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The effect of fatigue on performance and landing mechanics of adolescence taekwondo players

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Abstract

Background: Fatigue as one of the physiological factors can affect the physical performance of athletes. This issue is more important in young athletes and can expose them to injury.

Aim: The purpose of this research was to investigate the effect of functional fatigue on the performance and landing mechanics of adolescence taekwondo athletes.

Materials and Methods: This was a semi-experimental study. Participants were 20 male teenage taekwondo players. Pre-fatigue measurements included side-jump tests, figure-8 hop tests, and single-leg triple jump tests, as well as a lower limb biomechanics assessment using a landing error scoring system. After the functional fatigue protocol was applied, all the pre-fatigue variables were evaluated again. In order to examine the intra-group changes of the research variables in the pre and post-test stages, the paired t-test at a significance level of $P \leq 0.05$ was used.

Results: The paired-t test results revealed that following fatigue induction, performance in the side-jump and figure-8 hop tests significantly deteriorated ($P<0.05$). Additionally, performance in the single-leg triple hop test declined ($P<0.05$). Moreover, landing error significantly increased ($P<0.05$).

Conclusion: The finding of this study indicated that after applying fatigue, the subjects' performance decreased and the biomechanical error of the lower limbs increased. Fatigue can significantly impact adolescent taekwondo athletes' performance and biomechanics. So, taekwondo coaches should implement effective strategies to mitigate fatigue, enhance athletes' conditioning, and optimize their performance in training and competitions.

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1. Introduction

Fatigue is a multifaceted phenomenon characterized by neuro-muscular alterations that compromise the body's capacity to generate force, leading to performance impairments [1]. Fatigue is associated with the accumulation of metabolites like lactate, which alters pH levels and affects sensory receptors like muscle spindles and Golgi tendon organs [2]. These receptors relay information about limb movement to higher brain centers, triggering inhibitory motor signals that decrease muscular performance [3].

Fatigue also affects various components of the sensory-motor system, including the central nervous system, neuromuscular junctions, and muscle fibers. This leads to reduced muscle efficiency in force production and an increased susceptibility to performance limitations, ultimately increasing the risk of injury [4].

Athletes frequently experience fatigue during sports participation, leading to decreased joint stability and a heightened risk of injury [5]. Studies suggest that many injuries occur towards the end of competitions or training sessions when fatigue is most pronounced [6, 7]. This is particularly relevant in sports like taekwondo, where competitions are concentrated within a single day, with athletes participating in multiple consecutive bouts, sometimes within a half-day [7, 8]. The cumulative fatigue from these bouts can significantly increase the risk of injury [7].

Previous research has reported that decreased neural-muscular capacities, reduced performance, increased postural oscillation, impaired proprioceptive function, motor errors, and subsequent increased likelihood of lower limb injuries are associated with fatigue [9]. Muscular power of the lower limbs is among the valuable factors in sports competitions for achieving success [10]. This is because power, as one of the factors of physical fitness, can significantly impact an athlete's performance in executing various skills [10, 11]. Jump performance can indirectly predict the explosive power of the lower extremities and is intimately related to kinematic function [7]. However, like other factors affecting athletes' physical performance, this factor may also be influenced by fatigue [3].

Fatigue can also play a significant role in the mechanical behavior pattern of the lower limb joints during the execution of functional tasks such as cutting, rotating, or landing, by causing a decrease in neural-muscular performance [5]. Studies have indicated that fatigue leads to a decline in lower limb performance and weakens biomechanical joint stability, which in some ways predicts the occurrence of lower limb injuries [9].

Some researchers have reported that after fatigue, an increase in knee valgus angle and a decrease in knee flexion angle occur during sports tasks [12, 13].

Tamura et al. (2017) reported the impact of fatigue on lower limb kinematics during landing in healthy young women, suggesting that changes in lower limb joint kinematics due to fatigue can be considered a contributing factor to common lower limb injuries, including anterior cruciate ligament tears [12].

These explanations are important, as weak biomechanical control during sports activities is more prevalent in younger individuals, increasing the likelihood of knee injuries in this age group [14, 15]. Adolescents, who are in the puberty stage, are more susceptible to musculoskeletal injuries than adults [15].

