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Reliability of the Hop Test and Asymmetry Index in University Athletes: A Cross-Sectional Study Assessing Injury Risk

Sporcu Üniversite Öğrencilerinde Hop Test ile Asimetri İndeksi Belirlemenin Güvenirliği: Yaralanma Riskini Değerlendiren Kesitsel Bir Çalışma

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ABSTRACT

This study aims to assess the reliability of hop tests among healthy university athletes and to identify leg asymmetries through these assessments. A cohort of 212 university athletes, active in sports, participated in the study. Hop tests, comprising four distinct procedures, were administered to evaluate lower extremity strength. The hop tests demonstrated high reliability, with reliability coefficients ranging from 0.704 to 0.990. Examination of asymmetry indices revealed mean values of 101.07%, indicative of symmetrical limb function among participants. Gender-based differences were notable in hop test results, particularly in the crossover hop test, which showed significant asymmetry ($p<.05$). Age-related variances were observed solely in the single-leg hop test ($p<.05$), while asymmetry indices did not significantly differ across age groups ($p>.05$). As a result, it can be concluded that strength imbalances between gender and age are important functions affecting explosive power and the hop test gives reliable results in measuring these parameters. Moreover, the study hints at a low risk of injury among athlete students, given the inferred association between asymmetry indices and injury risk. Engaging in tailored physical activities and sports-specific training regimens may foster and sustain normal limb symmetry, potentially mitigating injury risks.

Keywords: Injury, jump, reliability, strength

ÖZ

Bu çalışmanın amacı, sağlıklı üniversite sporcularında hop testlerinin güvenilirliğini değerlendirmek ve bu değerlendirmeler aracılığıyla bacak asimetrilerini belirlemektir. Çalışmaya toplamda 212 sporcu öprenci katılım gösterdi. Alt ekstremite kuvvetini değerlendirmek için dört farklı prosedürden oluşan hop testleri uygulandı. Analiz sonuçlarında hop testin Türk sporcu öğrenci örnekleminde güvenirlik düzeyleri 0,704-0,990 arasında olduğu ve yüksek düzeyde güvenirliğe sahip olduğu belirlendi. Sporcu öğrencilerin asimetri indekslerine bakıldığında ortalamaların 101,07% olduğu ve bu grubun normal uzuv simetrisine sahip olduğu belirlendi. Sporcu öğrencilerin cinsiyetleri açısından hop test değerlerinde farklılıkların olduğu, asimetri indeksi açısından ise sadece çapraz atlamada fark oluştuğu görüldü (p<,05). Sporcu öğrencilerin yaşları ile hop test değerleri arasında negatif yönede anlamlı ilişkilerin olduğu (p<,05), asimetri indeksinde ise yaş açısından ilişkiye rastlanmadığı görüldü (p>,05). Sonuç olarak cinsiyet ve yaş arasındaki kuvvet dengesizliklerinin patlayıcı gücü etkileyen önemli fonksiyonlar olduğu ve bu parametreleri ölçede hop testin güvenilir sonuçlar verdiği çıkarımı yapılabilir. Asimetri indeksleri ile yaralanma riski arasındaki çıkarımsal ilişki göz önüne alındığında, çalışmamız sporcu öğrenciler arasında düşük bir yaralanma riskine işaret etmektedir. Bu bağlamda kişiye özel fiziksel aktivitelere veya antrenman programlarına katılmak, normal uzuv simetrisini teşvik edebilir ve sürdürebilir, bu da potansiyel olarak yaralanma risklerini azaltabilir.

Anahtar Kelimeler: Güvenilirlik, kuvvet, sıçrama, yaralanma

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Introduction

It is a well-established fact that in both team sports and individual sports, factors such as speed, strength, agility, endurance, flexibility, balance, which are influenced by the sequential use of aerobic and anaerobic systems, contribute to performance (Bojic et al., 2015). In today's sporting landscape, many athletes are consciously and professionally trained by experts to elevate themselves to higher levels physically and physiologically, tailored to their respective sports. While each sport has its unique developmental needs, there are common physical, physiological, and performance factors that nearly all sports must develop and maintain at the highest level for optimal performance. Some of these requirements include lower and upper extremity strength, explosive power, and aerobic endurance and functions (Bojic et al., 2015; Stradijot et al., 2012). Particularly in sports where competition is of great importance, lower extremity strength and certain performance components associated with the lower extremities have been the subject of researchers' interest in terms of performance monitoring, injury tendencies, and the effects of certain training models on these components (Hermassi et al., 2014; Kockum & Anette, 2015). Studies that provide more information on how and with which training models aerobic and anaerobic systems are developed can also be considered in this context (Hoff & Helgerud, 2004; Helgerud et al., 2007).

