Effect of Eccentric Fatigue of the Hamstrings on Knee Joint Proprioception. 1998.
31. Miura K, Ishibashi Y, Tsuda E, Okamura Y, Otsuka H, Toh S. The effect of local and general fatigue on knee proprioception. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2004;20(4):414-8.
32. Torres R, Vasques J, Duarte J, Cabri J. Knee proprioception after exercise-induced muscle damage. International journal of sports medicine. 2010;31(06):410-5.
33. Cafarelli E. Peripheral contributions to the perception of effort. Medicine and science in sports and exercise. 1982;14(5):382-9.
34. Brockett C, Warren N, Gregory J, Morgan D, Proske U. A comparison of the effects of concentric versus eccentric exercise on force and position sense at the human elbow joint. Brain research. 1997;771(2):251-8.
35. Ribeiro F, Venâncio J, Quintas P, Oliveira J. The effect of fatigue on knee position

sense is not dependent upon the muscle group fatigued. Muscle & nerve. 2011;44(2):217-20.
36. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. Journal of Orthopaedic & Sports Physical Therapy. 1996;23(6):348-52.
37. Piitulainen H, Botter A, Merletti R, Avela J. Muscle fiber conduction velocity is more affected after eccentric than concentric exercise. European journal of applied physiology. 2011;111(2):261-73.
38. Vogt M, Hoppeler HH. Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. Journal of applied Physiology. 2014;116(11):1446-54.
39. Ortiz A, Olson SL, Etnyre B, Trudelle-Jackson EE, Bartlett W, Venegas-Rios HL. Fatigue effects on knee joint stability during two jump tasks in women. Journal of strength and conditioning research/National Strength & Conditioning Association. 2010;24(4):1019.
40. Fagenbaum R, Darling WG. Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. The American journal of sports medicine. 2003;31(2):233-40.
41. Rodacki AL, Fowler NE, Bennett SJ. Multi-segment coordination: fatigue effects. Medicine & Science in Sports & Exercise. 2001;33(7):1157-67.
42. Orishimo KF, Kremenic IJ. Effect of fatigue on single-leg hop landing biomechanics. Journal of applied biomechanics. 2006;22(4):245-54.