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Functional dimorphism and relationship between different lower extremity strength tests in young elite judokas

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ORIGINAL PAPER

Abstract

The present study investigated the limb symmetry index (LSI) and the relationship between different functional strength tests in young elite judokas. Seventeen males (age= 16.88±1.40 years, height= 179.00±7.00 cm, weight= 78.76±15.22 kg and BMI 24.40±3.36 kg/m^2) participated in the study voluntarily. Participants were tested with single leg (SL), and triple leg (THD) hop for distance, crossover hop for distance (CHD), 6 m Timed Hop Test (6mTHT), and single-leg vertical jump (SLVJ) tests, and countermovement jump (CMJ). All SL hop tests (SLHT) were applied to both right (R_s) and left sides (L_s), while CMJ was applied as without (CMJ_{WAS}) and with arm swing (CMJ_{AS}). Paired sample t-test and Pearson correlation tests were used in statistical analyses. In all SLHTs, no statistical significance was found between R_s and L_s. However, significance was found between CMJ_{WAS} and CMJ_{AS}. There was also no significance in LSIs between all SLHTs. Correlations were found between SL, THD, CHD, VJ tests, while negative and significant correlations were found between SL, THD, CHD, VJ tests, and 6 m THT. No significance was found between SLHTs and CMJ_{WAS} and CMJ_{AS}. As a result, it was found that R_s and L_s of young judokas produced similar strength in SLHTs, while they caused differences in CMJ_{WAS} and CMJ_{AS} values; when evaluated in terms of LSI, judokas showed similar rates in all SLHTs, and these rates were within reliable ranges; SLHTs had correlations with each other, but they did not show any correlation with CMJ.

Keywords: Martial arts; combat sports; judo; limb symmetry; limb symmetry index; hop tests.

Dimorfismo funcional y relación entre diferentes test de fuerza de extremidades inferiores en jóvenes judokas de élite

Resumen

El presente estudio investigó el índice de simetría de las extremidades (LSI) y la relación entre diferentes pruebas de fuerza funcional en jóvenes judokas de élite. Diecisiete varones (edad=16,88±1,40 años, altura=179,00±7,00 cm, peso=78,76±15,22 kg e IMC 24,40±3,36 kg/m2) participaron voluntariamente en el estudio. Los participantes fueron evaluados mediante el *single hop test* (SL), *triple hop test* (THD), *crossover hop test* (CHD), *6-m hop test* (6mTHT) y test de salto vertical a una pierna (SLVJ) y salto con contramovimiento (CMJ). Todos los SL *hop test* (SLHT) se aplicaron tanto en la pierna derecha (R_s) como en la izquierda (L_s), mientras que el CMJ se aplicó sin (CMJ_{WAS}) y con balanceo de brazos (CMJ_{AS}). En los análisis estadísticos se utilizaron *t-test* de muestras pareadas y test de correlación de Pearson. En todos los SLHT no se encontraron diferencias significativas entre la entre ambas extremidades. Sin embargo, se encontraron diferencias entre el CMJ*WAS* y el CMJ_{AS}. Tampoco hubo diferencias en los LSI entre todos los SLHT. Se encontraron correlaciones entre los test SL, THD, CHD, VJ, y se encontraron correlaciones negativas y significativas en los test SL, THD, CHD, VJ y THT 6 m. No se encontraron diferencias en los test SLHT y CMJ_{WAS} y CMJ_{AS}. En consecuencia, se encontró

Dimorfismo funcional e relação entre diferentes testes de força das extremidades inferiores em jovens judocas de elite

Resumo

O presente estudo investigou o índice de simetria dos membros superiores e inferiores (IEL) e a relação entre diferentes testes de força funcional em jovens judocas de elite. Dezassete indivíduos (idade= 16,88 ± 1,40 anos; altura= 179,00 ± 7,00 cm; peso= 78,76 ± 15,22 kg; e IMC 24,40 ± 3,36 kg/m2) participaram voluntariamente no estudo. Foram avaliados por meio de vários testes: *single hop test* (SL), *triple hop test* (THD), *crossover hop test* (CHD), 6-m *hop test* (6mTHT), salto vertical de perna única (SLVJ) e salto com contramovimento (CMJ). Todos os *SL hop test* (SLHT) foram aplicados, tanto na perna direita (Rs), como na perna esquerda (Ls), enquanto o CMJ foi aplicado sem (CMJ_{WAS}) e com braço *swing* (CMJ_{AS}). O *t-test* de amostras emparelhadas e o teste de correlação de *Pearson* foram usados nas análises estatísticas. Em todos os SLHTs, não foram encontradas diferenças significativas entre as duas extremidades. No entanto, foram encontradas diferenças entre CMJ_{WAS} e CMJ_{AS}. Também não houve diferenças no LSI entre todos os SLHTs. Foram encontradas correlações entre os testes SL, THD, CHD, VJ, e correlações negativas e significativas foram encontradas nos testes SL, THD, CHD, VJ e THT 6 m. Nenhuma diferença foi encontrada nos testes SLHT e CMJ_{WAS} e CMJ_{AS}.

