Spor Hekimliği Dergisi, 58(2):82-87; 2023
Turkish Journal of Sports Medicine
Turk J Sports Med. DOI: 10.47447/tjsm.0705

Research Article / Araştırma Makalesi

The effect of neuromuscular fatigue created in the core region on the biomechanics of landing

Çekirdek bölgesinde oluşturulan nöromüsküler yorgunluğun sıçramadan sonra yere iniş biyomekaniğine etkisi

Görkem Kıyak, Sabriye Ercan

Sports Medicine Department, Faculty of Medicine, Süleyman Demirel University, Isparta, Türkiye

ABSTRACT

Objective: The aim of this study is to determine the effect of neuromuscular fatigue created in the core region on the biomechanics of landing.

Materials and Methods: Healthy individuals aged between 18-25 years and without any musculoskeletal injury that prevented them from performing the landing test were included in the study. In the study, cross-over randomization was applied. After the descriptive characteristics of the individuals (lower extremity length, Q angle, range of motion etc.) participating in the study were recorded, core region endurance was evaluated with curl-up test, static back endurance test (Biering Sorenson test) and horizontal side bridge test. Subjective fatigue protocol was created with the prone bridge test. The effect of the fatigue caused by the prone bridge test performed during applied time on the biomechanics landing was examined with the 'Landing Error Scoring System'.

Results: The study included 21 women (77.8%) and six men (22.2%) whose age was 21.7±0.2 (21-25) years, height 168.7±1.6 (156-190) cm, body weight 59.3±1.6 (46-80) kg and body mass index 20.8±0.5 (17.5-28.8) kg/m². It was determined that fatigue caused by the prone bridge test performed during applied time did not make a difference in the landing error score of the participants (p=0.545). It was determined that the results of the curl-up test and right horizontal side bridge test, in which endurance of the core region was determined, revealed a negative linear relationship with the landing error scores obtained after the fatigue protocol.

Conclusion: Increasing core region endurance of healthy individuals is associated with the response of lower extremity biomechanics to fatigue. Therefore, it is recommended that endurance exercises for the core region should be made a part of training programs.

Keywords: *Abdominal core, muscle fatigue, physical endurance, biomechanical phenomena*

ÖZ

Amaç: Bu çalışmanın amacı, çekirdek bölgesinde oluşturulan nöromüsküler yorgunluğun sıçramadan sonra yere iniş biyomekaniğine etkisinin belirlenmesidir.

Gereç ve Yöntem: Yaşları 18-25 yıl arasında olan, sıçrama testi yapmasına engel kas-iskelet sistemi yaralanması bulunmayan sağlıklı bireyler çalışmaya dâhil edildi. Çalışmada, çapraz randomizasyon uygulandı. Çalışmaya katılan bireylerin tanımlayıcı özellikleri (alt ekstremite uzunluğu, Q açısı, eklem hareket açıklığı vs.) kaydedildikten sonra çekirdek bölgesinin kas dayanıklılığı; mekik testi, statik sırt dayanıklılık testi ve horizontal yan köprü kurma testi ile değerlendirildi. Sübjektif yorgunluk protokolü yüzüstü köprü kurma testi ile oluşturuldu. Uygulanan süredeki yüzüstü köprü kurma testinin oluşturduğu yorgunluğun, sıçramadan sonra yere iniş biyomekaniğini etkileme düzeyi 'Sıçramadan Sonra Yere İniş Hata Puanlama Sistemi' ile incelendi.

Bulgular: Araştırmaya, yaşları 21.7±0.2 (21-25) yıl, boyları 168.7±1.6 (156-190) cm, vücut ağırlığı 59.3±1.6 (46-80) kg, vücut kütle indeksi 20.8±0,5 (17.5-28.8) kg/m² olan 21 kadın (%77.8) ve altı erkek (%22.2) dahil edildi. Uygulanan süredeki egzersizin oluşturduğu yorgunluğun, katılımcıların sıçramadan sonra yere iniş hata puanında fark oluşturmadığı (p=0.545) belirlendi. Çekirdek bölgesi dayanıklılığının belirlendiği mekik testi ve sağ tarafa ait horizontal yan köprü kurma testi sonuçlarının yorgunluk protokolü sonrası elde edilen sıçramadan sonra yere iniş hata puanları ile negatif yönlü doğrusal ilişki gösterdiği belirlendi.