Although the mechanisms of ligamentous injury in the lower extremities are well-known, further research is needed in the adolescent age group, as the characteristics associated with puberty can influence injury mechanisms in young athletes. While numerous studies have investigated the effects of fatigue on performance and biomechanics of the lower extremities in athletes from various sports disciplines, the majority of these studies have focused on adults and team sports such as football and volleyball [5, 7, 9].

Taekwondo is a sport where most movements are performed by the lower extremities. Consequently, almost half of all injuries in taekwondo competitions occur in the lower extremities, with sprain ligament injuries being the most common type [8, 16]. This issue is more important in adolescent taekwondo athletes [17, 18].

Taekwondo athletes in the child and adolescent age groups have been reported to be at a higher risk of musculoskeletal injuries [8]. Insufficient skills, lower muscular strength and endurance, and reduced neuromuscular coordination are considered reasons for this [19]. Therefore, studying lower extremity injuries in young taekwondo athletes is important, as this sport is inherently high-risk, especially during competitions where factors such as competition excitement, the competition environment, and officiating can influence the athlete's performance and concentration, increasing the risk of injury [20].

Despite the significant participation of adolescents in taekwondo, the impact of fatigue on lower extremity injuries in this population has received limited research attention. This study aims to address this gap by investigating the effects of fatigue on performance and biomechanics in adolescent taekwondo athletes, providing valuable insights for injury prevention and performance optimization strategies.

2. Materials and Methods

2.1. Study design

This study adopts a semi-experimental design with a single-group pre-test/ post-test intervention. The intervention consists of a fatigue protocol, and the effects of fatigue on performance and biomechanics of the lower extremities will be assessed through pre-test and post-test measurements.

2.2. Participation

The statistical population of the study includes all male adolescent taekwondo practitioners aged 15-18 years in Karaj city.

A sample of 19 taekwondo practitioners was selected from the statistical population and based on Paired t-test statistical method. The sample size was determined using G*Power software version 1.3, with an effect size of 0.7, alpha of 0.05, and statistical power of 0.9, based on the mean and standard deviation of previous similar study [5]. To account for potential non-participation, the sample size was increased from 19 to 20.

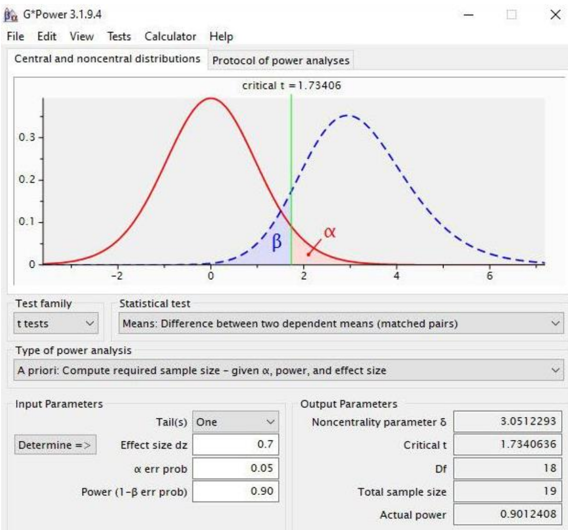

Figure 1. G- Power Software (Sample size calculation)

The samples were selected from athletes who had a three-year history of continuous activity at the league level of taekwondo in Alborz province.

Inclusion criteria comprised age range: 15-18 years, male gender, minimum 3 years of participation in taekwondo competitions in Alborz province, regular taekwondo training (at least 3 sessions per week), no history of severe lower extremity or lumbar surgery, no lower extremity abnormalities (flat/ hollow foot, valgus/ varus knee, unlevel hip), no lower extremity musculoskeletal injuries in the past year, no ankle, knee, or hip joint instability.

Participants were excluded if they reported physical problems during the fatigue protocol (weakness), pain or disability during jump tests and lack of cooperation for proper implementation of the research stages.

2.3. Procedure

Initially, coordination was established with taekwondo clubs in Karaj city that participated in the Alborz province league. During a coordination session, the research objectives and procedures were explained to coaches and athletes. Among the clubs that volunteered, 20 adolescent taekwondo practitioners were randomly selected based on the inclusion criteria. Informed consent forms were obtained from the participants' parents, and the potential benefits and risks of participation were explained. This study adheres to the ethical principles of the Helsinki Treaty.