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que las extremidades inferiores de los jóvenes judokas producían una fuerza similar en los SLHT, y se encontró que había diferencias en los valores de CMJ_{WAS} y CMJ_{AS}; cuando se evaluó en términos del LSI, los judokas mostraron tasas similares en todos los SLHT, y estas tasas estaban dentro de rangos fiables; los SLHT tenían correlaciones entre sí, pero no mostraron ninguna correlación con el CMJ.
Palabras clave: Artes marciales; deportes de combate; judo; simetría de extremidades; índice de simetría de extremidades; *hop tests*.

Consequentemente, verificou-se que os membros inferiores dos jovens judocas produziram uma força semelhante no SLHT, enquanto ocorreram diferenças nos valores de CMJ_{WAS} e CMJ_{AS}. Quando avaliados em termos de LSI, os judocas mostraram taxas semelhantes em todos os SLHTs, e essas taxas estavam dentro dos intervalos de confiança. Os SLHTs foram correlacionados entre si, mas não apresentaram correlação com o CMJ.
Palavras-chave: Artes marciais; desportos de combate; judo; simetria dos membros inferiores e superiores; índice de simetria dos membros inferiores e superiores; *hop tests*.

1. Introduction

Judo has a complicated structure regarding its performance components (Ermiş et al., 2019; Yılmaz et al., 2020). This is because it requires showing a high level of physical properties since it includes high levels of pushing, pulling, and various other technical elements (throws, pins, chokes, and armbars) in addition to technical, tactical, and psychological factors (Franchini & Del Vecchio, 2008; Yoshitomi et al., 2006; Perrin et al., 2002). Therefore, reaching a perfect level of physical fitness (maximal strength, power, and endurance) is essential, especially for judokas participating in international competitions (Franchini et al., 2005). Muscle strength is the leading physical property that forms the basis of success in judo (Ermiş et al., 2019). Studies have reported that in terms of movement structure, strong knee, thigh, shoulder, and back muscles are very important in performing movements specific to judo and in maintaining balance (Franchini et al., 2011; Thomas et al., 1989; Imamura et al., 2007; Drid et al., 2015).

Lower extremity strength is especially important for judokas in movements such as various throw techniques because, during these specific movements, judokas continuously expose muscles with agonist-antagonist structures such as knee muscles to reverse concentric and eccentric contractions, and they may have to do this constantly from a few seconds to four minutes or even longer times with golden score (Detanico et al., 2012; Torres-Luque et al., 2015; Zaggelidis et al., 2012; Kons et al., 2020).