The assessment of lower extremity strength indices is important in determining when athletes are ready to return to sports or when non-athletes are ready to return to activities following an injury, without risking further injury. Sports injuries are a significant factor affecting athletes' performance and a major concern for athlete health. In recent years, limb asymmetry has been suggested to be associated with sports injuries (Fousekis et al., 2010). Limb asymmetry can indicate imbalances in activities performed by athletes and differences in muscle strength, thus increasing the risk of injury. Limb asymmetry can be calculated using various parameters, one of which is the asymmetry index measuring the difference between different limbs. This index is commonly used to assess the asymmetry between specific limbs in athletes (Fousekis et al., 2010). Assessment of the limb asymmetry index offers several important benefits. Firstly, it can be utilized for performance analysis. Asymmetry in athletes' bodies may indicate differences in muscle strength or flexibility in specific areas. This information can help coaches and athletes optimize training programs and enhance performance. Additionally, it is crucial for assessing injury risk (Hides et al., 2017). Particularly, if one limb is weaker or more flexible than the other, it may increase the risk of injury. Evaluation of the limb asymmetry index enables athletes to identify their injury risks and take preventive measures (Hides et al., 2017). Moreover, it can be used in the rehabilitation process. Assessing the limb asymmetry index is a significant tool for monitoring the recovery process of injured athletes and addressing imbalances. Rehabilitation programs can be personalized based on the results of the asymmetry index. It also plays a role in performance optimization (Hides et al., 2017). Assessment of the limb asymmetry index helps athletes understand their body imbalances and correct them, leading to more effective and efficient movements. Lastly, it is essential for long-term health and injury prevention. Evaluation of the limb asymmetry index can assist athletes in maintaining long-term health and preventing injuries through preventive measures (Fousekis et al., 2010). A balanced body structure can help athletes sustain their performance and prevent injuries.

Limb asymmetry can indicate imbalances in muscle strength, and these imbalances have a direct impact on performance. For example, in footballers, the dominant leg is generally stronger and more coordinated, which can make a performance difference in movements such as shooting or rapid change of direction (Impellizzeri et al., 2007). Asymmetric muscle strength and power can also have an effect on explosive movements and speed. Single leg jump tests reveal performance differences by measuring the explosive power capacity of both legs (Bishop et al., 2020). These tests also show how much the injured leg has recovered during the rehabilitation process and how close it is to normal function (Myer et al., 2011). Limb asymmetry can increase athletes' risk of injury. For example, knee injuries, especially anterior cruciate ligament (ACL) injuries, are often associated with asymmetries in strength and balance between the legs. One leg being weaker or less stable than the other increases the risk of such injuries (Hewett et al., 2005). Various tests are used to determine the limb asymmetry index, including measurements of circumference or length, strength tests, flexibility tests, functional tests, and imaging techniques (Hides et al., 2017). Physical performance measures such as single-leg hop tests, commonly utilized in lower extremity assessment, are frequently employed to evaluate an athlete's functional status, detect limb asymmetries, and enable intervention through athlete monitoring (Hegedus et al., 2015; Logerstedt et al., 2017). These tests are characterized by their ease of administration, requiring only minimal equipment, time, and expertise (Ageberg et al., 1998). Additionally, hop tests can be utilized to assess limb symmetry, predict muscle strength, and power in healthy populations. The Limb Symmetry Index (LSI), which expresses the percentage of one limb compared to the other, is the most commonly used method for this assessment. An LSI ≥85% indicates 'normal' limb symmetry and suggests restoration of function in the injured limb when assessed post-injury (Reid et al., 2007; Ross et al., 2002). Hewett et al. (2005) reported that limb asymmetry increases the risk of ACL injury, especially in young athletes, and that force imbalances are an important factor in predicting these injuries. Impellizzeri et al. (2007) examined the effects of leg strength asymmetry on performance and injury risk in football players and showed that asymmetric force distribution can lead to performance losses and injury risk. Myer et al. (2011) examined the effects of injury prevention programmes in young athletes and found that reducing leg strength asymmetries significantly reduced the risk of injury. Croisier et al. (2008) investigated how hamstring and quadriceps muscle strength asymmetries increase the risk of injury and how this risk can be reduced with appropriate training.

A hop test battery that can be utilized for the functional assessment of athletes consists of the Single Hop (SH) Test, Triple Hop (TH) Test, Crossover Hop (CH) Test, and the 6-meter Timed Hop Test. One limitation of the original Hop Test battery is its predominantly forward linear movements, similar to other jumping tests (Clark et al., 2001). Considering that athletes move in multiple directions during competition and training (Coppieters et al., 2002), focusing solely on forward-directed jumping tests may limit the potential to identify deficiencies in performance enhancement, injury prevention, or limb asymmetry rehabilitation (Delextrat & Cohen, 2008). However, studies evaluating both relative and absolute reliability measurements of multidirectional jumping tests compared to forward-directed jumping tests are limited. Several test-retest reliability studies focusing on forward-directed jumping tests have been widely used in both uninjured (Hamilton et al., 2008) and injured athletes (Miller et al., 2006). Mangine et al. (1999) recommended the use of two single-leg hop tests - one for distance and one for a specific time interval - in the assessment of elite soccer players. Noyes et al. reported that hop tests (single-leg hop tests including single hop for distance, timed hop, triple hop for distance, and crossover hop for distance) could be used in the evaluation of patients with knee injuries (Noyes et al., 1991). Similarly, Barber et al. (1990) utilized hop tests (single-leg hop tests including hop for distance, vertical jump, hop for time, shuffle run with no pivot, and shuffle run) to compare normal athletes with those with knee injuries. Researches generally show that hop tests can be used to evaluate lower extremity functions, to evaluate functional recovery after injury, to determine the risk of injury, to monitor performance in training and rehabilitation processes, to determine and manage limb asymmetries (Croisier et al., 2008; Hamilton et al., 2008; Miller et al., 2006; Myer et al., 2011).