2.4. Data collection

The research was conducted at the participants' taekwondo club. Anthropometric measurements (height, weight, body composition) were recorded. Participants then performed a 7-min warm-up consisting of stationary bike cycling, stretches, and taekwondo-specific exercises [21]. Pre-fatigue measurements included: side-jump tests, figure-8 hop tests, single-leg triple jump tests, lower limb biomechanics assessment using a landing error scoring system [22, 23]. Following these measurements, the fatigue protocol was implemented. Participants were instructed to perform the protocol to the best of their ability [24]. Post-fatigue measurements included a repetition of all pre-fatigue assessments.

2.5. Fatigue protocol

This study employed the functional fatigue protocol used in taekwondo, previously validated by Mirjani et al. (2017) [21]. Participants performed dolyo-chagi kicks with maximum power and minimal time along an 8m path (equivalent to a taekwondo floor), alternating between left and right legs. Each back-and-forth movement was considered one set. Before the fatigue protocol, participants performed two sets to familiarize themselves with the procedure.

Following the initiation of the fatigue protocol, participants engaged in active recovery between sets. This recovery consisted of taekwondo footwork dancing for twice the duration of the first set, adhering to a work-to-rest ratio of 1:2. This clarifies the proportion of work (fatiguing exercise) to rest (footwork dance) during each cycle. In this case, for every 1 unit of time spent doing the fatiguing exercises, they spent 2 units of time doing the recovery activity. Fatigue was deemed to have been reached when participants completed 30 sets within a minimum of 19 min and reported a fatigue level of 17 or higher on the Borg scale [21].

2.6. Performance tests

Participants' performance was evaluated

using side-jump tests, figure-8 hop tests, and single-leg triple jump tests. Each test was performed twice, and the best record was recorded as the score for the respective performance test [22].

The side-jump test measured power, speed, balance, and rotational stability of the lower limbs, emphasizing control on one leg. This test has a reported reliability of 0.97 [25]. Participants performed side-jump back and forth over a 30cm distance marked on the ground using their dominant leg. The time was measured using a chronometer with an accuracy of 0.1 sec [22].

The figure-8 hop tests also measured power, speed, balance, and coordination of the lower limbs, emphasizing control on one leg [25]. This test was performed along an eight-shaped path with a length of 5m and a width of 1m. Participants completed the path twice using their dominant leg (with a lunge technique and maximum speed). The time was recorded using a chronometer with an accuracy of 0.1 sec [22].

The single-leg triple jump test measured lower limb power and strength [26]. Its reliability coefficient has been reported as 0.98 by Hamilton et al. (2008) [26]. Participants stood with their dominant leg behind the starting line and executed three consecutive maximal jumps with the same leg in a straight line. The score was calculated in centimeters from the starting line to the point of heel contact with the ground on the third jump [22].

2.7. Measurement of landing biomechanics

In order to evaluate the landing biomechanics of the participants, the landing error scoring system test was used [27]. The procedure for conducting this test involves the participant standing on a 30cm box while a target line is drawn on the ground at 50% of their height. The participant is instructed to perform a forward jump from the box and immediately after landing with both feet on a designated point, execute a maximum vertical jump. The participant must not pause between landing on the ground and initiating the vertical jump. After demonstrating the test procedure by the examiner, the participant is usually given two or three practice attempts. The participant does not receive any specific instructions from the examiner regarding proper landing mechanics. Two iPhone 11 Pro Max cameras, manufactured in China, with a 12-megapixel resolution and HD full image clarity, were installed on fixed stands at a side view distance of 4.8m and a front view distance of 4m for video recording purposes [27, 28]. The recorded videos were then slowed down using the lnk1.0.ReSpeedr software (Germany, proDAD GmbH) and analyzed by the examiner [23]. ReSpeedr is a software application designed for creating stunning slow-motion videos. ReSpeedr is suitable for a wide range of video editing projects including sports highlights and also artistic expression. The Landing Error Scoring System (LESS) form consists of 17 items that assess the landing and jumping mechanics of the individuals. In each item, a score of 0 is considered correct movement, while a score of 1 indicates an error [23].

2.8. Statistic

The data obtained from measuring the variables in this study were analyzed using SPSS version 22 software. Paired t-tests were used to examine intragroup changes in the research variables between pre-test and post-test stages. All statistical analyses used a significance level of $P<0.05$.

3. Results

The anthropometric characteristics, including age, height, weight, and body mass index, of the research participants are reported in Table 1.