Sonuç: Sağlıklı bireylerin çekirdek bölgesi dayanıklılıklarının arttırılması, alt ekstremite biyomekaniklerinin yorgunluğa verdikleri yanıt ile ilişkilidir. Bu nedenle; çekirdek bölgesine yönelik dayanıklılık egzersizlerinin antrenman programlarının bir parçası haline getirilmesi önerilmektedir.

Anahtar Sözcükler: *Çekirdek bölgesi, kas yorgunluğu, fiziksel dayanıklılık, biyomekanik fenomen*

INTRODUCTION

Exercises for the core region have become an important part of exercise programs of athletes and healthy individuals (1). This is due to the core region acting as a bridge that provides power transfer between the lower and upper extremities (2-4). All of the movements during sports or exercise originate from the core region and are transmitted to other parts of the body (2). Core muscles are of great importance in daily living activities, and strength and endurance exercises (4-6).

Received / Geliş: 07.07.2022 · **Accepted / Kabul:** 05.01.2023 · **Published / Yayın Tarihi:** 20.02.2023

Correspondence / Yazışma: Görkem Kıyak · Süleyman Demirel Üniversitesi, Tıp Fakültesi, Spor Hekimliği Bölümü, Isparta, Türkiye · gorkemkiyako@gmail.com

Cite this article as: Kiyak G, Ercan S. The effect of neuromuscular fatigue created in the core region on the biomechanics of landing. *Turk J Sports Med.* 2023 58(2):82-7; https://doi.org/10.47447/tjsm.0705

The core region generally includes abdominal and lumbar region muscles (4,5). On the other hand, there are opinions arguing that the core region cannot be limited only to these muscles and that the stabilization of extremity movements is provided by the synchronous work of the thoracolumbar, abdominal, pelvic, and hip muscles (3,6,7). It is claimed that keeping these muscles stable and strong leads to injury avoidance and increased athletic performance (4,5). In two different studies conducted by Chen et al., the increase in endurance in the core region increased shooting accuracy in basketball players (8), and the acute fatigue created in the core region decreased shooting accuracy (9); emphasizing the impact of the core region on athletic performance. It is thought that the weak and unbalanced core region of runners will result in increased fatigue, decreased endurance and increased risk of injury of the athlete (5). In our study, the effect of fatigue caused by the prone bridge test performed during applied time on the biomechanics of landing was examined in healthy individuals.

Regular strength and endurance exercise has been shown to delay muscle fatigue (10,11). If the individual is not adequately trained, muscles will tire more quickly during exercise or competition, which will increase the risk of injury (5). The fact that injury rates are higher in individuals towards the end of competition or exercise (12,13) also supports the fact that increased fatigue is a risk factor for injuries.

An important component of sports medicine practice is the prevention of sports injuries. Determining the risk factors of sports injuries beforehand and preventing these risks without injury still poses many questions for clinicians. Although one of the important risk factors causing injury is poor training, it should not be forgotten that this situation is multifactorial (14). On the other hand, it is clear that the core region has a key role in both lower and upper extremity injuries due to its location (3-5).

Jumping and landing movements are also movement patterns studied in terms of prevention of sports injuries. The 'Landing Error Scoring System' is a test developed by Padua et al. (15), for which validity and reliability in Turkish was assessed by Ercan et al. (16). In our study, the relationship between core region muscles and injury risk by using this test was investigated.

There are not enough studies concerning the effect of core region on lower extremity biomechanics, and how lower extremity injuries can be prevented by increasing the endurance of the core area in the literature. The hypothesis of this study is that the fatigue caused by the prone bridge test performed during applied time, will negatively affect the biomechanics of landing. The aim of this study is to determine the effect of neuromuscular fatigue created in the core region on the biomechanics of landing.

MATERIALS and METHODS

The research was approved by the local ethics committee's decision dated 18/08/2021 and numbered 270. The sample of the study consisted of 27 individuals, aged between 18-25 years, and without any musculoskeletal injury that prevented them from performing the landing test. Those younger than 18 years, older than 25 years, or those with musculoskeletal injuries (lower extremity injury in the last six months, or with a history of fracture or surgery in the lower extremity in the last two years) were not included in the study. In the study, a cross-over design was applied (Figure 1).