Today, sports scientists measure lower extremity strength with different methods; the most important of these methods are hop tests, some functional tests performed with bodyweight or specific weight loads, and tests performed with devices operating with simple mechanisms or isokinetic dynamometers that have high validity and reliability but do not reflect functional characteristics (Negrete & Brophy, 2000). One of the most important methods is the Single-Leg Hop Test (SLHT), which reflects the functional movement structure of the knee and isokinetic measurements (Yılmaz & Kabadayı, 2020; Millikan et al., 2019; Ross et al., 2002). Single-Leg Hop Tests are intensely preferred since their easy application and reliability have been proven by many researchers (Reid et al., 2007; Hegedus et al., 2015; Logerstedt et al., 2012; Yılmaz & Kabadayı, 2020). It is also a known fact that SLHTs, which are applied to a single side, can be used to examine strength differences in right and left sides, to show susceptibility to lower extremity injuries, and to evaluate lower extremity strength differences that occur after return from injury (Gokeler et al., 2017). Strength differences between SLHTs and right and left extremities are found with limb symmetry index (LSI) rate, and this rate is calculated with the dominant side/non-dominant side x100 % formula (Grindem et al., 2011). >90% LSI rate shows that the strength difference between the two sides does not include a risk of injury or the rehabilitation process after the injury can be terminated; however, if this rate is below 90%, it indicates that there is a risk of injury or the need for post-injury rehabilitation and strengthening the limb producing low strength (Noyes et al., 1991; Thomee et al., 2011). Researchers have also stated that it would be a more valid and more reliable method to determine whether asymmetry occurs between lower extremities by using at least two different SLHTs (Augustsson et al., 2004). In one review, it has been reported that the SLHTs which are most frequently used and which best reflect the functional structure of the knee are single-leg hop for distance (SL), triple leg hop for distance (THD), crossover hop for distance (CHD), 6 m Timed Hop Test (6mTHT) and single-leg vertical jump (SLVJ) tests (Hegedus et al., 2015). All this information makes it possible to evaluate lower extremity strength, which is important to make the movements specific for judo successfully and correctly and stay in balance, especially during competition, with SLHTs that can be easily applied and have high validity. Also, SLHTs are very important in judo in allowing for separate evaluation of both sides since one leg is used as an attacking leg and the other is used as a support leg in standing attacks. It is also known that not only SLHTs which are applied unilaterally but also bilateral tests such as countermovement jump (CMJ), in which both extremities jump vertically show high positive correlations with judo-specific tests such as the Special Judo Fitness Test (SJFT) (Detanico et al., 2012).

Based on all this information, the present study examines the strength found with five different SLHTs on both sides of the lower extremities in young elite judokas and examines LSIs and CMJ results calculated from these strengths. The present study is the first study in which five different SLHT and CMJ results of elite young judokas are evaluated in the same sample group. Our study hypothesized that LSI rates would be similar in all SLHTs, and there will be positive correlations between SLHTs and CMJ.

2. Method

2.1. Experimental Design

The study was designed according to a single-blind crossover experiment design with randomized repeated measurements. With this design, the correlations between single-leg hop for distance (SL), triple leg hop for distance (THD), crossover hop for distance (CHD), 6 m Timed Hop Test (6mTHT), and single-leg vertical jump (SLVJ) tests and countermovement jump without arm swing (CMJ_{WAS}) and countermovement jump with arm swing (CMJ_{AS}) tests were examined. At the same time, according to the results in the right side (Rs) and left side (Ls) in all SLHTs, the subjects' LSI were calculated, and asymmetry rates in all SLHTs were compared. The subjects visited the laboratory seven times with intervals of 48 hours. In the first visit, the subjects were informed about the test protocols; their height, weight, and body mass index (BMI) measurements were taken with Gaia 359 plus body analyzer, and SLHTs and countermovement jump (CMJ) tests to be applied in future visits were demonstrated, but not practiced. The subjects were randomized with application cards in the other visits, and the tests were randomly applied as SL, THD, CHD, 6 m THT, VJ, and CMJ tests. All SLHT tests were applied to both R_s and L_s tests randomly. Countermovement jump tests were applied as CMJ_{WAS} and CMJ_{AS}. Before tests, the subjects warmed up (five minutes with Monark 894E Wingate testing bike ergometer at 100 rpm, the participant was set as 0.8*body weight, in Nm, and then ten minutes stretching) for lower extremity muscles. During the applications, the subjects were warned not to do any exercise or physical activity. The applications were carried out at the same hour of the day (15:00-17:00). The study was organized and implemented following the Helsinki Protocol. Approval was obtained from Sinop University's Human Research Ethics Committee (Number: 2021:13).

2.2. Subjects

Seventeen males (age 16.88 years, height 179.00 cm, weight 78.76 kg, and BMI 24.40 kg/m^2) between the ages of 15 and 21 participated in the study voluntarily. Athletes who had been training regularly for at least five years (at least four days a week) and who regularly participated in national and international competitions participated in the study voluntarily. All judokas in the study were in the Turkish Young National Team, so we evaluated them as elite judokas. All subjects' dominant legs were Rs. Every participant was healthy and free from any current or ongoing neuromuscular diseases or musculoskeletal injuries of the lower limbs. All subjects signed a written consent form before measurements.

