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Original Article

Bilateral and ipsilateral peak torque of quadriceps and hamstring muscles in elite judokas

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Abstract

Objective: To examine bilateral and ipsilateral peak torque values of quadriceps (Q) and hamstring (H) muscles in elite judokas. **Methods:** 16 elite male judokas were tested in concentric isokinetic strength of the quadriceps (Q) and hamstrings (H) muscles at 60° and 180° sec^{-1}. Variables comprised average peak torque and the traditional H/Q, Q/Q, H/H ratios. Asymmetries between legs and differences between isokinetic muscle strength ratios were examined using paired t-tests and Cohen's d. **Results:** In right (Rs) and left (Ls) extremity peak torque values, no significant difference was found between 60° and 180° sec^{-1} angular velocities ($p>0.05$). In peak torque values between PLs and NPLs, significant difference was found only in extension (Ex) phase at 60° sec^{-1} angular velocity $p=0.001$). (Significance was identified between (Q/Q) and (H/H) muscle ratios at 60° sec^{-1} ($p=0.029$). No significant difference was found in ipsilateral strength ratios at 60° and 180° sec^{-1} angular velocity ($p>0.05$). **Conclusions:** The Ex knee strength of PLs was high, particularly at low angular velocities, leading to differences of bilateral asymmetry in the Q muscle group. Regarding ipsilateral strength ratios, there were no differences in the H and Q muscle groups at both angular velocities, indicating that both legs were similar in terms of ipsilateral asymmetry.

Keywords: H/Q ratio, Knee Strength, Functional Asymmetry, Muscle Weakness

Introduction

Judo is a discipline that involves high-intensity pushing; pulling; and various other techniques (throws, pins, chokes, and arm bars)[1-3]. Moreover, owing to the high level of competition, athletes are required to have specific physical characteristics[4]. Achieving a perfect physical fitness level (maximal strength, power, and endurance) bears importance for success, especially for judokas who participate in international competitions, with muscle strength being one of the most important factors[5]. In terms of the structure of movement, various muscle actions and strength types are important for performing throw techniques and maintaining balance, which are directly associated with having strong knees, thighs, shoulders, and back muscles[6-9]. In addition, specific morphological parameters, such as a low fat percentage and high muscle ratio, improve the performance of judokas[6,10].

Strength differences between agonist and antagonist muscles of athletes are one of the best testing parameters to determine tendency for injuries[24]. The asymmetric strength of lower extremities is unequal strength between the right and left quadriceps (Q) and hamstrings (H) in similar contraction types[21]. Strength ratio between H and Q (H/Q ratio) increases as the test speed increases[37]. This ratio differs by 50-80% depending on the test speed, and angular velocity of 60° sec^{-1}, the ratio of 60% is considered normal[38]. Similarly, when difference in strengths between the right and left Q and H exceed 10-15%, asymmetry is considered to exist between the two sides[39]. According to Kannus[40], injury risk is high when this difference exceeds 20%.

According to Brown[36], isokinetic measurements are the most valid and reliable knee strength markers, which objectively indicate knee extensor and flexor strengths in both eccentric and concentric contractions conducted with isokinetic dynamometers under laboratory conditions. Reportedly, body muscles, which are critical in judo

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performance, produce similar results in judokas competing in the same weight categories. In terms of knee and thigh strengths, the dominant and non-dominant legs show no significant differences[4,22,23]. In particular, strengths of lower extremity are vital for judokas for maintaining balance and delivering absolute performance of their upper extremities during competitions. Therefore, understanding of agonist/antagonist and bilateral strength ratios of lower extremity muscles is important for both performance and injury risk prevention[22,23,41]. Although increasing number of studies have focused on strength in martial arts[4,13,14,20,22,27,28,34], studies of strength asymmetries or ratios in different martial arts are limited[11,13,24,29,30]. In these studies, the H/Q rates between right and left sides were typically examined. For instance, Drid et al.[11] examined judokas, wrestlers, and untrained individuals at the angular velocity of 60° sec^{-1} without differentiating between dominant and non-dominant side. Similarly, Stradijot et al.[29] differentiated between right and left sides at angular velocities of 60° sec^{-1}, 180° sec^{-1}, and 240° sec^{-1} in young judokas and wrestlers. In addition, in both these studies, the H/Q ratios of right and left sides were compared, but bilateral differences were not examined. In this respect, our study provides a novel and original resource to assess lower extremity asymmetry in judokas.