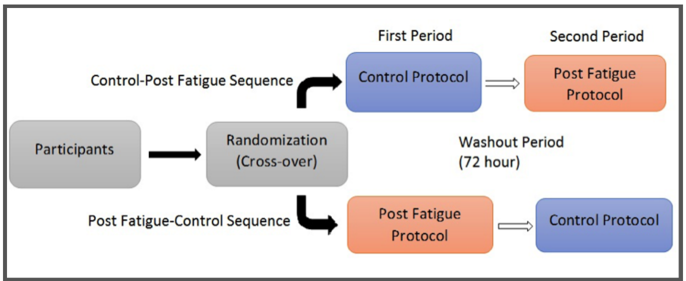

Figure 1. Cross-randomization design, applied in order not to create bias due to learning the tests performed, and not to affect the results of the study

Researchers performed the recording of descriptive features, the muscle endurance tests, the subjective fatigue protocol (by GK), and evaluation of biomechanics of landing (by SE) in the Sports Medicine Rehabilitation Unit. During the study, blindness of the researcher, who will evaluate the biomechanics of landing, was maintained.

In addition to obtaining information on descriptive features; bilateral lower extremity length, Q angle, ankle plantar flexion/dorsiflexion/eversion/inversion, knee flexion/extension, hip flexion/extension/abduction/adduction, and trunk flexion/extension/right lateral flexion/left lateral flexion angles were measured with a goniometer, and recorded by one of the researchers. These measurements were made to present the descriptive features of the lower extremity, since the 'Landing Error Scoring System' used in the study was for the lower extremity risk analysis. After the descriptive characteristics of the individuals participating in the study were recorded, core region endurance was evaluated. For core muscle endurance; curl-up test, static back endurance test (Biering Sorenson test) and horizontal side bridge test were used (17,18).

Core Region Endurance

Curl-up test: This test measures the endurance of abdominal muscles. In the test starting position, the individuals lie on their back. Their lower extremities are about shoulder-width apart, their hips abducted, and their knees semi-flexed. Ankles of the individuals are fixed. Upper extremities are placed on the opposite shoulders. Individuals are asked to flex their trunks and get up until their elbows touch their knees, and the number of curl-ups they can do in 1 min is recorded (18).

Static back endurance test (Biering Sorenson test): This test measures the endurance of lumbar muscles. In the prone position, the individual lies flat on the stretcher with the pelvis, hips and knees on the stretcher, with the inguinal region at the end of the stretcher. The ankles of the individual are fixed. They are requested to put their upper extremities next to the trunk. The time that the individual can stay on a straight line in the horizontal position is recorded by stopwatch. When the individual falls down from the horizontal position or cannot maintain his/her position, the test is finished and the time is recorded (18).

Horizontal side bridge test: This test measures the endurance of spinal stabilizer muscles. The individual is in a side-lying position with the lower extremities extended. Top foot is placed in front of bottom foot for support. The individual elevates on the forearm and ankle until the pelvis and trunk become horizontal. The researcher should make sure that the body is in a straight line. The time that the individual can maintain this position is determined by the stopwatch and the time is recorded. Measurement is made for both sides (18).

Subjective Fatigue Protocol

A subjective fatigue protocol was applied with the prone bridge test (17). Subjective fatigue was assessed with the Borg Rating of Perceived Exertion (RPE) every 5 s. The subjective fatigue protocol was continued up to the score (Borg Category-Ratio 10), where the RPE was 10 (17).

Subjective fatigue protocol with prone bridge test: The individual maintains the prone plank stance without losing the contact of his/her feet and elbows with the ground. The time it stays in this position is recorded with a stopwatch. If the individual deteriorates the position, feels pain and exhaustion in his/her muscles, the fatigue protocol is terminated (17).

Evaluation of Biomechanics of Landing

Biomechanics of landing of individuals were evaluated with the Landing Error Scoring System (LESS) method (15,16). Video recordings were made in accordance with the protocol recommended in the Turkish validity and reliability study of the LESS method (16). The analysis was carried out with the help of a free video-based image analysis program (Kinovea v0.8.15, free software with GPL v2 license, https://www.kinovea.org/).