2.3. Procedures

- Single-Leg Hop Tests and Countermovement Jump Test Procedures

All SL, THD, CHD, and 6 m THT tests were performed on a 0,3 m. band designed as the start line and a 6m long and 15 cm wide band extending right in the middle of this. VJ and CMJ tests were performed using an 84x95 cm Newtest Powertimer 300 device with automatic calibration and a large and precise measuring surface. Photocells of the Newtest Powertimer 300 device were used for 6 m THT test measurements. The subjects made three trial repetitions for each test. After the trials, the subjects were exposed to 3 main measurements in all tests, and the success criterion was determined as the subjects landing on the leg with full stabilization and remaining for three seconds (Yılmaz & Kabadayı, 2020). The best jump distance was recorded and taken to further analyses in cm for SL, THD, CHD, and CMJ; in seconds for 6 m THT; and in Watt and millisecond (ms) for VJ. In all other SLHTs except VJ and CMJ_{WAS} test and CMJ_{AS}, arm movements were allowed, and no restrictions were made.

- Single and Triple Hop for Distance

In the SL test, the subjects stood on one foot on the marked starting line, and when they were ready, they jumped horizontally as far as they could to fall on the same leg; in the THD test, when they were ready, they jumped horizontally forward as far as they could three times in a row without stopping. Between the trials, the subjects rested with intervals of 1 minute (Munro & Herrington, 2011).

- Crossover Hop for Distance Test

The participants stood on one foot at the starting line in CHD tests and made three jumps forward. The first jump started diagonally in the opposite direction of the foot used and continued laterally to the fallen side. The subjects were given a 1-minute resting interval between each test (Peebles et al., 2019).

- 6 m Timed Hop Test

In the 6 m THT test, the participants stood behind the photocell on the starting line on one foot, and when they were ready, they hopped on one foot for a band of 6 meters and finished in the fastest time possible. The test started from the starting line and ended when the participant passed from the photocell at the end of the 6 meters band. The test was applied three times to all subjects, and a rest interval of two minutes was given between each test (Yılmaz & Kabadayı, 2020).

- Single-Leg Vertical Jump

The subjects stood on one leg in a half squat (90 degrees bent knee joint) on the contact mat with the hands held by the waist, and when they were ready, they kept the body position and jumped to maximum level. The subjects were given the rest of two minutes between each test.

- Countermovement Jump

Subjects performed two different CMJ on the contact mat without ($CMJ_{WAS)}$ and with arm swing (CMJ_{AS}) with legs hip-wide. The subjects made a rapid descent to approximately 90 degrees of knee flexion during the test, followed by a sudden and rapid upward vertical jump. After the jump, the successful test criterion was determined as the subjects landing both feet simultaneously within the contact mat frame. In $CMJ_{WAS,}$ the subjects kept their hands on their waist during the jump and landing. In CMJ_{AS}, they completed the test hands-free. The subjects made three jumps for both CMJ, and the best results were recorded.

2.4. Statistical Analysis

SPSS 22.0 software was used for statistical analysis. The normality assumption of the data was examined with the Shapiro Wilk test, and the data were shown to have a normal distribution. In addition, the Levene test was used for homogeneity tests, and it was found that the variances were homogeneous. Paired sample t-test and Pearson correlation test were used in statistical analysis. Statistical results were assessed within a 95% confidence interval and at a significance level of $p<0.05$. Limb symmetry index (LSI) was calculated with this formula; Rs/Ls x100 %.

