Research Paper

Effects of Fatigue on Knee and Ankle Joint Angle Restoration After a Mountaineering Program

Morteza Barzegar Bafrouei[1], Amirhossein Barati[1*], Mina Haghighi[2]

1. Department of Health and Rehabilitation in Sport, Faculty of Sports and Health Sciences, Shahid Beheshti University of Tehran, Tehran, Iran.
2. Department of Biological Sciences, Faculty of Physical Education and Sports Sciences, Shahrood University of Technology, Shahrood, Iran.

Use your device to scan and read the article online

Citation Barzegar Bafrouei M, Barati A, Haghighi M. Effects of Fatigue on Knee and Ankle Joint Angle Restoration After a Mountaineering Program. Iranian Rehabilitation Journal. 2024; 22(2):245-254. http://dx.doi.org/10.32598/irj.22.2.1986.1

http://dx.doi.org/10.32598/irj.22.2.1986.1

Article info:
Received: 26 Dec 2022
Accepted: 20 Jun 2023
Available Online: 01 Jun 2024

Keywords:
Fatigue, Pain, Proprioception, Climbers

ABSTRACT

Objectives: Fatigue leads to an increase in joint restoration errors because of nervous system fatigue and a lack of understanding of joint position and imbalance that may be due to the changes in walking patterns and excessive pressure on bones and soft tissue structures, which may ultimately lead to injuries in climbers. Accordingly, this study investigates the effect of fatigue on the restoration error of the knee and ankle joint angles.

Methods: This was a quasi-experimental study. A total of 35 mountaineers aged 20-35 years were selected by the non-random sampling method. This research was conducted on September 10, 2022, at the Tochal Climbing Rout in Velenjak, Tehran City, Iran. The tests were taken before and after a mountaineering program for a distance of 8 km at an average speed. The position sense of knee and ankle joints was evaluated using the Mobimed, which is a type of electrogoniometer. The normal distribution of the data was statistically analyzed using the Shapiro-Wilk test, and the data were analyzed using the paired t-test. The SPSS software, version 24, was used for all statistical operations ($P \leq 0.05$).

Results: The findings showed that fatigue causes errors and significant changes in the restoration of knee and ankle joint angles and 30° (P=0.003), 45° (P=0.004), 60° (P=0.007), dorsiflexion of 10° (P=0.009) and plantar flexion of 20° (P=0.001), the restoration and sense of position is disturbed, which shows that fatigue is effective in understanding the state of the joints.

Discussion: Fatigue increases the error of restoration of the knee and ankle joint angles, which can reduce the optimal performance of the muscles around the joints by reducing the person's understanding of the angles and the sense of the joint position.

*** Corresponding Author:**
Amirhossein Barati, Associate Professor.
Address: *Department of Health and Rehabilitation in Sport, Faculty of Sports and Health Sciences, Shahid Beheshti University of Tehran, Tehran, Iran.*
Tel: *+98 (912) 1930811*
E-mail: *ahbarati20@gmail.com*

Highlights

● Fatigue is one of the factors that can disrupt the sense of proprioception of the knee and ankle joints during the mountain climbing route, which can ultimately be considered a risk factor for injury.

● Risks include a reduction of the climber's awareness of the state of her joints, which can cause twisting in her joints on slippery surfaces and may eventually lead to the climber's fall.

Plain Language Summary

Fatigue is the result of sports activities, especially mountain climbing. This can reduce the climbers' awareness and sense of the position of their knee and ankle joints and disturb their sense of the condition of these joints, which can make the joints vulnerable. Climbers should be aware of this situation to avoid injuries that include twisting, sprains, and even falling on the climbing route.

Introduction

Mountaineering is a sport that has become popular recently. This sport used to be exercised by professionals and experienced people; however, it is now exercised by people of all ages and skills at different levels [1]. Mountaineering injuries have increased significantly as the sport has become more popular. The global number of mountaineers and mountaineering sites has increased by approximately 50% over the last decade (2010–2020) [2]. Accordingly, it is reasonable to assume that the mountaineering community will continue to grow. Over the last decade, this large sports community has been outfitted with technological advances and improved safety equipment. Natural mountaineering routes face geographic and environmental obstacles, such as changing weather and rock falls. Nevertheless, with this increase, reports of injury from this sport have increased [3]. According to Lutter et al. (2022), 93% of all injuries recorded by mountaineers are caused by overuse of limbs [4]. Schöffl et al. (2013) analyzed 515 and 337 indoor climbers and found that 6 of 22 injuries occurred in people under the age of 18 years, requiring immediate medical intervention. Four of the injuries occurred in boys and two in girls with an average age of 13.7 years [5]. According to Barendrecht et al. (2023), the injury rate was 40.7% in lower limbs, 32.5% in upper limbs, 15.6% in the head and 9.4% in the trunk [6]. The results of the studies by Jones & Johnson (2016) and Schöffl et al. (2012) showed that most injuries occurred in the upper limbs of adults in all climbing cases [7, 8]. Climbing injuries are divided into two age groups: climbers aged 20 to 35 years who suffer from trauma and climbers aged 45 to 55 years who suffer from non-contact injuries in addition to contact injuries [8, 9]. Moreover, men are significantly more involved in fatal accidents compared to women [10]. In a study by Rauch et al. (2019), an injury rate of 2.5% in 1000 mountaineers was reported, with 0.56 injuries per 1000 exercise hours. Most of the studies conducted on mountaineer mortality are shown as per 1000 climbers or 1000 ascents, which is difficult to compare with studies based on 1000 h of performance [1]. There are few studies on mountaineering; however, the sport is now being followed professionally and has affected training schedules, dietary patterns, and the incidence and prevalence of body injuries because of its inclusion in the Tokyo 2020 Olympic Games and 2018 Summer Youth Olympic Games [5, 11].