Statistical Analysis

In the power analysis (G*power v.3.1.9.7, Germany) performed with the data obtained in the pilot study before the analysis of research data, it was determined that the sample size to be reached was 26 people when a power of 0.80 and an alpha of: 0.05 were accepted. The conformity of the data of 27 people included in the study to the normal distribution was examined with the Shapiro-Wilk test. Since it was determined that the data were not suitable for normal distribution, the Mann-Whitney U test for independent groups and the Wilcoxon test for dependent groups were used. The Spearman correlation test was used in the correlation analysis. The p value was considered significant at the 0.05 level, and data were presented as frequency (n), percent (%) and median ± standard error (min-max).

RESULTS

The study included 21 women (77.8%) and six men (22.2%) whose age was 21.7±0.2 (21-25) years, height 168.7±1.6 (156-190) cm, body weight 59.3±1.6 (46-80) kg, and body mass index 20.8±0.4 (17.5-28.8) kg/m^2. Dominant extremity of all participants was the right side. Descriptive characteristics of the participants are presented in Table 1 and Table 2.

It was determined that the fatigue caused by the prone bridge test performed during applied time did not make a difference in the landing error score (LESS) of the participants (as mean±SE (min-max); Control protocol: 6.7±0.4 (2-12), Post Fatigue protocol: 6.5±0.3 (3-9); p=0.545, Wilcoxon test).

On the other hand, it was determined that the results of the curl-up test and horizontal side bridge test of the right side, where the endurance of the core region was determined, a negative linear relationship was revealed with the landing error scores obtained after the fatigue protocol. In other words, the higher the endurance of the core region, the lower the landing error score after this protocol (Table 3).

Table 1. Descriptive characteristics of the participants

Side	Right		Left		
Parameter	Mean±SE	Min-Max	Mean±SE	Min-Max	p[a]
Lower extremity length (cm)	87.8±1.1	(76-100)	87.7±1.1	(75-100)	0.952
Q angle (°)	9.2±0.7	(0-15)	9.0±0.7	(0-15)	0.875
Ankle plantar flexion (°)	44.8±1.7	(30-60)	45.2±1.6	(30-60)	0.874
Ankle dorsiflexion(°)	18.1±1.0	(10-30)	18.5±1.0	(10-30)	0.753
Ankle inversion (°)	29.8±1.4	(20-60)	28.9±1.4	(20-60)	0.276
Ankle eversion (°)	20.0±0.6	(15-30)	20.2±0.6	(15-30)	0.758
Knee flexion (°)	132.6±2.0	(110-155)	132.8±2.0	(110-155)	0.916
Knee extension (°)	0±0	(0-0)	0±0	(0-0)	1.000
Hip flexion (°)	111.8±2.7	(90-130)	111.5±2.8	(90-130)	0.958
Hip extension (°)	24.4±1.5	(15-45)	24.1±1.5	(10-45)	0.913
Hip abduction (°)	34.9±1.6	(20-55)	35.4±1.9	(20-60)	0.958
Hip adduction (°)	24.8±1.3	(15-45)	24.1±1.4	(10-45)	0.788
Trunk flexion (°)	84.4±2.7	(55-110)	84.4±2.7	(55-110)	1.000
Trunk extension (°)	24.2±1.4	(15-45)	24.2±1.4	(15-45)	1.000
Trunk lateral flexion(°)	30.9±1.5	(15-55)	30.6±1.6	(20-55)	0.742

a: Mann-Whitney U test; SE: standard error

Table 2. Core region endurance of participants

Test	Mean±SE	Min-Max
Curl-up test	22.0±1.5	(10-50)
Static back endurance test (Biering Sorenson test)	131.6±9.9	(52-274)
Right horizontal side bridge test	53.6±8.0	(10-230)
Left horizontal side bridge test	46.2±3.6	(11-85)
Subjective fatigue protocol with prone bridge test	62.7±6.3	(28-160)
SE: standard error		

Table 3. Relationship between core region endurance and landing error scores after jumping