In light of this information, instead of focusing solely on forward jumping tests in our study, utilizing multidirectional jumping tests may better reflect athletes' real sports performance. This approach would provide a more realistic basis for training programs and performance benchmarks. Furthermore, our research can demonstrate the effectiveness of multidirectional jumping tests in identifying potential injury risks among athletes. This would facilitate the development of injury-preventive and rehabilitation-focused training programs. Additionally, by evaluating the reliability of multidirectional jumping tests, our research would provide a new contribution to the literature. This would enable us to develop a more comprehensive understanding of the reliability of tests used in assessing training programs and athlete performance. Unlike previous studies, our research focusing on healthy athletes can better elucidate the natural progression of performance and variations in healthy populations. The findings obtained can directly inform the development of training programs and performance assessment protocols for athletes, aiding coaches and athletes in optimizing performance. Ultimately, this research could advance knowledge in sports science, contribute to strategies for enhancing athletes' performance and health, and facilitate the creation of more effective training programs. Upon review of the national literature, it is observed that there are studies utilizing hop tests; however, reliability data for hop tests have not been reported.

This research's originality and novelty stem from several key points. Firstly, instead of focusing solely on forward-directed hop tests, you will employ multidirectional hop tests to more comprehensively assess athletes' true sports performance. This approach ensures that training programs and performance metrics are based on a more realistic foundation. Additionally, demonstrating the effectiveness of multidirectional hop tests in identifying potential injury risks among athletes will contribute to the development of injury-prevention and rehabilitation-focused training programs. Your study will provide a novel contribution to the literature by evaluating the reliability of multidirectional hop tests. By focusing on healthy athletes, it will offer insights into the natural progression of performance and variability within a healthy population, providing directly applicable data for coaches and athletes. Consequently, this research can advance knowledge in sports science, contribute to strategies aimed at improving athletes' performance and health, and assist in creating more effective training programs. Therefore, the primary aim of our study is to examine the reliability of hop tests (single-leg hop, triple hop, crossover hop, and 6-meter timed hop) in healthy university athletes. Secondly, the objective is to identify limb asymmetries in athletes through jump tests. It is expected that this protocol will contribute to the formation of normative value tables in the Turkish population.

Methods

Participants

Ethics committee approval was received for this study from the ethics committee of Recep Tayyip Erdogan University Non-Interventional Clinical Research (Date: March 16, 2023, Decision Number: 2023/75, Protocol No: E-40465587-050.01.04-648). Verbal consent was obtained from all the participants.

University athletes aged between 18-21 years participated in the study (18 years n= 56, 19 years n=50, 20 years n= 58, 21 years n= 48). Participants confirmed that they had not experienced any lower extremity injuries at least 6 months prior to the test. All participants filled out an informed consent form to be included in the study. A total of 212 athlete students, comprising 84 females and 128 males, with a mean age of 24±3.60, participated in the study. Determination of the total sample size (n) was based on a priori analysis using a power of 0.90 and an effect size of 0.70. The sample calculation followed the methodologies outlined by Dingenen et al. (2019). Inclusion criteria for the study were as follows:

- Being a student of the Faculty of Sports Sciences,
- Having a minimum of 3 years of athletic history.

In this study, designed within a quantitative research framework, a correlational method was employed. The primary aim of correlational studies is to test the relationship between parameters. Accordingly, participant test performance parameters were identified, and the difference and relationship between two measurements were examined.

Procedures

The study was designed according to a repeated measures experimental design. In accordance with this design, single-leg hop (SLH), triple hop (TH), crossover hop (CH), and 6-meter timed single-leg hop (6m. TSLH) tests were applied to determine the lower extremity strength. A tape measure was used for the test. Hop test battery was performed separately for both legs. In addition, photocell gates (Sinar Fotosel, Karabuk, Turkey) were placed at the starting line and 6 m distance for the timed jump test. Before the first test, height and weight measurements were taken and the dominant and non-dominant sides of the subjects were written on the measurement form. Before the tests, an 8-minute general warm-up for the lower extremity muscles was performed. The subjects were warned not to do any exercise or physical activity before the applications and the applications were performed at the same time of the day between 14:00-18:00. A rest period of 40 seconds was given between all tests. For the reliability of the test, the second measurement of 50 subjects who would participate in the double measurement was repeated with an interval of 1 week. The asymmetry index (AI) of the subjects in the hop tests was calculated according to the formula (Dominant/Non-dominant) * 100 (Ross et al., 2002).