One of the injury factors in mountaineering is fatigue, which occurs due to the lack of appropriate functioning of the central or peripheral nervous system. In central fatigue, the central nervous system is disturbed, and in peripheral fatigue, peripheral nerves, neuromuscular junction, or muscle contractile tissue are disturbed [12]. Some studies suggest that injuries occur more toward the end of an exercise session, indicating the relationship between fatigue and the increase in the incidence of injuries. Meanwhile, fatigue affects several kinematic and kinetic biomechanical variables of the lower limb [13], neuromuscular factors, such as reflex and co-appropriate contraction activities, and proprioceptive function [14, 15].

Fatigue can affect proprioception, which consists of positional or movement awareness received by the sensory receptors in the muscles, tendons, joints, and even skin, whose input is sent to the central nervous system and consists of joint position sense and force detection [16]. Joint position sense reflects a person's ability to perceive the joint angle. Joint kinesthesia is the ability of a person to actively recreate the same angle when

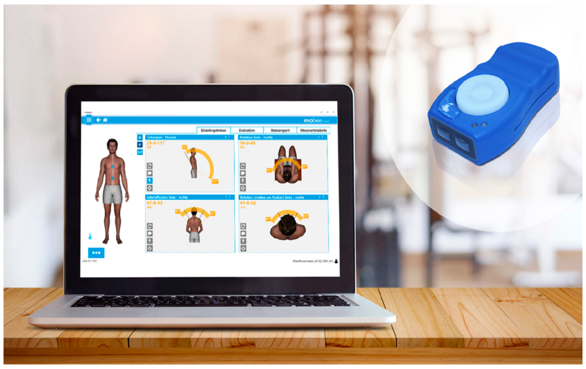

Figure 1. Mobeemed device Iranian Rehabilitation Journal

their limbs are passively placed at an angle [17]. Proprioception significantly contributes to muscle reflexes, joint dynamic stability, and movement planning for neuromuscular control [18]. Mechanical stability can be disturbed by any factor, such as ligamentous injury, that reduces proprioception. Therefore, the injury occurs by increasing the tension and pressure on the joint [19, 20]. The ankle joint is particularly important among the joints of the body because it bears the weight of the body. A decrease in this joint position sense can disturb and reduce the balance [21]. According to studies that have investigated the relationship between these two factors, the reduction of ankle position sense increases the possibility of an ankle injury and falls and muscle fatigue is one of the most important factors affecting the decline of position sense [22].

The foot and ankle joints are connected by the proximal joints in the lower limbs and play an essential role in bearing the weight of the trunk and limbs. In addition, the pressures and rotational movements in the ankle joint complex are transferred to the proximal joints, especially the knee [23]. By affecting the sense of knee position, neuromuscular fatigue causes changes in lower limb control. A knee joint injury is reported to be the most common injury, accounting for approximately 39% of all injuries [17]. According to the study, the probability of injury increases at a third of the end of an exercise session or climbing due to frequent eccentric contractions during descent, changes in neuromuscular control, and changes in the ability to maintain knee joint stability; however, the main cause of this disorder has not been determined precisely [24]. It can be attributed to the reduction of joint proprioception [25]. Impaired proprioception caused by physical and mental fatigue may increase the possibility of knee ligament damage [26, 27].

There are several studies on other sports, and the effect of fatigue on the position sense (angle restoration) of the lower limb has been investigated using different protocols in laboratory medium and artificial conditions. However, no study has been conducted on the effect of fatigue on the restoration of lower limb angles in outdoor and natural environments and real mountaineering conditions. Accordingly, this study investigates the effect of fatigue on lower limb joint angle restoration before and after the climbing program in natural environments and conditions.

Materials and Methods

Study participants

This was a semi-experimental study. The sample included 35 mountaineers aged 20-35 years. This research was conducted on September 10, 2022, at Tochal Climbing Rout in Velenjak, Tehran City, Iran.

The inclusion criteria were 1 to 3 years of mountaineering experience, passing mountaineering training courses, official membership in the Iran Mountaineering and Sport Climbing Federation, having proper shoes and backpack, no history of any fracture in the lower limb, ankle strain, and sprain, injury in the spine knee, and ankle joints, not having obvious abnormalities in the lower limb. Meanwhile, the exclusion criteria were leaving the climb incompleted task for any reason, unwillingness to participate in the pre-test and or post-test, the occurrence of any unforeseen event leading to a serious change in the way of climbing on the route, obtaining a score of less than 15 on the Borg rating of perceived exertion [28], and descending by cable car or chairlift.