Parameter		LESS score-Controlprotocol	LESS score-Post fatigue protocol
LESS score control protocol	r	1.000	**0.573**[**]
	p	.	0.002
LESS score post fatigue protocol	r	**0.573**[**]	1.000
	p	0.002	.
Age (year)	r	-0.095	-0.306
	p	0.636	0.121
Body Mass Index (kg/m²)	r	-0.120	-0.109
	p	0.552	0.588
Curl-up test	r	-0.334	**-0.566**[**]
	p	0.088	0.002
Static back endurance (Biering Sorenson) test	r	-0.176	-0.270
	p	0.379	0.173
Right horizontal side bridge test	r	-0.188	**-0.462**[*]
	p	0.348	0.015
Left horizontal side bridge test	r	-0.167	-0.339
	p	0.406	0.083
Prone bridge test	r	-0.167	-0.331
	p	0.406	0.092

*: correlation is significant at the 0.05 level (2-tailed), **: correlation is significant at the 0.01 level (2-tailed). If p<0.05 and r=0.4-0.6, a moderate relationship was accepted.

DISCUSSION

There are not enough studies in the literature on the effect of core region fatigue and endurance on extremity biomechanics and injury risk (1). In our study, we investigated the effect of the core region on the biomechanics of landing, and therefore on the risk of lower extremity injury. The main hypothesis in this study was that acute fatigue in the core region would increase the landing error score and, as an effect, increase the risk of lower extremity injury. However, it was determined that fatigue caused by the prone bridge test performed during applied time did not make a difference in the landing error score of the participants. On the other hand, higher core endurance was associated with lower landing error score after the subjective fatigue protocol.

In a study conducted by De Oliviera et al. (19), the effects of acute core stabilization and sensorimotor exercises during sitting and standing positions on postural control in young adults were compared. It was then reported that the effect of core stabilization and sensorimotor exercises on postural control could not be observed, compared with the control group. Although investigations were made on different parameters from our current study, it was suggested that acute core region fatigue does not affect body biomechanics, in parallel with our study. However, when the literature is reviewed, there are also articles suggesting that increased fatigue in the core region disrupts body biomechanics (5).

It is thought that physiological fatigue in general, but not only in the core region, causes poor technique, and poor technique causes poor performance and increased injury risk (20). It was observed that after the battle rope exercise, in which the core region muscles and upper extremities were activated (21), some performance components such as shooting accuracy and passing speed in basketball were adversely affected, with no change in countermovement jump height (9). In this study, contrary to our study, it was suggested that acute core region fatigue increases the risk of injury. In future studies, the effect of acute fatigue in the core region on body biomechanics, and thus injury risk should be investigated in more detail.

In our study, although the fatigue caused by the prone bridge test performed during applied time had no effect on the biomechanics of the landing, it was determined that the results of the curl-up test, and right horizontal side bridge test, in which endurance of the core region was determined, displayed negative linear relationship with the landing error scores obtained after the subjective fatigue protocol. This revealed that as core region endurance increases, neuromuscular fatigue reduces the level of negative effects on lower extremity biomechanics. In our study, although a negative linear relationship was shown between landing error scores and the right horizontal side bridge test, it was thought that all participants' right extremity dominancy could be the reason for the lack of correlation in the left horizontal side bridge test.

When the literature is examined, core endurance and stabilization exercises are found to improve lower extremity biomechanics, and thus reduce the risk of injury, supporting our study. In a review study by Rivera (5), it was reported that instability and inadequacy in the core region of runners may result in decreased endurance and increased risk of injury. In another study conducted by Sharma and Geovinson (6), it was shown that as a result of 9-week core strengthening exercises applied to volleyball athletes with trunk instability, athletes' trunk stability increased, and their vertical jump values improved. In Watson et al.'s study on competitive dancers, it was reported that 9-week core stabilization exercises improved static and dynamic balance, and muscle performance measurements in dancers (22). In another study on chronic core stabilization exercises, it was revealed that an 8-week exercise program improved functional movement patterns and dynamic postural control in college athletes (23). These studies and others directly or indirectly predict that core muscle endurance reduces the risk of lower extremity injury (24).