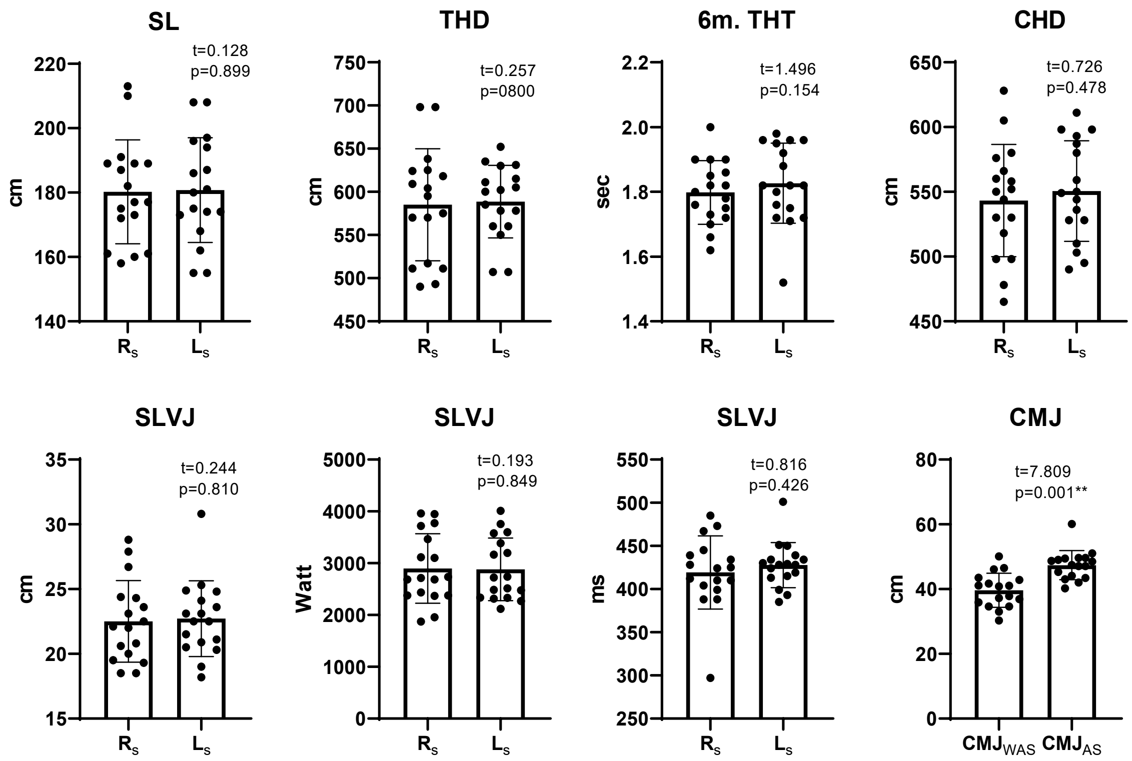
3. Results

Table 1 shows the sample characteristics and the results of the performed tests. When the results of judokas between Rs and Ls in SLHTs and between with and without arm swing in CMJ were evaluated, no statistical significance was found in any SLHTs ($p>0.05$). In CMJ, CMJAS was found to show higher and more statistically significant results when compared with CMJWAS ($p<0.05$) (Figure 1).

Table 1. Descriptive information of participants (*n*=17).

Variables	**Min.**	**Max.**	***M***	***SD***
Age (years)	15.00	21.00	16.88	1.40
Height (cm)	163	190	179	7
Weight (kg)	58.00	107.00	78.76	15.22
Body Mass Index (kg/m^2)	18.94	30.42	24.40	3.36
Single-Leg Hop Tests	**Rs (*M±SD*)**	**Ls (*M±SD*)**		
SL (cm)	180.24±16.14	180.76±16.30		
THD (cm)	585.06±64.81	588.59±41.93		
6 m THT (sec)	1.79±0.10	1.82±0.12		
CHD (cm)	543.29±43.31	550.52±38.85		
SLVJ (cm)	22.50±3.15	22.72±2.92		
SLVJ (Watt)	2899.29±670.89	2881.94±604.89		
Countermovement Jump Test (cm) (*M±SD*)				
With Arms Swing	47.38±4.50			
Without Arms Swing	39.64±5.27			
Limb Symmetry Index (*M±SD*)				
SL (%)	**THD (%)**	**6 m THT (%)**	**CHD (%)**	**SLVJ (%)**
100.10±8.66	99.50±9.27	98.62±4.32	98.89±7.37	99.91±14.41