To evaluate the effect of the fatigue protocol on the research variables in the pre-test and post-test condition (intragroup changes), paired t-tests were used. Descriptive statistics of the research variables at different measurement stages, as well as the results of the paired t-tests, are presented in Table 2. The paired t-test results revealed that following fatigue induction, performance in the side-jump and figure-8 hop tests significantly deteriorated ($P<0.05$), as evidenced by increased completion times. Additionally, performance in the single-leg triple hop test declined ($P<0.05$), as indicated by a reduced distance covered. Moreover, landing error significantly increased ($P<0.05$).

Table 1. Central tendency indices and anthropometric variables of the participants

Variable	Age (Year)	Height (Cm)	Weight (Kg)	BMI (kg.m^2)
Mean	17.86	174.37	65.61	23.46
SD	4.4	5.2	6.1	1.5

Table 2. Descriptive statistics of research variables at pre-test and post-test stages and the results of paired t-test

Variable		Pre-test	Post-test	t	P
Landing biomechanic (LESS)		9.52±2.2	14.68±2.7	3.2	0.001
Performance	Side-jump (s)	7.35±1.1	11.22±1.5	2.9	0.021
	Figure-8 hop (s)	8.13±2.0	11.91±2.1	1.6	0.005
	Single-leg triple jump (Cm)	238.63±7.7	193.72±9.1	2.5	0.001

4. Discussion

The aim of this study was to examine the effect of fatigue on the performance and landing biomechanics of adolescent taekwondo athletes. The results of the present research showed that the application of the fatigue protocol can cause a decrease in performance and the occurrence of incorrect landing patterns in young taekwondo athletes. These results can be attributed to a disorder in the myoelectric function of the muscles due to the biochemical effects of fatigue on the neuromuscular system [29].

The topic of fatigue and its effects on landing performance is an important area of research. According to the definition provided by Fitts RH (2008), local (peripheral) fatigue appears on the surface of the muscles and causes various disorders in the factors that generate force and power in the muscle [30]. On the other hand, general (central) fatigue is related to the whole body, especially the central nervous system [30].

In this context, Paillard (2012), in a review study and also Ghram et al. (2014) showed that both local and general fatigue have similar effects on body balance [31, 32].

Khalkhali et al. (2012) observed that the sense of strength increases after both local and general fatigue, and there is no significant difference between these two types of fatigue [33]. Therefore, regardless of the type of fatigue, it can be claimed that the appearance of fatigue in athletes can cause physical performance impairment [4].

The results of electromyography studies on fatigue and muscle function indicate that the decrease in mean frequency is generally due to two factors. First, there is a decrease in the conduction speed of the muscle fiber action potential. Second, there is an increase in the duration of the action potential of the motor unit [29]. This suggests that the decrease in motor unit discharge, the increase in extracellular potassium ions, and the disruption of sodium channels may lead to decreased stimulation of the muscle fiber membrane. As a result, the conduction speed of the muscle fiber action potential decreases [34]. Consequently, the fatigue program appears to cause a decrease in the speed of nerve transmission in both the afferent and efferent pathways to the target muscle group. This, in turn, leads to a decrease in the mean frequency of the muscle after the fatigue program is applied [4].

The findings of the present study on landing biomechanics revealed that following fatigue induction, movement error significantly increased during the landing error scoring system test. In general, following the development of fatigue, the risk of various injuries during functional movements increases, which is probably the main reason for the movement's biomechanical changes or compensatory mechanisms of the central nervous system [5].

The compromised muscular strength and power translation due to peripheral fatigue would mean decreased hip and knee flexion velocity and end range upon ground contact [13].

At the same time, the suboptimal neuromuscular coordination stemming from central fatigue would interfere with fine motor control, possibly increasing valgus knee motion and ground reaction force spikes [24]. It really elucidates how fatigue undermines proper mechanics at multiple levels. No wonder it heightens injury risk, especially in the young athletes still developing motor skills [14, 24]. Managing fatigue is paramount for sport performance as well as long term athlete health and development.

The results of this study showed that after applying functional fatigue, the subjects' performance decreased and the biomechanical error of the lower limbs increased. These findings align with previous research demonstrating the effects of fatigue on the performance and biomechanics of the lower limbs in athletes [5, 9, 24]. Indeed, being fatigued could negatively impact mechanics and risk of injury [5]. It seems fatigue disproportionately affects landing mechanics in adolescent athletes.