Data extraction

This research included 35 climbers (20 men and 15 women). It was conducted on September 10, 2022, at the route of climbing Tochal Peak in Velenjak, Tehran City, Iran.

The implemented mountaineering program included an 8 km distance and a height of 1800 m above sea level at the start point and 2300 m at the top point of the route. It took 3 h at an average speed, in the form of a climbing group, and the tests were done before and after the mountaineering program. The tests measured the restoration rate of joint angles at angles of 30°, 45° and 60° for the knee, 10° dorsiflexion, and 20° plantar flexion for the ankle using Mobeemed (Figure 1), which is an electrogoniometer with a validity of 0.90. The device was used to evaluate the joint angle restoration rate before and after climbing [29].

Figure 2. Evaluation of knee proprioception at angles of 30, 45 and 60 degrees

Figure 3. Evaluation of ankle proprioception at 10 degrees of dorsiflexion and 20 degrees of plantar flexion

Knee joint positional sensation

The device was attached to the tibia and fixed by an estrap band to measure the knee joint angles. The position of the joint angle at any moment was shown numerically on the monitor. Furthermore, a pad was placed under the thigh in such a way that the femur was parallel to the horizon during the test. The evaluation of the position sense by the active test method along with the active restoration of the same limb was used to evaluate the knee joint proprioception [30].

At the end, the subject was asked to sit on a chair so that the legs were hanging from the edge of the chair and the eyes were closed. The hip and knee joint angles were bent at 90° and the Mobeemed was set at 0° after sitting. In this method, the examiner first took the subjects' legs passively to 30°, 45° and 60°, which are the target angles, and asked them to actively keep their legs at these angles and remember them (5 s). The examiner first raised the subjects' legs to the target angle to determine the test angles. The knee was then placed in a rest position (90° flexion) by the examiner. The subjects were then asked to reconstruct the target angle with the same limb actively without using the sense of sight and only relying on proprioception. The error rate of the subjects in reconstructing the target angle was recorded as joint position sense error. The rest position is 90° knee flexion and 90° hip flexion (Figure 2).

Ankle joint positional sensation

The test was repeated three times for each target angle. The subjects sat on a chair in such a way that the angle of the trunk with the thigh and the thigh with the knee was at 90° to measure the ankle proprioception. The height of the seat was adjusted so that the subjects' soles did not reach the ground. The subjects' eyes were closed by blindfolds to eliminate visual feedback during measurement. The examiner passively placed the subjects at a certain angle called the target angle and asked them to remember it for 5 s while actively keeping their legs at this angle. The rest time between each angle test was one minute. The angles were considered for dorsiflexion of 10° and plantar flexion of 20°. The difference between the angle set by the subjects and the target angle was considered an error. The test was repeated three times for each movement. Finally, the average of the three angles obtained was recorded as the main number for each movement [29] (Figure 3).

Statistic analysis

The data were statistically analyzed using the SPSS software, version 24, and the normality of the data was checked using the Shapiro-Wilk test. Since the data were normally distributed, parametric statistics were used, and a paired sample t-test was used to compare the data ($\alpha \leq 0.05$.)

Results

Descriptive findings

The frequency and percentage frequency of gender of the samples are provided in Table 1. Accordingly, 20 people (57.1%) were male, and 15 people (42.9%) were female. Meanwhile, the subjects were 20 to 35 years old, and the total sample number was 35.

Table 1. Frequency and percentage frequency of age and gender of the samples (n=35)

Age (y)	Gender	%	No. (%)
20-35	Male	54.3	20(57.1)
	Female	45.7	15(42.9)
Total		100	35(100)

Iranian Rehabilitation Journal

Table 2. The results of the Shapiro-Wilk test to check the normality of the data related to the research variables

Variables	Indicator	Phase			
		Pre-test		Post-test	
		Z	P	Z	P
Knee angle	30°	0.134	0.061	0.098	0.200
	45°	0.124	0.175	0.125	0.185
	60°	0.104	0.184	0.127	0.167
Ankle angle	10° dorsiflexion	0.132	0.200	0.131	0.122
	20° plantar flexion	0.134	0.400	0.134	0.112

Iranian Rehabilitation Journal

The normality of the distribution of variables in research groups

In this research, the assumption of normality of data distribution was confirmed by the Shapiro-Wilk test (P>0.05). According to Table 2, the data related to the variables of knee angle (30°, 45° and 60°), and ankle angle (10° of dorsiflexion and 20° of plantar flexion) is not significant (P>0.05). Therefore, the data-related to the following variables have a normal distribution and the condition of using parametric tests is established.

Descriptive findings for knee and ankle angles

Table 3 shows the descriptive findings of knee angle (30°, 45° and 60°) and ankle angle (10° dorsiflexion and 20° plantar flexion).