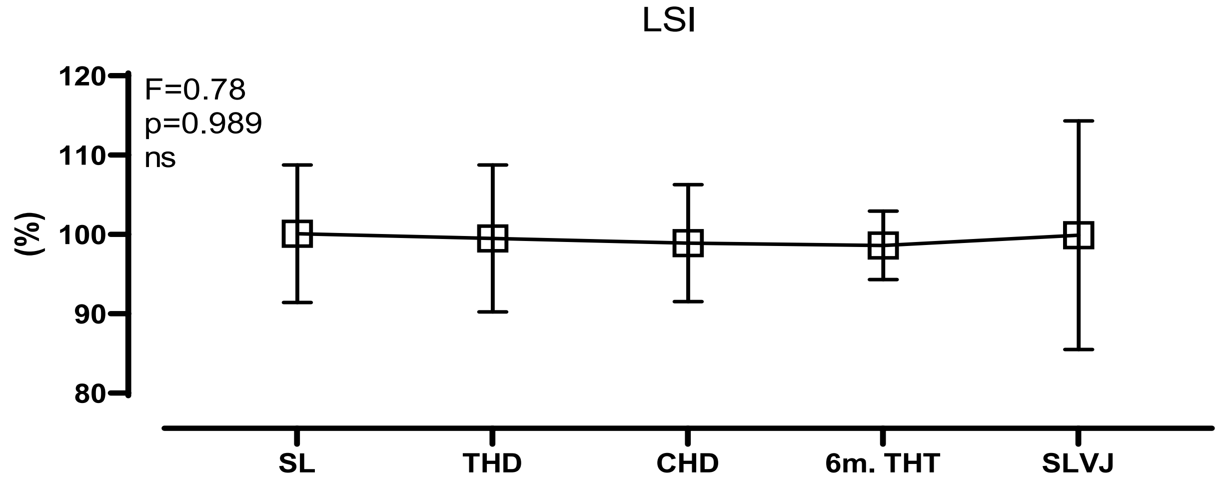
SL=single-leg hop test for distance; THD=triple leg hop test for distance; 6 m THT=6 m timed hop test; CHD=crossover hop test for distance; SLVJ=single-leg vertical jump test.



**p<0.01; t=result of paired sample t-test; SL=single-leg hop for distance; THD=triple leg hop for distance; 6mTHT=6 m timed hop test; CHD=crossover hop for distance; SLVJ=single leg vertical jump; CMJ_{WAS}=without arm swing countermovement jump test; CMJ_{AS}=with arm swing countermovement jump test R_s=right side; L_s=left side.

Figure 1. Comparison of all single-leg hop tests between right and left sides and countermovement jump between without and with arm swing

When the LSIs calculated from the results of R_s and L_s of judokas in all SLHTs were compared, no statistical significance was found (p>0.05) (Figure 2). These results showed that the LSIs found in all SLHTs of judokas were similar.



F= results of One-Way ANOVA; ns=non-significant; LSI=limb symmetry index; SL=single-leg hop test for distance; THD=triple leg hop test for distance; 6mTHT=6 m timed hop test; CHD=crossover hop test for distance; SLVJ=single leg vertical jump test.

Figure 2. Comparison of all single-leg hop tests' LSI in judokas

Table 2 shows the correlations between all SLHTs of judokas on Rs and Ls and CMJWAS and CMJAS. According to these results, moderate and high positive correlations were found between SL, THD, CHD, VJ tests, while negative and significant correlations were found between SL, THD, CHD, VJ tests, and 6 m THT ($p<0.05$). Also, when the correlations between SLHTs and CMJ_{WAS} and CMJ_{AS} were examined, no significance was found ($p>0.05$).

Table 2. Correlation between all tests in judokas

		SL_{RS}	**SL_{LS}**	**THD_{RS}**	**THD_{LS}**	**CHD_{RS}**	**CHD_{LS}**	**$6M_{RS}$**	**$6M_{LS}$**	**VJ_{RS}**	**VJ_{LS}**	**CMJ_{WAS}**	**CMJ_{AS}**
SL_{RS}	r	1											
	p												
SL_{LS}	r	,452	1										
	p	,068											
THD_{RS}	r	,902**	,430	1									
	p	,000	,085										
THD_{LS}	r	,504*	,772**	,507*	1								
	p	,039	,000	,038									
CHD_{RS}	r	,882**	,467	,834**	,510*	1							
	p	,000	,059	,000	,036								
CHD_{LS}	r	,298	,592*	,359	,657**	,504*	1						
	p	,245	,012	,157	,004	,039							
$6M_{RS}$	r	-,358	-,571*	-,351	-,540*	-,344	-,499*	1					
	p	,158	,017	,168	,025	,176	,042						
$6M_{LS}$	r	-,228	-,531*	-,120	-,393	-,222	-,339	,778**	1				
	p	,378	,028	,647	,119	,393	,182	,000					
VJ_{RS}	r	,478	,255	,494*	,395	,395	,350	-,146	,002	1			
	p	,052	,322	,044	,116	,117	,169	,576	,995				
VJ_{LS}	r	,167	,069	,086	,283	,327	,338	-,249	-,223	,310	1		
	p	,521	,792	,742	,271	,200	,185	,335	,390	,225			
CMJ_{WAS}	r	,003	-,055	-,076	-,153	,059	,042	-,123	-,109	,377	,281	1	
	p	,992	,833	,772	,557	,822	,873	,638	,676	,136	,275		
CMJ_{AS}	r	,101	,073	,180	,169	,156	,285	-,107	-,127	,409	-,013	,661**	1
	p	,699	,782	,488	,517	,551	,268	,682	,626	,103	,962	,004	