On the other hand, it was shown that the 6-week core strengthening exercise performed by Sato and Mokha (25) on athletes did not affect lower extremity stability. In another study conducted by Santos et al. (26) on inactive individuals, it was shown that the endurance of the core region did not have a significant effect on agility and jumping, unlike the study of Sharma and Geovinson, but it affected the ability to apply maximum power and force in intermittent running, and exercises performed in the pushing, pulling, and lifting actions. Although these studies are not in line with our results, it should not be forgotten that the biomechanics of landing is not only dependent on lower extremity stability and jumping/ landing parameters.

In a meta-analysis study conducted by Huxel Bliven and Anderson in 2013, the effects of core stabilization exercises on injury prevention were investigated. Conclusive evidence of a relationship between core region instability and injury is lacking; however, it has been reported that multifaceted anti-injury exercise programs that include core stabilization exercises appear to be effective in reducing lower extremity injury rates (24).

The non-homogeneous gender of the participants in the study and the fact that the female participants were in the majority could be counted among the limitations of this study. On the other hand, as far as we know, the original aspect of the research is that it is the first study to examine the effect of fatigue caused by the prone bridge test performed during applied time created in the core region, on Landing Error Scoring System results.

CONCLUSION

The importance of exercises for the core region is understood day by day. Core exercises are important to improve the biomechanics of healthy individuals and athletes, and to prevent sports injuries. Therefore, we suggest that the effects of acute and chronic fatigue in the core region on performance and injury prevention should be investigated in the future, and that literature on this subject should be developed.

On the other hand; as a result of the study, it is recommended that healthy individuals and athletes make core exercises a part of their programs in order to avoid sports injuries and improve their biomechanics. In addition, as the techniques of athletes whose biomechanics improve, their individual performance will also improve. In this context, it was thought that the incidence of injury in healthy individuals and athletes will decrease with the regular performance of core exercises, thus reducing the financial and psychological effects caused by injuries to a great extent.

Ethics Committee Approval / Etik Komite Onayı

This study was approved by the Suleyman Demirel University Faculty of Medicine Scientific Research Ethics Committee (approval number 270, date: 18.08.2021).

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

Financial Disclosure / Finansal Destek

The authors received no financial support for the research and/or publication of this article.

Author Contributions / Yazar Katkıları

Concept: SE; Design: SE; Supervision: SE; Materials: GK; Data Collection and Processing: GK, SE; Analysis and Interpretation: SE; Literature Review: GK; Writing Manuscript: GK, SE; Critical Reviews: SE.

REFERENCES

1. Örsçelik A. The importance of the core region in sports injuries and sports performance. *Türkiye Klinikleri J Sports Med-Special Topics*. 2017;3(3):191-5.
2. Bliss LS, Teeple P. Core stability: the centerpiece of any training program. *Curr Sports Med Rep*. 2005;4(3):179-83.
3. Hill J, Leiszler M. Review and role of plyometrics and core rehabilitation in competitive sport. *Curr Sports Med Rep.*2011;10(6):345-51.