Discussion

This study investigates the effect of fatigue on the restoration error of the knee and ankle joint angles, fatigue due to the effect on the neuromuscular conduction process increases the restoration error, which leads to in-

Table 3. Mean±SD of the variables

Variables	Indicator	Mean±SD		t	P
		Pre-test	Post-test		
Knee angle	30°	6.20±5.11	9.28±6.08	-3.91	0.003
	45°	7.00±4.24	9.91±4.97	-3.04	0.004
	60°	8.54±5.52	11.94±8.25	-2.84	0.007
Ankle angle	10° dorsiflexion	5.11±3.64	6.77±4.86	-2.77	0.009
	20° plantar flexion	4.42±3.96	7.60±5.60	-4.09	0.001

Iranian Rehabilitation Journal

juries, falls, and even death of climbers. Also, no study specifically examines the mechanism of the effect of fatigue on climbers, and the reports in this study are based on studies on other sports or the effect of fatigue due to physical activity.

The effect of fatigue on knee and ankle angle restoration

According to the results, there was a significant difference between the restoration of the angles of 30°, 45°, and 60° in the knee and 10° dorsiflexion and 20° plantar flexion before and after the mountaineering program so that the mean scores of the post-test increased significantly compared to the pre-test. Therefore, the difference between knee and ankle angle restoration increased in the post-test stage compared to the pre-test. In the literature review, no study on mountaineering was found to investigate the effect of fatigue on the above variables.

Physiological factors of fatigue

Fatigue is believed to affect the neuromuscular junction on the one hand and gradually reduce the involuntary muscle activation affect the muscles and their contraction mechanisms, increase the muscle spindle discharge threshold, and affect the simultaneous alpha-gamma activity on the other hand [31]. The knee joint restoration error in the proposed angles increased significantly after fatigue probably for this reason.

The Golgi tendon organ is another proprioceptor in muscle tendons in addition to the proprioceptors of the muscle spindle which is found in the muscle ventricle and sends information about muscle length to the nervous system. The Golgi tendon organ has a lower stimulation threshold for the changes resulting from the contraction of muscle tension and a higher threshold for the tension resulting from muscle stretching. Muscle stretching does not always activate Golgi tendon organs, while muscle contraction always activates these proprioceptors [32]. The mechanism of muscle fatigue is that metabolic substances, such as lactic acid accumulate inside the muscle in the final stages of exercise [33]. Metabolic substances reduce nerve conduction velocity and decrease muscle contraction [34]. Various factors, such as muscle weakness and decreased neuromuscular coordination cause joint injuries, such as ligaments and joint capsules during fatigue [35]. Muscle fatigue also reduces the functional capacity of muscles, disrupts the simultaneous activation of agonist muscles, and reduces the function and efficiency of the neuromuscular system [36]. Muscle fatigue affects proprioception and balance, inhibiting neuromuscular control and preventing mechanoreceptors from properly activating [37]. The effect of knee muscle fatigue on knee joint proprioception in professional karate practitioners was investigated in a study by Boroushak and Roshani, and it was found that muscle fatigue significantly affects the knee joint restoration error at a 60° motion angle [38]. This was in line with the results of the present study on knee joint restoration at a 60° motion angle. The results also suggested that the joint restoration error increased after fatigue at angles of 30° and 45°, which was not statistically significant. The researchers concluded that the decrease in the ability of the knee joint to control the position caused by muscle fatigue in karate practitioners, especially at the end of the range of motion, made the knee prone to injury in addition to the weakness in performing the correct technique [39]. The results of a study by Sutton et al. (2022), showed that disturbances in proprioception after fatigue can be due to a decrease in motor neuron output and sensitivity of group III and IV muscle afferents [40]. According to studies on the biomechanical characteristics of the tissue after muscle stretching, the degree of stiffness in the inner and outer fibers of the muscle spindle decreases immediately after stretching so that it can reduce the muscle spindle discharge [41]. The muscle spindle is sensitive to stretching, and the decrease in the accuracy and function of the muscle spindle after stretching is likely to increase the joint angle restoration error [42].

According to the results of various studies, physical fatigue reduces the activity of muscle receptors. In mountaineering, respiratory acidosis occurs due to a decrease in oxygen pressure at altitude in addition to metabolic acidosis due to continuous physical activity, intracellular H^+, and a decrease in sodium bicarbonate (HCO_{3-}). The decreased level of oxygen and the decrease in the central nervous system function on the one hand and the increased level of H^+ in the neuromuscular synapses and the decrease in the function of neurotransmitters on the other hand decrease neuromuscular control, ultimately leading to a decrease in the ability of a person to control the lower limbs [43]. Contrary to the results of this study, Ghahremani et al. (2017) reported that the fatigue of the erector spinal muscles does not significantly affect the position sense of 30° and 60° knee flexion, 30° hip flexion, and the potential for injury of this joint. Regular movement and sports activities strengthen the knee area and joint proprioception [44]. In contrast to the present study, Gurney et al. suggested that muscle fatigue is not involved in the reduction of joint position sense. This can be attributed to the low muscle force and the application of local fatigue [45].

According to the results of the statistical analysis of ankle fatigue, there was a significant difference between 10° dorsiflexion and 20° plantar flexion of the ankle in the post-test and pre-test phases. This means that the fatigue caused by the mountaineering program led to an increase in the ankle angle restoration error in the participants of this study.