Test protocol

Single-Leg Hop (SLH) and Triple Single-Leg Hop (TSLH): A strip of 0.3 m in width was designated as the starting line, with a perpendicular strip measuring 6 m in length and 20 cm in width placed exactly at its midpoint. Participants began by standing on one foot at the marked starting line. For the SLH test, participants attempted to jump horizontally as far forward as possible onto the same leg. In the TSLH test, participants stood on one foot at the starting line and performed three consecutive horizontal jumps without pausing. For both tests, the successful attempt was measured in centimeters from the starting line to the heel of the participant. The successful test criterion for participants was considered to be landing with full stabilization on one leg and maintaining stability for three seconds (Ross et al., 2002).

Crossover Hop (CH): The CH test was conducted using two 0.3-meter strips as the starting and finishing lines, with a perpendicular strip measuring 6 meters in length and 15 cm in width placed exactly at the midpoint of the two strips. Participants stood on one foot at the starting line and performed three jumps forward in a crossover manner. The first jump started laterally opposite to the used foot, and the subsequent jumps continued laterally towards the fallen side. In the CH test, the successful attempt was recorded in centimeters from the starting line to the heel of the participant (Ross et al., 2002).

6-Meter Timed Single-Leg Hop (6m. TSLH): The 6m. TSLH test was conducted using two 0.3-meter strips as the starting and finishing lines, with a perpendicular strip measuring 6 meters in length and 15 cm in width placed exactly at the midpoint of the two strips. Participants stood on one foot at the starting line and, when ready, performed maximal forward jumps along the 6-meter strip. The time taken to cross the 6-meter distance was recorded in seconds using a photocell (Ross et al., 2002).

Statistical analysis

Statistical analyses were conducted using the licensed package program SPSS 26.0. Prior to analysis, normality distributions of the data were examined, and it was determined that the data followed a normal distribution based on skewness and kurtosis values (Cakir, 2021; Kalkavan, 2021). For comparing hop test results by gender, the T-test was used (Cakir, 2021b). In this direction, it was seen that our data met the assumptions of the test [(1) there should be 2 independent groups compared, (2) the dependent variable should be at equal interval or equal proportional measurement level, (3) the dependent variable should be normally distributed in both groups]. Pearson correlation analysis was utilized to determine the relationship between age and hop test data (Kayhan, 2021). The results of the analysis show that the data meet the assumptions of Pearson correlation coefficient [(1) both variables have normal distribution, (2) the relationship between the variables is linear, (3) homogeneity of variances]. Test-Retest Method was employed to examine the reliability of hop tests on the Turkish population. Intraclass correlation coefficient (ICC) was examined to evaluate test-retest reliability. ICC values range from 0.00 to 1.00, where values between 0.60-0.80 indicate good reliability, and values above 0.80 indicate excellent reliability (Zagumny, 2001). Data were evaluated at a significance level of α=0.05.

Results

Table 1.
Test-Retest Reliability of Hop Test Measurements

Measurement (n=50)	Pre		Post		ICC
	M	Sd	M	Sd	
Dominant					
SLH	181.12	13.32	186.04	13.29	0.930**
TSLH	589.64	65.22	601.18	72.48	0.723**
CH	530.84	62.25	534.24	78.92	0.704**
6 m. TSLH	1.71	0.14	1.70	0.14	0.990**
Non-Dominant					
SLH	177.80	14.77	182.10	14.42	0.952**
TSLH	587.20	65.72	591.52	77.23	0.781**
CH	532.28	67.87	533.50	67.75	0.930**
6 m. TSLH	1.68	0.16	1.67	0.20	0.816**
Total Asymmetry Index	101.33	4.74	101.12	8.77	0.734**

n: Number of people, **M:** Mean, **Sd:** Standard deviation, **ICC:** Intraclass Correlation Coefficients, **SLH:** Single-leg hop, **TSLH:** Triple single-leg hop, **CH:** Crossover hop, **m:** Meter

The results of the test-retest reliability analysis of the hop test measurements are presented in Table 1. Test-retest reliability was assessed using ICC. SLH, TSLH, CH and 6 m. TSLH measurements of the hop test protocol in both dominant and non-dominant legs were found to have statistically high reliability (Dominant: SLH=0.930, TSLH=0.723, CH=0.704 and 6 m. TSLH=0.990; Non Dominant: SLH=0.952, TSLH=0.781, CH=0.930 and 6 m. TSLH=0.816). These high reliability values indicate that these measurements can be used in Turkish student athletes ($p < 0.05$).

Table 2.
Asymmetry Indexes Calculated as A Result of The Hop Test of Student Athletes

AI		M±Sd
SLH AI (%)		100.51±9.75
TSLH AI (%)		102.08±11.62
CH AI (%)		101.40±12.77
6 m TSLH AI (%)		100.30±11.76
	Total AI (%)	101.07±06.49

M: Mean, **Sd:** Standard deviation, **AI:** Asymmetry index, **SLH:** Single-leg hop, **TSLH:** Triple single-leg hop, **CH:** Crossover hop, **m:** Meter

In Table 2, both the asymmetry indices obtained from four different long jumps and the total asymmetry index scores of athletes are presented on average. It was observed that the mean total asymmetry index of athletes was 101.07% ± 6.49.