However, Fallah et al. (2019) did not observe a significant difference in the knee angle at the initial contact of the foot with the surface, maximum knee flexion, and maximum vertical force after the implementation of the fatigue protocol [35]. Therefore, their results are in contrast with the results of the present research, which can be attributed to the difference in the subjects, the method and type of fatigue protocol application, and the method of evaluating the biomechanics of the lower limbs.

Our results revealed that following fatigue induction, the athlete's performance significantly deteriorated and also landing error significantly increased. The issue of fatigue is important in adolescent athletes because research indicates the presence of neuromuscular and biomechanical defects in children and adolescents compared to adults [24].

Holden et al. (2016) believe that adolescents use proximal control strategies when performing functional tasks such as landing [36]. Presetting the tension in the thigh and knee muscles before landing is important for the posture at the moment the foot hits the ground [35].

In children, the pre-adjustment of simultaneous contraction in the knee is low, and controlling the body position during landing is considered a big challenge for children [14]. Weakness in neuromuscular control in this age group may be one of the possible reasons for this issue [36]. Also, due to the lack of sufficient strength in the muscles, during landing, the ankle is not able to remove the ground reaction force through the ankle strategy; therefore, by using the proximal control strategy, they perform the landing movement [14].

According to the above material, it can be said that fatigue can aggravate these conditions and pose more challenges in physical performance and motor control of teenagers [24]. For this reason, all the trainers who are working with young athletes should pay attention to the issue of fatigue and its effects on the variables affecting the occurrence of lower limb injuries.

5. Conclusion

Our results revealed that following fatigue induction, the athlete's performance significantly decreased and also landing error significantly increased. Understanding the mechanisms of fatigue and its impact on athletic performance is crucial for developing effective training and recovery strategies. In high-intensity sports like taekwondo, managing fatigue and implementing appropriate recovery protocols is essential for mitigating injury risk and optimizing athlete performance. The trainers must be aware and structure practices appropriately for younger athletes. It certainly seems fatigue management should be a training priority for adolescent athletes to help protect long-term health.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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References

[1] Twomey R, Aboodarda SJ, Kruger R, Culos-Reed SN, Temesi J, Millet GY. "Neuromuscular fatigue during exercise: Methodological considerations, etiology and potential role in chronic fatigue". *Neurophysiologie Clinique/ Clinical Neurophysiology*. 2017; 47(2): 95-110. doi: https://doi.org/10.1016/j.neucli.2017.03.002.

[2] Mitchell JB, Rogers MM, Basset JT, Hubing KA. "Fatigue during high-intensity endurance exercise: the interaction between metabolic factors and thermal stress". *The Journal of Strength & Conditioning Research*. 2014; 28(7): 1906-14. doi: 10.1519/JSC.0000000000000319.

[3] Grassi B, Rossiter HB, Zoladz JA. "Skeletal muscle fatigue and decreased efficiency: Two sides of the same coin?". *Exercise and Sport Sciences Reviews*. 2015; 43(2): 75-83. doi: 10.1249/JES.0000000000000043.

[4] Nasrabadi R, Sadeghi H, Yousefi M. "Effects of local and global fatigue on the myoelectric variables of selected lower limb muscles in healthy young active men in single jump-landing task". *The Scientific Journal of Rehabilitation*

Medicine. 2020; 9(1): 1-10. doi: 10.22037/JRM.2020.112745.2247.

[5] De Ste Croix MB, Priestley AM, Lloyd RS, Oliver J. "ACL injury risk in elite female youth soccer: Changes in neuromuscular control of the knee following soccer-specific fatigue". *Scandinavian Journal of Medicine & Science in Sports*. 2015; 25(5): e531-e8. doi: https://doi.org/10.1111/sms.12355.

[6] Bengtsson H, Ekstrand J, Waldén M, Hägglund M. "Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year prospective study with more than 130 000 match observations". *British Journal of Sports Medicine*. 2018; 52(17): 1116-22. doi: https://doi.org/10.1136/bjsports-2016-097399.

[7] Hyun SH, Kim YP, Ryew CC. "Effects of fatigue induction on ground reaction force components, postural stability, and vertical jump performance in taekwondo athletes". *Korean Journal of Sport Biomechanics*. 2016; 26(2): 143-51. doi: 10.5103/KJSB.2016.26.2.143.