Naderian et al. (2018), in a study titled "effect of functional fatigue on position sense of ankle joint in female futsal players," by creating futsal functional fatigue through the Bangsbo modified futsal fatigue protocol in 22 female futsal players, found that the error rate of futsal players in reconstructing the target angle increased significantly after fatigue. Moreover, the fatigue level of the subjects in the post-test was significantly higher than in the pre-test according to the Borg rating of perceived exertion. This was in line with the results of the present study [46]. The peroneus longus muscle is the first defense mechanism against ankle inversion, contributing to preventing forces and maintaining balance [47]. The mechanism of lateral ankle sprain is that the foot is naturally placed in plantar flexion and inversion during exercises after jumping up and the person then lands on the toe and outer edge of their foot in the same position. Most ankle sprains are lateral and belong to the anterior talofibular ligament due to the low stability of the foot in plantar flexion and ligament stretching in this position [48]. The ankle joint becomes unstable and prone to reinjury following injury [49]. Fatigue increases the risk of ankle injury due to impaired ankle joint position sense [50]. Muscle fatigue reduces the activity of the peroneus longus and neuromuscular transmission velocity; however, increasing resistance of the fibula muscles can prevent sprains [51]. Most researchers agree on the effect of fatigue and the proposed mechanisms mentioned in the study by Naderian et al. (2018). In a study by Mohammadi et al. (2015), the effect of functional fatigue on static and dynamic balance indices of athletes with unstable ankles was investigated. According to the results, balance in static and dynamic conditions decreased, and posture fluctuations increased following fatigue. The general index of static and dynamic balance decreased due to the decrease of both anteroposterior and mediolateral indices [52]. The reduced balance in the present study was due to a lack of muscle function during fatigue and the effects of fatigue on proprioception [53]. Insensitivity of muscle spindles and Golgi tendon organs can reduce neural afferents and impair balance [54]. The results of some studies were not consistent with the findings of the present study. For example, Alderton et al. argued that right foot plantar muscle fatigue did not increase postural sway while standing on the right leg on the force plane [55]. Accordingly, postural control in static conditions can be maintained by the compensatory mechanisms activated during muscle fatigue. The results indicated that fatigue can reduce the optimal function of the muscles around the joints and increase the risk of injuries and falls for mountaineers by reducing the person's perception of the angles and knee and ankle joint position sense after a mountaineering program. Long activity, altitude change, environmental conditions such as stony paths, and sometimes conflicts with ice and snow, wind and rain, and other factors are factors that can lead to fatigue in mountaineering. Altitude also leads to loss of appetite. The lack of air oxygen partial pressure leads to a decrease in the saturation of red blood cells and ultimately a decrease in the oxygen available to the muscles, and the supply of adenosine triphosphate in heavy and long-term climbing activities is a serious challenge [56].

Conclusion

Fatigue can disturb the sense of the angles of the knee and ankle joints of climbers, which reduces the climber's understanding of the condition of their joints and can increase the risk of injuries and falls. They can benefit from proprioception and neuromuscular coordination exercises. It can also be recommended to place resting spots on the way up and take rest during these times, and you can get rid of fatigue to some extent by massaging them so that they have optimal performance in climbing. According to the findings of the study, it was found that fatigue could change the feeling of knee and ankle angles in climbers, which can increase the risk of damage and falls. Climbers can know their proprioception to improve their physical condition and prevent injury. Use exercises to improve your sense of joint status. It can also be recommended that you rest on the climbing path, and these times can be restored and fatigue can be relieved to some extent to optimize hiking.

Study limitations

Among the limitations of this research, we can point out that due to the conditions of the COVID-19 pandemic, conducting the test in mountainous conditions, and the non-cooperation of mountaineering groups, it was not possible to include more people in the research. Also, the momentary speed of the climbers on the climbing route could not be controlled and the average speed was used.

Ethical Considerations

Compliance with ethical guidelines

All the subjects in the present study entered the study with full consent and after filling out the consent form. Before starting the research process, all the steps of doing the work and how to perform the test were explained to the subjects and they were assured that the personal information and files of these people will remain completely confidential with the researcher. At the same time, any of the people participating in the research could withdraw from the cooperation in the research at any stage of the research without paying damages. This research approved by the Ethical Committee of Shahid Beheshti University (Code: IR.BU.REC.1401.002), and the Sports Sciences Research Institute of Iran (SSRII) (Code: SSIR.REC-2203-1558) and was registered by UMIN Clinical Trials Registry (UMIN-CTR) (Code: R000053893).

Funding

This article was extracted from master's thesis of Morteza Barzegar Bafrouei, approved by Department of Health and Rehabilitation in Sport, Faculty of Sports and Health Sciences, Shahid Beheshti University.

Authors' contributions

All authors contributed equally to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors highly appreciate the Salam Hamanvard Mountaineering Club, which helped in conducting this study.