The aim of this study was to determine knee extension (Ex) and flexion (Flx) strength profiles of elite judokas and to identify whether there is strength asymmetry between the Q and H muscles in the lower extremities. The present study hypothesizes that there is no strength asymmetry between the Q and H muscle groups in preferred (PLs) and non-preferred legs (NPLs) of judokas.

Material and method

Experimental procedures

We determined the knee isokinetic profiles of elite judokas and analyzed the strength asymmetry between the Q and H muscles. Subjects were tested twice under laboratory conditions. During their first laboratory visit, subjects were informed about the test protocols, their heights and weights were measured, body mass index (BMI) was calculated, and dominant legs were identified. During the second visit, isokinetic knee strength (which was used to calculate the concentric peak torque values at angular velocities of 60° sec^{-1} and 180° sec^{-1}) was measured. Subjects were asked to perform the test with the maximum effort. For 24 hours before measurements, subjects were instructed not to perform any exercise or physical activity.

Subjects

The study included 16 male judokas (age, 18.31 years; height, 170.07 cm; weight, 77.39 kg; BMI, 26.80 kg/m^2) who were actively involved in judo at the elite level and who reported a training history of at least 5 years (Table 1). Subjects had not suffered knee injuries previously were included. The study was conducted according to the principles of the Declaration of Helsinki and its latest amendments, and voluntary consent form was obtained from all subjects.

Procedures

Anthropometric measurement

A Gaia 359 Plus BodyPass analyzer was used to determine height, weight, and BMI. Before measurements, the device was introduced to all subjects, and they were verbally informed to remain as quiet and immobile as possible during the test. Individuals who had previously been tested using the analyzer were re-examined. Thus, subjects also perceived the test visually. After giving instructions and performing sample tests, subjects stood on the analyzer bare feet and with t-shirt and shorts on, and the results were recorded as height (cm), weight (kg), and BMI (kg/m^2) values.

Identification of the dominant leg

Currently, many tests are available to identify the dominant leg, including self-reported leg dominance, observed leg dominance, ball-kick, and step-up, among others. In our study, ball-kick and step-up tests were preferred since it is important for athletes to step steadily and react in a balanced and strong way to the opponent as well as to perform pushes and pulls efficiently while performing moves specific for judo. Moreover, both ball-kick and step-up test are the most used tests in the literature for determining the dominant leg.

In the ball-kick test, subjects were asked to kick a soccer ball with moderate intensity and maximal accuracy through a set of cones placed 1 m apart and 10 m away from subjects. The leg used to kick the ball was identified as the dominant leg. Successfully kicking the ball through the cones was not a criterion for the test. In the step-up test, subjects were asked to step onto a 20-cm-high step. The leg used to perform the step-up was determined as dominant for each trial[53]. While 11 of the subjects had dominant right legs, 5 had dominant left legs. After identification, dominant legs were classified as PLs and non-dominant legs as NPLs. Following tests, results of subjects were compared and no inconsistency was found.

Assessment of knee strength indicators

Knee strength can be measured using different methods. With the development of technology, simple methods have been replaced by isokinetic dynamometers, which provide the most objective results of strength measurements[11-16]. In addition to providing an objective assessment among the muscle groups, assessment of the resulting strength helps predict injury risks[17-20].

The subjects were asked to perform knee Ex and Flx movements at angular velocities of 60° sec^{-1} and 180° sec^{-1} with concentric/concentric (Con/Con) contraction. Angular velocities of 60° sec^{-1} and 180° sec^{-1} were selected because muscle fibrils generate more strength at low angular velocities[42]. To perform a proper joint movement, antagonists perform eccentric contraction to lengthen the muscle and to prevent supraphysiological joint

Table 1. Descriptive data of judo athletes.