Table 3.
Hop Test Evaluations of Student Athletes in Terms of Their Gender

Hop Test	Male (n=128)		Female (n=84)		Df	t	p	d
	M	Sd	M	Sd				
Dominant SLH	157.67	23.28	114.25	19.76	210	14.087	**0.000***	2.010
Non-Dominant SLH	156.98	22.70	114.98	20.21		13.755	**0.000***	1.954
Dominant TSLH	518.41	98.75	361.80	70.65		12.572	**0.000***	1.824
Non-Dominant TSLH	513.38	100.23	357.01	75.81		12.189	**0.000***	1.759
Dominant CH	445.98	96.97	298.48	53.42		12.725	**0.000***	1.884
Non-Dominant CH	449.80	97.24	292.11	60.90		13.249	**0.000***	1.943
Dominant 6 m TSLH	1.82	0.23	2.40	0.39		-13.467	**0.000***	1.811
Non-Dominant 6 m TSLH	1.83	0.29	2.42	0.43		-11.736	**0.000***	1.608

n: Number of people, **M:** Mean, **Sd:** Standard deviation, **Df:** Degrees of freedom, **d:** Cohen D, **SLH:** Single-leg hop, **TSLH:** Triple single-leg hop, **CH:** Crossover hop, **m:** Meter

In Table 3, an independent samples t-test was conducted at a significance level of α=0.05 to determine whether there were significant differences in hop test values based on the athletes' genders. The test results revealed significant differences in dominant foot single-leg hop (t_{210}=14.087; p=0.000), non-dominant foot single-leg hop (t_{210}=13.755; p=0.000), dominant foot triple hop (t_{210}=12.572; p=0.000), non-dominant foot triple hop (t_{210}=13.249; p=0.000), dominant foot crossover hop (t_{210}=12.725; p=0.000), non-dominant foot crossover hop (t_{210}=13.249; p=0.000), dominant foot 6-meter timed hop (t_{210}=-13.467; p=0.000), and non-dominant foot 6-meter timed hop (t_{210}=-11.736; p=0.000). It was observed that the mean values of males were significantly higher than those of females in all parameters. Upon examining effect sizes, it was determined that gender had a significant impact on hop test values.

Table 4.
AI Evaluations of Student Athletes in Terms of Their Gender

AI Dimensions (%)	Male (n=128)		Female (n=84)		Df	t	p	d
	M	Sd	M	Sd				
SLH AI	100.88	9.72	101.97	9.85		0.666	0.506	
TSLH AI	101.29	7.68	103.31	15.84		-1.239	0.217	
CH AI	99.62	10.61	104.11	15.18	210	-2.534	**0.012***	0.342
6 m TSLH AI	100.15	9.01	100.55	15.08		-0.244	0.807	
Total AI	100.48	5.28	101.98	7.95		-1.650	0.100	

n: Number of people, **M:** Mean, **Sd:** Standard deviation, **Df:** Degrees of freedom, **d:** Cohen D, **AI:** Asymmetry index, **SLH:** Single-leg hop, **TSLH:** Triple single-leg hop, **CH:** Crossover hop, m: Meter

In Table 4, an independent samples t-test was conducted at a significance level of α=0.05 to determine whether there were significant differences in asymmetry index values based on the athletes' genders. The test results revealed a significant difference in the crossover hop asymmetry index (t_{210}=-2.534; p=0.012) in favor of males. Upon examining the effect size, it was determined that gender had a low impact on the crossover hop asymmetry index value.

Table 5.
The Relationship Between the Ages of Student Athletes and Hop Test Results

Variable	Age	
	r	p
Dominant SLH	**-0.231***	0.001
Non-Dominant SLH	**-0.271***	0.000
Dominant TSLH	**-0.142***	0.039
Non-Dominant TSLH	**-0.168***	0.014
Dominant CH	**-0.172***	0.012
Non-Dominant CH	**-0.188***	0.006
Dominant 6 m TSLH	**-0.174***	0.011
Non-Dominant 6 m TSLH	**-0.230***	0.001

SLH: Single-leg hop, **TSLH:** Triple single-leg hop, **CH:** Crossover hop, **m:** Meter

In Table 5, a Pearson correlation test was conducted at a significance level of α=0.05 to determine whether there were associations between the athletes' ages and hop test values. The test results indicated a negative correlation between age and the following hop test values: dominant foot single hop (r=-0.231; p=0.001), non-dominant foot single hop (r=-0.271; p=0.000), dominant foot triple hop (r=-0.142; p=0.039), non-dominant foot triple hop (r=-0.158; p=0.014), dominant foot crossover hop (r=-0.172; p=0.012), non-dominant foot crossover hop (r=-0.188; p=0.006), dominant foot 6-meter timed hop (r=-0.174; p=0.011), and non-dominant foot 6-meter timed hop (r=-0.230; p=0.001).

Table 6.
The Relationship Between the Ages of Student Athletes and Their AI Results

Variable	Age	
	r	p
SLH AI	0.112	0.103
TSLH AI	0.098	0.154
CH AI	0.108	0.119
6 m TSLH	0.074	0.283
Total AI	0.105	0.126

AI: Asymmetry index, **SLH:** Single-leg hop, **TSLH:** Triple single-leg hop, **CH:** Crossover hop, **m:** Meter

In Table 6, a Pearson correlation test was conducted at a significance level of α=0.05 to determine whether there were associations between the athletes' ages and asymmetry index values. No significant relationship was found in the test results (p > 0.05).