*p<0.05; **p<0.01; SL=single-leg hop test for distance; THD=triple leg hop test for distance; 6m=6 m timed hop test; CHD=crossover hop test for distance; SLVJ=single leg vertical jump test; CMJ_{WAS}=without arm swing countermovement jump test; CMJ_{AS}=with arm swing countermovement jump test; RS=right side; LS=left side.

4. Discussion

Strength differences in Rs and Ls of the lower extremity in athletes are very important in evaluating injury risks and preventing performance losses resulting from strength imbalance (Thomee et al., 2011). In some sport disciplines, the strength differences between Rs and Ls are expected to be similar; in normal circumstances, the difference between the two sides should not be greater than 10% (Yılmaz & Kabadayı, 2020). In judo, which is one of these disciplines, it is important for low extremity strength to be similar on R_s and L_s to have balance stabilization during specific movements such as pushes and pulls (Ermiş et al., 2019). In this direction, the present study examined the results of two different formats of CMJ and five different SLHTs and the LSIs calculated from SLHTs in elite young judokas. Our study gave different results. No significance was found between R_s and L_s in all SLHTs; however, significance was found between CMJ_{WAS} and CMJ_{AS} in favor of CMJ_{AS}. No significance was found in LSI comparisons calculated from five different SLHTs (SL, THD, CHD, 6m. THT, and SLVJ). No significant correlation was found between SLHTs and two different formats of CMJ. Significant correlations were found between the SLHTs. In line with these results, while our hypothesis that all SLHTs would give similar LSI rates was confirmed, our hypothesis that there would be correlations between SLHTs and two formats of CMJ was rejected.

Although there are studies in literature in which martial arts and especially the lower extremity strengths in judokas were examined with different test measurement methods (Monteiro et al., 2011; Ermiş et al., 2019; Kons et al., 2020), no studies were found in which five different SLHT and CMJ were evaluated on the same sample group. When studies in which lower extremity strength in judokas was evaluated with different tests, it can be seen that Stradijot et al. (2012) measured SLVJ and isokinetic knee strength of young elite judokas on R_s and L_s at angular velocities of 60, 180, and 240 °/s and found significant difference only at an angular velocity of 240 °/s. When evaluated in terms of kinematics, the results show that tests requiring sudden and high strength, especially SLVJ and isokinetic measurements such as the angular velocity of 60 °/s, do not show an asymmetric rate between two sides in judo. In addition, during competitions, judokas need movements that require sudden and high strength with severe contractions in the lower extremity; therefore, no asymmetry may have occurred at low angular velocities. Ermiş et al. (2019) and Drid et al. (2009) evaluated the lower extremity strength of elite judokas with isokinetic tests and did not report significance between R_s and L_s. Researchers emphasized that similar lower extremity strength parameters on both sides in judokas may be since the strong side comes to the more intensively in throwing techniques and the weak side has more strength attainment to maintain movement in training techniques such as *uchi-komi* (Kons et al., 2020; Dopico et al., 2014). In a study evaluating the isokinetic lower extremity strength of young judoka competing at <73 kilograms, Šimenko et al. (2016) found asymmetry between the two sides; when we evaluated their results, we attributed the asymmetry found in lower extremities to the limited number of subjects in this study (five young judokas). Countermovement is the leading jump test used to evaluate lower extremity strength and anaerobic power in judokas. In literature, researchers have applied CMJ as both one foot and both feet. Koral & Dosseville (2009) examined the effects of 4 weeks combined and gradual weight loss on CMJ performance in elite judokas and found similar results with our study in the control group in which diet was not applied. Detanico et al. (2012) examined the relationship between CMJ and Special Judo Fitness Test (SJFT) and found high correlations between SJFT and CMJ. Researchers attributed this situation to the fact that elastic muscle components are a major factor in strength generation and stated that the results supported this situation. It is possible to support that CMJ is one of the best indices that express maximum muscle strength production based on the fact that Bosco et al. (1982) predicted strength production by using the elastic energy accumulating during the stretch-shortening cycle (SSC) of CMJ. These results show that considering the correlations between SJFT and CMJ, CMJ is a valid and reliable test to evaluate lower extremity strength in judo. It is thought that the significance found in our study between CMJ_{WAS} and CMJ_{AS} is due to the high strength generated during CMJ_{AS}, in addition to its activation in the upper extremity.