References

[1] Rauch S, Wallner B, Ströhle M, Dal Cappello T, Brodmann Maeder M. Climbing accidents-prospective data analysis from the international alpine trauma registry and systematic review of the literature. International Journal of Environmental Research and Public Health. 2019; 17(1):203. [DOI:10.3390/ijerph17010203] [PMID] [PMCID]

[2] Woollings KY, McKay CD, Emery CA. Risk factors for injury in sport climbing and bouldering: A systematic review of the literature. British Journal of Sports Medicine. 2015; 49(17):1094-9. [DOI:10.1136/bjsports-2014-094372] [PMID]

[3] Biswas C, Roy K, Dutta R, Kumar Gayen S. An exploratory analysis of mountaineering risk estimation among the mountaineers in the Indian himalaya. In: Sharma UC, Datta M, Sharma V, editors. Geography of the Physical Environment. Berlin: Springer; 2022. [DOI:10.1007/978-3-031-04532-5_37]

[4] Lutter C, Schöffl V. Climbing in older athletes. In: Schöffl V, Schöffl I, Lutter C, Hochholzer T, editors. Climbing medicine: A practical guide. Berlin: Springer; 2022. [DOI:10.1007/978-3-030-72184-8_15]

[5] Schöffl VR, Hoffmann G, Küpper T. Acute injury risk and severity in indoor climbing-a prospective analysis of 515,337 indoor climbing wall visits in 5 years. Wilderness & Environmental Medicine. 2013; 24(3):187-94. [DOI:10.1016/j.wem.2013.03.020]

[6] Barendrecht M, Barten CC, van Mechelen W, Verhagen E, Smits-Engelsman B. Injuries in physical education teacher students: Differences between sex, curriculum year, setting, and sports. Translational Sports Medicine. 2023; 2023:1-11. [DOI:10.1155/2023/8643402]

[7] Jones G, Johnson MI. A critical review of the incidence and risk factors for finger injuries in rock climbing. Current Sports Medicine Reports. 2016; 15(6):400-9. [DOI:10.1249/JSR.0000000000000304] [PMID]

[8] Schöffl V, Morrison A, Schöffl I, Küpper T. The epidemiology of injury in mountaineering, rock and ice climbing. Medicine and Sport Science. 2012; 58:17-43. [DOI:10.1159/000338575] [PMID]

[9] Morrison AB, Schöffl VR. Physiological responses to rock climbing in young climbers. British Journal of Sports Medicine. 2007; 41(12):852-61. [DOI:10.1136/bjsm.2007.034827] [PMID] [PMCID]

[10] Jing L, Shan W, Zhang Y. Risk preference, risk perception as predictors of risky driving behaviors: The moderating effects of gender, age, and driving experience. Journal of Transportation Safety & Security. 2022; 467-92. [DOI:10.1080/19439962.2022.2086953]

[11] Lutter C, El-Sheikh Y, Schöffl I, Schöffl V. Sport climbing: Medical considerations for this new olympic discipline. British Journal of Sports Medicine. 2017; 51(1):2-3. [DOI:10.1136/bjsports-2016-096871] [PMID]

[12] Cloke DJ, Spencer S, Hodson A, Deehan D. The epidemiology of ankle injuries occurring in English football association academies. British Journal of Sports Medicine. 2009; 43(14):1119-25. [DOI:10.1136/bjsm.2008.052050] [PMID]

[13] McLean SG, Fellin RE, Suedekum N, Calabrese G, Passerallo A, Joy S. Impact of fatigue on gender-based high-risk landing strategies. Medicine and Science in Sports and Exercise. 2007; 39(3):502-14. [DOI:10.1249/mss.0b013e3180d47f0] [PMID]

[14] Melnyk M, Gollhofer A. Submaximal fatigue of the hamstrings impairs specific reflex components and knee stability. Knee Surgery, Sports Traumatology, Arthroscopy. 2007; 15(5):525-32. [DOI:10.1007/s00167-006-0226-3] [PMID]

[15] Sokhangu MK, Rahnama N, Etemadifar M, Rafeii M, Saberi A. Effect of neuromuscular exercises on strength, proprioceptive receptors, and balance in females with multiple sclerosis. International Journal of Preventive Medicine. 2021; 12:5. [DOI:10.4103/ijpvm.IJPVM_525_18] [PMID] [PMCID]

[16] Proske U, Gandevia SC. The proprioceptive senses: Their roles in signaling body shape, body position and movement, and muscle force. Physiological Reviews. 2012; 92(4):1651-97. [DOI:10.1152/physrev.00048.2011] [PMID]

[17] Eftekhari F, Abbasi T. [Effect of knee cooling after local fatigue on proprioception in trained women (Persian)]. The Scientific Journal of Rehabilitation Medicine. 2018; 7(2):114-22. [DOI:10.22037/JRM.2018.110950.1647]

[18] Ferlinc A, Fabiani E, Velnar T, Gradisnik L. The importance and role of proprioception in the elderly: A short review. Materia Socio-Medica. 2019; 31(3):219-21. [DOI:10.5455/msm.2019.31.219-221] [PMID] [PMCID]

[19] Sonkodi B, Bardoni R, Hangody L, Radák Z, Berkes I. Does compression sensory axonopathy in the proximal tibia contribute to noncontact anterior cruciate ligament injury in a causative way? A new theory for the injury mechanism. Life. 2021; 11(5):443. [DOI:10.3390/life11050443] [PMID] [PMCID]

[20] Torp D, Donovan L. Chronic foot and ankle injuries. In: Ledoux WR, Telfer S, editors. Foot and ankle biomechanics. Amsterdam: Elsevier; 2023. [DOI:10.1016/B978-0-12-815449-6.00038-X]