Discussion

When examining the reliability levels of hop tests in the sample of Turkish student athletes, it was determined that the ICC values ranged from 0.704 to 0.990, indicating a high level of reliability. This finding demonstrates that the reliability levels of hop tests in Turkish student athletes are high. The ICC is a statistical measure used to assess the repeatability or reliability of a measurement tool. High ICC values indicate that the measurement tool is consistent and reliable. However, a more detailed examination is necessary to understand what these values mean in practice. High ICC values signify that the hop test has high repeatability. This means that the same individual is likely to achieve similar results when tested at different times. This indicates that the hop test is a reliable measurement tool for evaluating changes in athletes' performance over time or monitoring the effectiveness of treatment or rehabilitation (Zagumny, 2001). ICC values can also be used to evaluate the effectiveness of training programs. For example, obtaining similar hop test results among athletes after implementing a specific training protocol demonstrates the consistency and effectiveness of the program. While ICC measures the ratio of variance in a single measure, other reliability statistics evaluate different aspects such as accuracy, repeatability, and consistency of the measurement tool (Zagumny, 2001). ICC is commonly used to measure test-retest reliability, but using these statistics together can provide a more comprehensive assessment of the overall reliability of the measurement tool. In conclusion, high ICC values indicate that the hop test is a reliable measurement tool that can be practically used to evaluate athletes' performance, optimize training programs, and monitor rehabilitation processes. However, it is advisable to consider other reliability statistics alongside ICC values for a more comprehensive assessment (Zagumny, 2001). Additionally, it suggests that hop tests can be used to monitor the effectiveness of training programs and evaluate rehabilitation processes. The high reliability of hop tests makes them an important tool for coaches and physiotherapists to monitor athletes' performances and adjust training programs. Furthermore, they can also be used to assess athletes' risk of injury and manage post-injury rehabilitation processes. Therefore, the reliability of hop tests provides a valuable contribution to improving sports health and performance. Similar studies have been examined; Ross et al. (2002) evaluated the reliability and validity of single-leg hop tests in healthy individuals. The findings showed that single-leg hop tests can be reliably and validly used. Dingenen et al. (2019) examined the reliability of single-leg and double-leg hop tests in individuals with normal knee function. The findings indicate that both single-leg and double-leg hop tests are reliable and can be used. Millikan et al. (2019) evaluated the reliability and validity of single-leg hop tests applied with different methods in healthy young adults. The findings demonstrate that single-leg hop tests are reliable and effective for detecting asymmetry in athletes.

Regarding the asymmetry indices of the student athletes, it was found that the averages were 101.07%, indicating that this group had normal limb symmetry. This finding indicates that student athletes exhibit an average asymmetry index in their bodies or specific limbs or body regions. With an average asymmetry index of 101.07%, it suggests that, overall, the student athlete group examined does not display significant asymmetry between their right and left limbs. This suggests that the body structures of the group are balanced and symmetric overall. This situation has significant implications for athletes in terms of performance and risk of injury. Normal body symmetry is generally associated with better biomechanical efficiency and balance, which can positively affect athletes' performance (Fousekis et al., 2010). Athletes with symmetrical body structures may experience improved coordination, agility, and power transfer during sports activities, thereby enhancing their overall performance. Additionally, symmetry in body structure is often observed to reduce the risk of injuries in athletes. Asymmetric body alignment or muscle imbalances can increase the risk of overuse injuries, strains, and even more severe musculoskeletal injuries (Fousekis et al., 2010). Therefore, student athletes with normal body symmetry may exhibit less susceptibility to such injuries. In this context, asymmetry indices derived from body symmetry can serve as valuable tools in sports medicine and athletic training. Coaches, trainers, and healthcare professionals can use these indices to identify athletes with potential asymmetries and implement targeted interventions such as corrective exercises, biomechanical assessments, or individualized training programs to address imbalances and reduce the risk of injury. In conclusion, the presence of normal body symmetry among student athletes has significant implications for both performance and injury prevention. The use of asymmetry indices in practice can aid in identifying targeted interventions to optimize performance and reduce the likelihood of injury in this population (Fousekis et al., 2010). This situation is believed to be due to the fact that the student athletes in our study had at least 5 years of athletic experience and engaged in regular physical activity. Additionally, it was observed that the asymmetry indices of the athletes in our study ranged from 87.74% to 120.52%. This wide range of asymmetry indices can stem from several different factors. Firstly, physical differences among athletes and their training backgrounds may contribute to this variability. Some athletes may have greater muscle development or flexibility in specific limbs compared to others, leading to differences in asymmetry indices. Additionally, specialization in different sports or disciplines among athletes can also contribute to the variability in asymmetry indices. For instance, a basketball player may focus on different muscle groups than a swimmer during training, potentially resulting in asymmetry in the body. Furthermore, the wide range of asymmetry indices can also result from imbalances in athletes' training programs. Overloading or inadequate training of specific limbs or muscle groups can lead to asymmetry in the body. For example, if an athlete performs one exercise, such as squats, more frequently than others, it may increase asymmetry between the legs. Moreover, past injuries or traumas experienced by athletes can also contribute to the variability in asymmetry indices. The recovery process of an injured limb may differ from that of others, resulting in asymmetry as a consequence. Overall, the wide range of asymmetry indices among athletes can result from various factors such as physical differences, training history, specialization in sports, and past injuries. Therefore, each athlete should be individually assessed, and a tailored training program should be designed according to their specific needs. Munro and Herrington (2011), examined the asymmetry indices of hop test results on a similar sample in terms of both gender and age average and obtained values close to our study's findings.