Variable	N	Min.	Max.	Mean	S.D.
AGE (years)	16	16,00	20,00	18,31	1,40
HEIGHT (cm)	16	153,21	183,40	170,07	8,42
WEIGHT (kg)	16	55,70	136,20	77,39	20,50
BMI (kg/m^2)	16	19,27	41,27	26,80	6,25

loading, whereas agonists perform concentric contraction to shorten the muscle. Imbalance in concentric agonist/eccentric antagonist movement ratios can cause injury in the corresponding muscle groups, and poor eccentric strength of the H muscles can also cause injuries[43-45]. Therefore, our study was conducted with concentric contractions alone to prevent injuries of the H muscles in subjects.

Tests were conducted in the morning between 11:00 and 13:00 using a computer-controlled isokinetic dynamometer (Humac Norm Testing and Rehabilitation System, CSMI, USA). For general warm-up, subjects performed 5 min of low-intensity aerobic run and 10 min of first dynamic and then static stretching of the lower extremity muscles before the tests[26].

The tested subject sat on the seat of the dynamometer, at an 85° torso inclination. The range of motion was 90° (maximum extension was marked and set as anatomic zero "0°"). The subject's trunk and the thigh of the tested leg were fixed with the dynamometer's fixing straps (tested thigh and thorax; pelvis). Thus, movement was confined to a single-joint movement (knee Ext-Flx). Dynamometer was calibrated as per the manufacturer's instructions, and torque was gravity corrected[24].

To provide subjects' with adaptations and to protect them from injury, three trials were conducted before the tests at both angular velocities, and a 30-s rest was allowed. Following the 30-s rest, subjects performed five non-stop maximal Ext/Flx movements at the angular velocity of 60° sec^{-1}. After a 1-min break, the subjects performed 10 non-stop maximal Ext/Flx movements at the angular velocity of 180° sec^{-1}. To ensure the best performance during the whole test, subjects were verbally encouraged. Average peak tork (PT) values at all angular velocities were recorded in Newton (Nm). Average values were analyzed, and no extreme data were determined. To determine the strength balance ratios based on the obtained results, bilateral strength ratios of PLs and NPLs were determined as Q/Q and H/H, whereas ipsilateral strength ratios were determined as H/Q; all ratios were recorded in %.

Statistical analysis

SPSS program (SPSS for Windows, version 21.0, SPSS Inc., Chicago, Illinois, USA) was used for statistical analyses. The data were presented as mean and standard deviation. Shapiro-Wilk test was used for normality; Levene's test was used for the homogeneity. Skewness and kurtosis values were checked for datasets that were not normally distributed, and those within ±2 were accepted to be normally distributed. Paired sample t-test was used to compare paired groups. In addition, in the comparison of paired groups, effect sizes were determined based on Cohen's d $[(M_2 - M_1)/SD_{\text{pooled}}]$. According to this formula, a d value of <0.2 was defined as weak effect size, a d value of 0.5 was defined as moderate, and a d value of >0.8 was defined as strong effect size. Statistical results were assessed within 95% confidence interval and at a significance level of p<0.05.

Results

Table 1 shows the descriptive information of the study.

When Rs and Ls peak muscle toque values were compared, there was no significant difference in both Ex and Flx phases at angular velocities of 60° sec^{-1} and 180° sec^{1} (p>0.05) (Table 2).

Results of comparison of peak muscle torque values between PLs and NPLs are summarized in Table 3. At the angular velocity of 60° sec^{-1}, the torque values were significantly different in the Ex phase (p=0.001, e.s=0.50, 95% CI=-13.52 to -40.65) but not in the Flx phase (p=0.451, e.s=0.16, 95% CI=-9.18 to 19.65). At the angular velocity of 180° sec^{-1}, the torque values were significantly different in both Ex (p=0.913, e.s=0.02, 95% CI=-16.94 to 15.27) and Flx (p=0.974, e.s=0.08, 95% CI=-9.55 to 9.26) phases. The results indicate that the strength of both PLs and NPLs decreases as the angular velocity increases. In addition, there were significant differences in strengths between PLs and NPLs. In particular, at the angular velocity of 60° sec^{-1}, PLs showed higher strength than NPLs in the Ex phase (p=0.001, e.s=0.50). Except at 60° sec^{-1} in the Ex phase, there were no differences in peak torque values between PLs and NPLs of subjects, which is the basic factor in the determination of Ex and Flx strength asymmetries between the knees.