[8] Son B, Cho YJ, Jeong HS, Lee SY. "Injuries in Korean elite taekwondo athletes: A prospective study". *International Journal of Environmental Research and Public Health*. 2020; 17(14): 5143. doi: https://doi.org/10.3390/ijerph17145143.

[9] Barber-Westin SD, Noyes FR. "Effect of fatigue protocols on lower limb neuromuscular function and implications for anterior cruciate ligament injury prevention training: a systematic review". *The American Journal of Sports Medicine*. 2017; 45(14): 3388-96. doi: https://doi.org/10.1177/0363546517693846.

[10] Pallarés J, Martínez-Abellán A, López-Gullón J, Morán-Navarro R, De la Cruz-Sánchez E, Mora-Rodríguez R. "Muscle contraction velocity, strength and power output changes following different degrees of hypohydration in competitive olympic combat sports". *Journal of the International Society of Sports Nutrition*. 2016; 13: 1-9. doi: https://doi.org/10.1186/s12970-016-0121-3.

[11] Albuquerque MR, Tavares LD, Longo AR, Mesquita PHC, Franchini E. "Relationship between indirect measures of aerobic and muscle power with frequency speed of kick test multiple performance in taekwondo athletes". *International Journal of Sports Medicine*. 2022; 43(03): 254-61. doi: 10.1055/a-1546-9221.

[12] Tamura A, Akasaka K, Otsudo T, Shiozawa J, Toda Y, Yamada K. "Fatigue influences lower extremity angular velocities during a single-leg drop vertical jump". *Journal of Physical Therapy Science*. 2017; 29(3): 498-504. doi: https://doi.org/10.1589/jpts.29.498.

[13] Klein CJ, Landry SC, Lattimer LJ. "Sex-based differences in lower extremity kinematics during dynamic jump landing tasks after neuromuscular fatigue of the hip extensors and knee flexors". *Orthopaedic Journal of Sports Medicine*. 2023; 11(12): doi: https://doi.org/10.1177/23259671231215848.

[14] Moir GL, Munford SN, Snyder BW, Davis SE. "Mechanical differences between adolescents and adults during two landing phases of a drop jump task". *The Journal of Strength & Conditioning Research*. 2022; 36(4): 1090-8. doi: 10.1519/JSC.0000000000003683.

[15] DiCesare CA, Montalvo A, Barber Foss KD, Thomas SM, Ford KR, Hewett TE, et al. "Lower extremity biomechanics are altered across maturation in sport-specialized female adolescent athletes". *Frontiers in Pediatrics*. 2019; 7: 268. doi: doi.org/10.3389/fped.2019.00268.

[16] Duarte VT, Seus TL, Vecchio FBD. "Sports injuries in amateur recreational taekwondo athletes". *Fisioterapia e Pesquisa*. 2022; 29: 113-20. doi: https://doi.org/10.1590/18092950/20004929022022EN.

[17] Oh H, Lim H, Jeon M. "Analysis of sports injury in lower extremities of high school taekwondo athletes". *Applied Sciences*. 2021; 11(24): 11690. doi: https://doi.org/10.3390/app112411690.

[18] Jeong HS, Ha S, Jeong DH, O'sullivan DM, Lee SY. "Injury and illness in world taekwondo junior athletes: An epidemiological study". *International Journal Of Environmental Research and Public Health*. 2021; 18(4): 2134. doi: https://doi.org/10.3390/ijerph18042134.

[19] Guan Y, Bredin SS, Taunton J, Jiang Q, Wu N, Warburton DE. "Predicting the risk of injuries through assessments of asymmetric lower limb functional performance: a prospective study of 415 youth taekwondo athletes". *Orthopaedic Journal of Sports Medicine*. 2023; 11(8): doi: https://doi.org/10.1177/23259671231185586.

[20] Lystad RP, Pollard H, Graham PL. "Epidemiology of injuries in competition taekwondo: A meta-analysis of observational studies". *Journal of Science and Medicine in Sport*. 2009; 12(6): 614-21. doi: https://doi.org/10.1016/j.jsams.2008.09.013.

[21] Mirjani M, Seidi F, Minoonejad H. "The effect of functional fatigue on pattern and onset of electromyography activation of selective lumbo-

pelvic and peroneal muscles in elite female taekwondo athletes". *Sport Sciences and Health Research*. 2017; 9(1): 35-51. doi: 10.22059/JSMED.2017.62870.