The findings indicate significant differences in hop test values and asymmetry indices among student athletes based on their genders. Firstly, it was found that hop test values were significantly higher in favor of males, which could be a reflection of physiological differences between genders. As noted in the literature, males are generally expected to have more muscle mass and strength compared to females (Reinke et al., 2011). Therefore, it is not surprising that males exhibit higher hop test values, which can be interpreted as a consequence of biological differences. Gender differences are a complex issue affecting sports performance. Although there are physiological and anatomical differences between men and women, individual variations are also important. These differences include many factors that influence performance (Reinke et al., 2011). Men generally have higher muscle mass and bone density, while women tend to have more flexibility and endurance. These biological differences shape athlete performance and abilities. It is important that training programmes are gender sensitive. Programmes should be adapted to meet the specific needs of male and female athletes (Holm & Vøllestad, 2008). For example, flexibility and balance-orientated exercises for women and strength and explosiveness development exercises for men are important. This approach can help each group of athletes achieve optimal performance and reduce the risk of injury. In conclusion, understanding gender differences contributes to the development of training programmes that meet the individual needs of athletes and provide the best performance (Holm & Vøllestad, 2008). Regarding the asymmetry index, a significant difference in favor of males was observed in the crossover hop, but no significant difference was found in general asymmetry indices. This suggests that different tests may yield different results, and the difference in crossover hopping could be significant in assessing asymmetry between genders. On the other hand, the lack of significant difference in general asymmetry indices may indicate the need for more sensitive or specific methods to detect asymmetry in other tests. This could be due to the inherent ability of males to produce more power than females, while the asymmetry index findings in females could be explained by their tendency to use one limb more dominantly than the other due to being less controlled. As for the source of these findings, it can be presumed that physiological differences between genders and athletes' training backgrounds play a determining role. Additionally, methodological differences such as technical requirements or implementation methods of the tests could also influence the results. Particularly, the lack of standardization during the administration and evaluation of the tests could be a contributing factor to the variability in the results. In conclusion, these findings demonstrate how physiological differences between genders and the specific technical requirements of the tests can affect the differences in hop test values and asymmetry indices among student athletes. Further research could contribute to a better understanding of these findings and the development of more effective strategies to improve athletes' performances. This finding is supported by studies indicating the influence of gender on jump tests (Holm & Vøllestad, 2008; Jaiyesimi & Jegede, 2005; Reinke et al., 2011). Ross et al. (2002) also reported better results for males in the hop test protocol. Read et al. (2016) examined the relationship between gender-associated asymmetry index and jump tests. Findings indicate a significant relationship between jump test performance and asymmetry index among young male soccer players. McCurdy et al. (2010) examined the relationship between gender-associated asymmetry index and jump tests. The findings indicate that female soccer players have lower jump test performance compared to males, and this is associated with the asymmetry index. De Ste Croix et al. (2015) investigated the impact of gender differences on asymmetry index and jump tests, particularly focusing on young female soccer players. The results suggest that female soccer players have different jump test performance compared to males, and this can be associated with the asymmetry index. This study emphasizes the importance of gender and asymmetry index in evaluating the injury risk of young female soccer players. Fousekis et al. (2011) examined the relationship between gender-associated asymmetry index and jump tests, particularly focusing on professional soccer players. The findings evaluate the effects of gender and training age on jump test performance and asymmetry index. Particularly, it shows that gender differences affect the relationship between jump test performance and asymmetry index.