4. Stephenson J, Swank AM. Core training: designing a program for anyone. *Strength Cond J*. 2004; 26(6):34-7.
5. Rivera CE. Core and lumbopelvic stabilization in runners. *Phys Med Rehabil Clin N Am*. 2016; 27(1):319-37.
6. Sharma A, Geovinson SG, Sandhu JS. Effects of a nine-week core strengthening exercise program on vertical jump performances and static balance in volleyball players with trunk instability. *J Sports Med Phys Fitness*. 2012;52(6):606-15.
7. Conte SA, Thompson MM, Marks MA, Dines JS. Abdominal muscle strains in professional baseball: 1991-2010. *Am J Sports Med*. 2012;40(3):650-6.
8. Chen W-H, Wu H-J, Lo S-L, Chen H, Yang W-W, Huang C-F, et al. Eight-week battle rope training improves multiple physical fitness dimensions and shooting accuracy in collegiate basketball players. *J Strength Cond Res*. 2018;32(10):2715-24.
9. Chen W-H, Yang W-W, Lee Y-H, Wu H-J, Huang C-F, Liu C. Acute effects of battle rope exercise on performance, blood lactate levels, perceived exertion, and muscle soreness in collegiate basketball players. *J Strength Cond Res*. 2020;34(10):2857-66.
10. Párraga-Montilla JA, García-Ramos A, Castaño-Zambudio A, Capelo-Ramírez F, González-Hernández JM, Cordero-Rodríguez Y, et al. Acute and delayed effects of a resistance training session leading to muscular failure on mechanical, metabolic, and perceptual responses. *J Strength Cond Res*. 2020;34(8):2220-6.
11. Theofilidis G, Bogdanis GC, Koutedakis Y, Karatzaferi C. Monitoring exercise-induced muscle fatigue and adaptations: making sense of popular or emerging indices and biomarkers. *Sports (Basel)*. 2018;6(4):153.
12. Barrett S, Midgley A, Reeves M, Joel T, Franklin E, Heyworth R, et al. The within-match patterns of locomotor efficiency during professional soccer match play: implications for injury risk?. *J Sci Med Sport*. 2016;19(10):810-5.
13. Carling C, McCall A, Le Gall F, Dupont G. The impact of short periods of match congestion on injury risk and patterns in an elite football club. *Br J Sports Med.* 2016;50(12):764-8.
14. Baroni BM, Pena Costa LO. Evidence-based prevention of sports injuries: is the sports medicine community on the right track? *J Orthop Sports Phys Ther*. 2021;51(3):91-3.
15. Padua DA, Boling MC, Distefano LJ, Onate JA, Beutler AI, Marshall SW. Reliability of the landing error scoring system-real time, a clinical assessment tool of jump-landing biomechanics. *J Sport Rehabil*. 2011;20(2):145-56.
16. Ercan S, Arslan E, Çetin C, Başkurt F, Başkurt Z, Baser Kolcu Mİ, et al. Turkish adaptation study of the landing error scoring system. *Kocaeli Tıp Dergisi*. 2021;10(2):174-8.
17. Cruz-Montecinos C, Bustamante A, Candia-González M, González-Bravo C, Gallardo-Molina P, Andersen LL, et al. Perceived physical exertion is a good indicator of neuromuscular fatigue for the core muscles. *J Electromyogr Kinesiol*. 2019;49:102360. doi: 10.1016/j.jelekin.2019.102360.
18. Doymaz F, Cavlak U. Relationship between thigh skinfold measurement, hand grip strength, and trunk muscle endurance: differences between the sexes. *Adv Ther*. 2007;24(6):1192-201.
19. de Oliveira MR, Fabrin LF, de Oliveira Gil AW, Benassi GH, Camargo MZ, da Silva RA, et al. Acute effect of core stability and sensory-motor exercises on postural control during sitting and standing positions in young adults. *J Bodyw Mov Ther*. 2021;28:98-103.
20. Zatsiorsky VM, Kraemer WJ, Fry AC. *Science and Practice of Strength Training.* 3rd ed. Champaign: Human Kinetics; 2020.
21. Calatayud J, Martin F, Colado JC, Benítez JC, Jakobsen MD, Andersen LL. Muscle activity during unilateral vs. bilateral battle rope exercises. *J Strength Cond Res*. 2015;29(10):2854-9.
22. Watson T, Graning J, McPherson S, Carter E, Edwards J, Melcher I, et al. Dance, balance and core muscle performance measures are improved following a 9-week core stabilization training program among competitive collegiate dancers. *Int J Sports Phys Ther*. 2017;12(1):25-41.
23. Bagherian S, Ghasempoor K, Rahnama N, Wikstrom EA. The effect of core stability training on functional movement patterns in college athletes. *J Sport Rehabil.* 2019;28(5):444-9.
24. Huxel Bliven KC, Anderson BE. Core stability training for injury prevention. *Sports Health*. 2013;5(6):514-22.
25. Sato K, Mokha M. Does core strength training influence running kinetics, lower-extremity stability, and 5000-M performance in runners? *J Strength Cond Res*. 2009;23(1):133-40.
26. Santos MS, Behm DG, Barbado D, DeSantana JM, Da Silva-Grigoletto ME. Core endurance relationships with athletic and functional performance in inactive people. *Front Physiol*. 2019;10:1490. doi: 10.3389/fphys.2019.01490.