[22] Kalantariyan M, Minoonejad H, Rajabi R, Seidi F. "The effect of six weeks suspension training on functional test’s score in athletes with functional ankle instability". *Journal of Paramedical Sciences & Rehabilitation*. 2020; 9(2): 64-75. doi: 10.22038/JPSR.2020.38893.1918.

[23] Kalantariyan M, Rahmani N, Samadi H. "The effects of TRX-based movement pattern correction exercises on the landing biomechanics and balance of female volleyball players susceptible to knee injuries". *Journal of Sport Biomechanics*. 2023; 9(2): 112-27. doi: 10.21859/JSportBiomech.9.2.375.1.

[24] Briem K, Jónsdóttir KV, Árnason Á, Sveinsson ó. "Effects of sex and fatigue on biomechanical measures during the drop-jump task in children". *Orthopaedic Journal of Sports Medicine*. 2017; 5(1). doi: https://doi.org/10.1177/2325967116679640.

[25] Rosen AB, Needle AR, Ko J. "Ability of functional performance tests to identify individuals with chronic ankle instability: A systematic review with meta-analysis". *Clinical Journal of Sport Medicine*. 2019; 29(6): 509-22. doi: 10.1097/JSM.0000000000000535.

[26] Hamilton RT, Shultz SJ, Schmitz RJ, Perrin DH. "Triple-hop distance as a valid predictor of lower limb strength and power". *Journal of Athletic Training*. 2008; 43(2): 144-51. https://doi.org/10.4085/1062-605043.2.144.

[27] Hanzlíková I, Hébert-Losier K. "Is the landing error scoring system reliable and valid? A systematic review". *Sports Health*. 2020; 12(2): 181-8. doi: https://doi.org/10.1177/1941738119886593.

[28] Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett Jr WE, Beutler AI. "The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study". *The American Journal of Sports Medicine*. 2009; 37(10): 1996-2002. doi: https://doi.org/10.1177/0363546509343200.

[29] Marco G, Alberto B, Taian V. "Surface EMG and muscle fatigue: multi-channel approaches to the study of myoelectric manifestations of muscle fatigue". *Physiological Measurement*. 2017; 38(5): R27. doi: 10.1088/1361-6579/aa60b9.

[30] Fitts RH. "The cross-bridge cycle and skeletal muscle fatigue". *Journal of Applied Physiology*. 2008; 104(2): 551-8. doi: https://doi.org/10.1152/japplphysiol.01200.2007.

[31] Paillard T. "Effects of general and local fatigue on postural control: a review". *Neuroscience & Biobehavioral Reviews*. 2012; 36(1): 162-76. doi: https://doi.org/10.1016/j.neubiorev.2011.05.009.

[32] Ghram A, Jeribi S, Yahia A, Elleuch M. "Effect of general and local fatigue on postural control during unipedal quiet standing of athlete". *Annals of Physical and Rehabilitation Medicine*. 2014. 57: e192. doi: 10.1016/j.rehab.2014.03.697.

[33] Khalkhali M, Bazrafkan M, Khademi Kalantari K, Rezasoltani A. "A comparative study of the effect of local and general fatigue on sense of force in healthy young men". *The Scientific Journal of Rehabilitation Medicine*. 2012; 1(3): 22-8. doi: 10.22037/JRM.2012.1100066.

[34] Cifrek M, Medved V, Tonković S, Ostojić S. "Surface EMG based muscle fatigue evaluation in biomechanics". *Clinical Biomechanics*. 2009; 24(4): 327-40. doi: https://doi.org/10.1016/j.clinbiomech.2009.01.010.

[35] Soleyman Fallah M, Sadeghi H, Motamedi P, Barati A. "Effect of one stage of exhaustive local fatigue on mechanical parameters of lower-limb joints during the single-leg landing of semi-professional sportsmen". *The Scientific Journal of Rehabilitation Medicine*. 2019; 8(4): 177-84. doi: 10.22037/JRM.2019.111454.2005.

[36] Holden S, Boreham C, Delahunt E. "Sex differences in landing biomechanics and postural stability during adolescence: A systematic review with meta-analyses". *Sports Medicine*. 2016; 46: 241-53. doi: https://doi.org/10.1007/s40279-015-0416-6.

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