In our final finding, negative correlations were found between the ages of athlete students and their hop test values. This result may suggest that a younger age could have a positive effect on physical performance (Landi et al., 2018). Young age is often associated with increased flexibility and speed development, which may lead to higher jump test values. However, the relationship between age and asymmetry index was not found to be significant (Haverkamp et al., 2020). This may be due to the similarity of the limb symmetries of the students in the research group due to their sports background. In addition, the low age difference between the students may have played an important role in the lack of difference (Malina et al. 2004). In young age, body structures are generally more balanced and symmetrical, which may result in lower asymmetry indices. Regarding the source of these findings, it can be speculated that changes in physical performance and body structure occurring with age influence these results (Falk & Dotan, 2006). Young age is a critical period for muscle and bone development, and it is known that proper training and exercises during this period lead to increased physical performance. This could be due to younger athletes being more agile and nimble, while the asymmetry index findings can be attributed to younger individuals being able to better control postural stability to avoid future injuries (Falk & Dotan, 2006). In conclusion, these findings demonstrate the effects of student athletes' ages on their physical performance and body symmetry. Considering that the students had normal limb symmetry, younger age was associated with better jump test values and improved limb symmetry, emphasising the importance of appropriate training and exercise at a young age. However, further research and analysis could contribute to a better understanding of these findings and the development of more effective strategies to enhance athletes' performance. The effects of age on sports performance and body symmetry are an important factor in the ageing process of athletes. As age progresses, physiological changes lead to decreases, especially in areas such as muscle mass, bone density, and flexibility (Malina et al. 2004). These reductions can lead to decreases in performance indicators. However, regular exercise and appropriate training programmes can help older athletes maintain and even improve their performance. The aging process can also affect body symmetry, which can affect performance and injury risk (Malina et al. 2004). The performance and body symmetry of older athletes should be monitored through regular monitoring and evaluation, and appropriate training programmes should be developed. Individualised approaches are important to meet the needs of athletes in the aging process. In this way, it may be possible to optimise athletes' performance and maintain good health throughout the ageing process (Falk & Dotan, 2006). This finding is supported by studies indicating the influence of age on jump tests and the potential muscle strength imbalances among athletes of different ages (Bailey et al., 2013; Fuentes et al., 2011; Hannah et al, 2015; Holm & Vøllestad, 2008; Iturriaga et al., 2012; Jaiyesimi & Jegede, 2005). Faigenbaum et al. (2009) evaluated the effects of resistance training on the physical performance of young athletes. They found that regular training at a young age positively influenced performance metrics such as muscle strength, speed, and symmetry (Faigenbaum et al., 2009). Malina et al. (2004) examined the relationship between growth, maturation, and physical activity in children. Specifically, they addressed how physical activity at a young age affects growth and development processes, discussing the positive role of these effects on sports performance and body symmetry (Malina et al. 2004). Falk and Dotan (2006) compared how children and adults respond to high-intensity exercise. They found that the performance of young athletes changes with age and that these changes have a positive effect on body symmetry (Falk & Dotan, 2006). Lloyd et al. (2016) defined the position of the National Strength and Conditioning Association on long-term athlete development. They stated that the physical performance of young athletes is influenced by age.

These findings, along with the supportive evidence from our study, are deemed to serve as a reference for future research endeavors.

Study limitations

The study used a sample limited to volunteers from university athletes only. This may limit the applicability of the results to the general athlete population. The fact that participants were selected only on a voluntary basis may limit the generalisability of the results. This means, for example, that factors such as participants' motivation levels or physical activity history may influence the results. Furthermore, the time interval between repeated measurements was only 1 week. This may have an impact on the reliability of the results because repeated measurements over a longer or shorter time interval could have yielded different results. Failure to include participants from different age groups or sports may prevent generalisation of the results. In addition, the results of the study were obtained using only physical tests. The influence of other factors on the results, such as training programmes, dietary habits or past injury history, may have been overlooked. Consideration of these limitations ensures that the results of the study can be correctly interpreted and provide a more comprehensive basis for future research.

Conclusion and Recommendations

In conclusion, our study underscores the robustness of the hop test as an assessment tool for Turkish student athletes. Notably, we found gender to exert a significant influence on hop test performance among university athletes, with age demonstrating a comparatively lesser impact. This highlights the pivotal role of muscle strength imbalances across genders and age groups in determining explosive power. Moreover, our investigation revealed that the student athletes exhibited normal limb symmetry, suggesting a reduced risk of injury. This favorable outcome may be attributed to their extensive athletic experience, with a minimum of 5 years of engagement in sports activities. It stands to reason that consistent physical activity and sports participation contribute to maintaining symmetrical limb function by shaping specific postural strategies. In light of these findings, it becomes imperative to consider gender, age, and activity levels in designing targeted training programs aimed at mitigating strength imbalances, enhancing functional performance, and preventing sports-related injuries. By elucidating the interplay between gender, age, asymmetry index, and hop test values, our study provides valuable normative data for student athletes, filling a crucial gap in the existing literature. Furthermore, the association between asymmetry index and injury risk underscores the utility of the hop test protocol employed in our study as a reliable tool for identifying potential injury susceptibility. This aspect of our research not only enhances our understanding of injury risk factors but also furnishes practitioners with a practical criterion for risk assessment in sports settings. In conclusion, our study contributes significantly to the literature by emphasizing the practical implications of our findings for sports practice. We recommend incorporating gender, age, and activity level considerations into training regimens to optimize performance and minimize injury risk among student athletes. By doing so, we aim to promote safer and more effective athletic training protocols that cater to the specific needs of this demographic. Therefore, the following suggestions are proposed to contribute to the literature and the field:

Coaches and trainers are advised to tailor training programs for student athletes by considering gender and age differences. This personalized approach not only improves sports performance but also mitigates the risk of injuries associated with explosive power activities. When evaluating injuries, it's essential to conduct a comprehensive assessment, taking into account factors such as gender, age, and activity level. This holistic perspective enables a more tailored response to athletes' needs and helps identify potential risks, facilitating the implementation of suitable preventive measures.

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