[21] Babakhani F, Heydarian M, Hatefi M. The immediate effect of Kinesio tape and wobble board training on ankle joint position sense in athletes with functional ankle instability. Journal of Advanced Sport Technology. 2020; 4(2):49-59. [Link]

[22] Vermeulen S, Bleecker C, Blaiser C, Kilinç ÖO, Willems T, Vanrenterghem J, et al. The effect of fatigue on trunk and pelvic jump-landing biomechanics in view of lower extremity loading: A systematic review. Journal of Human Kinetics. 2023; 86:73-95. [DOI:10.5114/jhk/159460] [PMID] [PMCID]

[23] Yalfani A, Givaki M, Ashoury H. [Comparison of the effect of two kinds of the common and the nasm corrective exercises on the changes of genu varum deformity and balance of adolescent soccer players; A mixed method study (Persian)]. Journal of Qualitative Research in Health Sciences. 2020; 8(2):14-30. [Link]

[24] Ribeiro F, Santos F, Gonçalves P, Oliveira J. Effects of volleyball match-induced fatigue on knee joint position sense. European Journal of Sport Science. 2008; 8(6):397-402. [DOI:10.1080/02614360802373060]

[25] Björklund M. Effects of repetitive work on proprioception and of stretching on sensory mechanisms: Implications for work-related neuromuscular disorders [Medical dissertations]. Umeå: Umeå University; 2004. [Link]

[26] Alshahrani MS, Reddy RS, Tedla JS, Asiri F, Alshahrani A. Association between Kinesiophobia and Knee Pain Intensity, Joint Position Sense, and Functional Performance in Individuals with Bilateral Knee Osteoarthritis. Healthcare. 2022; 10(1):120. [DOI:10.3390/healthcare10010120] [PMID] [PMCID]

[27] Lin JZ, Lin YA, Tai WH, Chen CY. Influence of landing in neuromuscular control and ground reaction force with ankle instability: A narrative review. Bioengineering . 2022; 9(2):68. [DOI:10.3390/bioengineering9020068] [PMID] [PMCID]

[28] van der Zwaard S, Hooft Graafland F, van Middelkoop C, Lintmeijer LL. Validity and reliability of facial rating of perceived exertion scales for training load monitoring. Journal of Strength and Conditioning Research. 2023; 37(5):e317-24. [DOI:10.1519/JSC.0000000000004361] [PMID] [PMCID]

[29] Suh K, Lee B, Lee Y, Seo D. The effects of sitting questionmark exercise and brugger's relief exercise on pain, ROM, proprioception, NDI in patients with chronic cervical pain. Journal of The Korean Society of Integrative Medicine. 2019; 7(4):151-9. [Link]

[30] Amato MP, Ponziani G. Quantification of impairment in MS: Discussion of the scales in use. Multiple Sclerosis. 1999; 5(4):216-9. [DOI:10.1191/135245899678846113] [PMID]

[31] Uysal SA, Düger T. Motor control and sensory-motor integration of human movement. In: Angin S, Şimşek I, editors. Comparative Kinesiology of the Human Body. Amsterdam: Elsevier; 2020. [DOI:10.1016/B978-0-12-812162-7.00024-2]

[32] Boroushak N, Rashedi H, Anbarian M. [Nerve and muscle physiology (Persian)]. Tehran: Avaye Zohour; 2015. [Link]

[33] Peng Y, Zhao L, Hu K, Yang Y, Ma J, Zhai Y, et al. Anti-fatigue effects of lycium barbarum polysaccharide and effervescent tablets by regulating oxidative stress and energy metabolism in rats. International Journal of Molecular Sciences. 2022; 23(18):10920. [DOI:10.3390/ijms231810920] [PMID] [PMCID]

[34] Tenan MS, McMurray RG, Blackburn BT, McGrath M, Leppert K. The relationship between blood potassium, blood lactate, and electromyography signals related to fatigue in a progressive cycling exercise test. Journal of Electromyography and Kinesiology. 2011; 21(1):25-32. [DOI:10.1016/j.jelekin.2010.09.002] [PMID]

[35] Granacher U, Wolf I, Wehrle A, Bridenbaugh S, Kressig RW. Effects of muscle fatigue on gait characteristics under single and dual-task conditions in young and older adults. Journal of Neuroengineering and Rehabilitation. 2010; 7:56. [DOI:10.1186/1743-0003-7-56] [PMID] [PMCID]

[36] Parijat P, Lockhart TE. Effects of quadriceps fatigue on the biomechanics of gait and slip propensity. Gait & Posture. 2008; 28(4):568-73. [DOI:10.1016/j.gaitpost.2008.04.001] [PMID] [PMCID]

[37] Ghamkhar L, Kahlaee AH. The effect of trunk muscle fatigue on postural control of upright stance: A systematic review. Gait & Posture. 2019; 72:167-74. [DOI:10.1016/j.gaitpost.2019.06.010] [PMID]

[38] Boroushak N, Roshani R. [Effect of muscular fatigue on the sensation of knee joint position in elite karate athletes (Persian)]. The Scientific Journal of Rehabilitation Medicine. 2020; 9(4): 228-34. [DOI: 10.22037/jrm.2020.111987.2136]