Although CMJ results in studies conducted were similar to the results of our study, especially the effects of different types of training on CMJ performance do not give clear information. Kubo et al. (2006) reported that 12-week isometric lower extremity training did not have any effect on CMJ (Pre CMJ= 38.2±7.9 cm, Post CMJ=38.3±7.8 cm), while Harris et al. (2000) reported that strength training did not increase jump height (Pre Vertical Jump=56.1±0.03 cm, Post Vertical Jump

=57.4±0.02 cm) and only isometric training with maximum 30% increased jump height (Pre Vertical Jump=59.1±0.01, Post Vertical Jump =61.5±0.02 cm). These results show that strength training consisting of basic training components takes judokas to maximal levels, and extra specific strength training will not affect strength but will provide functional attainments. At the same time, the fact that the judokas in our study had been training for a long time may have caused maximal strength results.

Strength imbalances that may occur in the lower extremities and the resulting increased injury tendency can be evaluated with LSI calculated with SLHTs. Researchers have stated that evaluating these results with at least two different SLHTs is important in getting correct findings (Augustsson et al., 2004). In the present study, five different SLHTs were evaluated, and when their LSIs were compared, no significance was found, and it was found that the rate between R_s and L_s of our subjects did not exceed 10% and did not cause any asymmetry. A large number of studies in which asymmetric rates were examined in studies showed that asymmetry rates of individuals who did not have an injury history were between the range of 10% (Ermiș et al., 2019; Stradijot et al., 2011; Drid et al., 2015; Prill et al., 2019). However, some studies have shown that practices such as the SSC fatigue protocol may cause asymmetry proportional to fatigue in judokas (Kons et al., 2020). This result shows it is important to follow whether asymmetry occurs by reapplying SLHTs after specific loads in judokas exposed to frequent competitions and training in addition to SLHTs performed in resting state. This follow-up process is very important in terms of the lower extremity, especially in judo, in which ACL incidence is 0.81 per year in 1000 athletes (Takahashi & Okuwaki, 2017). Finally, the number of participants and the levels of athletes are important while examining LSIs in judo. Lambert et al. (2020) examined the SL, THD, and CHD results of 105 judokas on both R_s and L_s and showed that approximately 1 in 4 showed more than a 10% LSI rate. It is thought that this result occurs due to athletes' training levels, injury history, or category.

Our study had some important limitations, the most important of these was that although our sample consisted of national team young judokas, information was not obtained about their belt degrees and which weight class they competed and the evaluations were based on this information. Our failure to evaluate SLHT results by dividing judokas into weight categories shows that our results cannot be generalized for a specific weight category. Therefore, evaluating SLHTs by dividing judokas into weight categories in future studies will provide significant contributions to the literature. Also, the fact that SLHT measurements were not made with an electronic device making detailed measurements caused not obtaining and evaluating data such as the subjects' jumping height, time on air, pressure applied on the floor. Evaluating all kinematic analysis during jumping and associating with limb symmetry in future studies will make important contributions to judo literature.

6. Conclusion

In conclusion, five different SLHTs (SL, THD, CHD, 6 m THT, SLVJ) we applied on R_s and L_s of elite young judokas showed similar results between both sides, LSI values were found to be in >90 % range, and no tendency for lower extremity injury was found. Considering the literature, which states that the results obtained from at least two SLHTs are enough for objective assessment, the results we obtained from five different SLHTs increased the validity and reliability of the study. High correlations found between the SLHTs also support the results of the study. Similar CMJ scores as those found in literature, although no correlation was found between SLHTs and CMJ, show that the judokas in our study showed CMJ results in normal norms. When the results of our study are evaluated in terms of practical applications, the fact that all SLHTs gave similar results in Rs and Ls sides in terms of jumping distance and LSI values showed that all tests could be applied on judokas. Regularly applying any of these two tests that are easy and cost-free to judokas at specific intervals is important in evaluating and tracking the strength rates between lower extremities. However, considering their applicability and the basis of judo-specific moves, we recommend that SL and SLVJ tests to be preferred with priority.

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