[39] Kamrani M, Khaleghi Tazeji M. [Effect of local fatigue in quadriceps and hamstring muscles on knee joint proprioception in healthy women (Persian)]. Journal of Sport Biomechanics. 2018; 4(3):28-37. [DOI:10.32598/biomechanics.4.3.28]

[40] Sutton P, Lund Ohlsson M, Röijezon U. Reduced shoulder proprioception due to fatigue after repeated handball throws and evaluation of test-retest reliability of a clinical shoulder joint position test. Shoulder & Elbow. 2024; 16(1 Suppl):100-9. [DOI:10.1177/17585732221139795] [PMID] [PMCID]

[41] Blum KP, Campbell KS, Horslen BC, Nardelli P, Housley SN, Cope TC, et al. Diverse and complex muscle spindle afferent firing properties emerge from multiscale muscle mechanics. Elife. 2020; 9:e55177. [DOI:10.7554/eLife.55177] [PMID] [PMCID]

[42] Santuz A, Akay T. Muscle spindles and their role in maintaining robust locomotion. The Journal of Physiology. 2023; 601(2):275-85. [DOI:10.1113/JP282563] [PMID] [PMCID]

[43] Lanuza MA, Just-Borràs L, Hurtado E, Cilleros-Mañé V, Tomàs M, Garcia N, et al. The impact of kinases in amyotrophic lateral sclerosis at the neuromuscular synapse: Insights into BDNF/TrkB and PKC signaling. Cells. 2019; 8(12):1578. [DOI:10.3390/cells8121578] [PMID] [PMCID]

[44] Ghahremani S, Ghahremani N, Abbasi A. [The effect of erector spinae muscle fatigue on the sensation of trunk, hip, and knee position among the male karate athletes (Persian)]. Journal of Research in Rehabilitation Sciences. 2017; 13(5):239-46. [DOI:10.22122/JRRS.V13I5.2910]

[45] Gurney B, Milani J, Pedersen ME. Role of fatigue on proprioception of the ankle. Journal of Exercise Physiology. 2000; 3(1):8-13. [Link]

[46] Naderian F, Mahdavinejad R, zolaktaf V. [Effect of functional fatigue on position sense of ankle joint in female futsal players (Persian)]. Journal for Research in Sport Rehabilitation. 2018; 6(11):33-42. [DOI:10.22084/RSR.2018.15326.1360]

[47] Shaw MY, Gribble PA, Frye JL. Ankle bracing, fatigue, and time to stabilization in collegiate volleyball athletes. Journal of Athletic Training. 2008; 43(2):164-71. [DOI:10.4085/1062-6050-43.2.164] [PMID] [PMCID]

[48] Yeung MS, Chan KM, So CH, Yuan WY. An epidemiological survey on ankle sprain. British Journal of Sports Medicine. 1994; 28(2):112-6. [DOI:10.1136/bjsm.28.2.112] [PMID] [PMCID]

[49] Verhagen RA, de Keizer G, van Dijk CN. Long-term follow-up of inversion trauma of the ankle. Archives of Orthopaedic and Trauma Surgery. 1995; 114(2):92-6. [DOI:10.1007/BF00422833] [PMID]

[50] Steib S, Zech A, Hentschke C, Pfeifer K. Fatigue-induced alterations of static and dynamic postural control in athletes with a history of ankle sprain. Journal of Athletic Training. 2013; 48(2):203-8. [DOI:10.4085/1062-6050-48.1.08] [PMID] [PMCID]

[51] Bove M, Faelli E, Tacchino A, Lofrano F, Cogo CE, Ruggeri P. Postural control after a strenuous treadmill exercise. Neuroscience Letters. 2007; 418(3):276-81. [DOI:10.1016/j.neulet.2007.03.036] [PMID]

[52] Mohammadi H, Sahebozamani M, Seyfaddini MRA. [Effect of functional fatigue on dynamic and static balance indexes in athletes with ankle instability (Persian)]. Journal of Rehabilitation Medicine. 2015; 4(1):63-71. [Link]

[53] Seo BD, Kim HJ, Ju JY. Effect of muscle fatigue on the proprioception by the taekwondo training type. Journal of The Korean Society of Physical Medicine. 2020; 15(3):1-9. [DOI:10.13066/kspm.2020.15.3.1]

[54] Niang AE, McFadyen BJ. Effects of physical activity level on unobstructed and obstructed walking in young male adults. Gait & Posture. 2005; 22(1):75-81. [DOI:10.1016/j.gaitpost.2004.07.003] [PMID]

[55] Adlerton AK, Moritz U, Moe-Nilssen R. Forceplate and accelerometer measures for evaluating the effect of muscle fatigue on postural control during one-legged stance. Physiotherapy Research International: The Journal for Researchers And Clinicians in Physical Therapy. 2003; 8(4):187-99. [DOI:10.1002/pri.289] [PMID]

[56] Luks AM, Ainslie PN, Lawley JS, Roach RC, Simonson TS. Ward, milledge and west's high altitude medicine and physiology. Boca Raton: CRC Press; 2021. [DOI:10.1201/9780429444333]