The Q/Q and H/H ratios were significantly different at the angular velocity of 60° sec^{-1} (p=0.029, e.s=0.68, 95% CI=-16.17 to -0.99); however, there was no difference in Q/Q and H/H ratios at the angular velocity of 180° sec^{-1} (p=0.872, e.s=0.03, 95% CI=-8.94 to 7.66). These results indicate that elite judokas show bilateral asymmetry at the angular velocity of 60° sec^{-1}. As angular velocity increased, nearly significant results were determined, indicating that

Table 2. Peak muscle torque of knee flexors and extensors (Nm) in the right (Rs) and left (Ls) extremities.

Velocity (°.s^{-1})		N	Mean	S.D.	t	95% CI	p	e.s
60_{Ex} (Nm)	**Rs**	16	204,80	60.00	.438	-15.92-24.14	0.668	0,11
	Ls	16	200.69	50.50				
60_{Flex} (Nm)	**Rs**	16	109.87	32.83	-.814	-19.88-8.89	0,428	0,16
	Ls	16	115.36	32.46				
180_{Ex} (Nm)	**Rs**	16	140.54	27,11	-1.795	-26.93-2.30	0,093	0,36
	Ls	16	152.85	39.35				
180_{Flex} (Nm)	**Rs**	16	85.45	16,13	-1.202	-14.05-3.91	0,248	0,28
	Ls	16	90.51	19.58				

95 % CI: Confidence interval, e.s: Cohen's d effect size, S.D.: Standard deviation.

Table 3. Peak muscle torque of knee flexors and extensors (Nm) in the preferred and non-preferred extremities.

Velocity (°.s^{-1})		N	Mean	S.D.	t	95% CI	p	e.s
60_{Ex} (Nm)	**PLs**	16	216,29	50,31	4,256	-13.52- -40.65	**0,001***	0.50
	NPLs	16	189,20	56,90				
60_{Flex} (Nm)	**PLs**	16	115,23	26,96	0,774	-9.18-19.65	0,451	0.16
	NPLs	16	110,00	37,50				
180_{Ex} (Nm)	**PLs**	16	146,28	27,29	-,111	-16.94-15.27	0,913	0.02
	NPLs	16	147,12	40,24				
180_{Flex} (Nm)	**PLs**	16	87,91	16,01	-,033	-9.55-9.26	0,974	0.08
	NPLs	16	88,06	20,03				

95 % CI: Confidence interval, e.s: Cohen's d effect size, S.D.: Standard deviation.

Table 4. Bilateral ratio between peak muscle torque of knee extensors (Q:Q) and flexors (H:H).

Velocity (°.s^{-1})		N	Mean (%)	S.D.	t	95% CI	p	e.s
60	**Q:Q**	16	87,04	12,51	-2.411	-16.17- -.99	**0,029***	0.68
	H:H	16	95,62	22,28				
180	**Q:Q**	16	100,72	18,10	-.164	-8.94-7.66	0,872	0.03
	H:H	16	101,36	20,14				

95 % CI: Confidence interval, e.s: Cohen's d effect size, S.D.: Standard deviation.

Table 5. Ipsilateral ratio between peak muscle torque of knee flexors and extensors in the preferred and non-preferred lower extremities (H:Q).

Velocity (°.s^{-1})		N	Mean (%)	S.D	t	95% CI	p	e.s
60	**PLs**	16	60,12	15,68	.986	-7.46-20.28	0,340	0.45
	NPLs	16	53,71	12,62				
180	**PLs**	16	65,41	10,93	1.995	-.584-17.65	0,065	0.85
	NPLs	16	56,88	8,89				

95 % CI: Confidence interval, e.s: Cohen's d effect size, S.D.: Standard deviation.

asymmetric differences occur at low angular velocities (Table 4).

There was no significant difference in ipsilateral peak muscle torque ratios between PLs and NPLs at the angular velocity of 60° sec^{-1} (p=0.340, e.s=0.45, 95% CI=-7.46 to 20.28); however, PLs showed higher ratios at the angular velocity of 180° sec^{-1} (p=0.065, e.s=0.85, 95% CI=-0.584 to 17.65). Based on these results, the rate was determined to be 15%, and ipsilateral ratio of H and Q was determined to be 10-15%. These results indicate that judokas in the present study did not show ipsilateral strengths that can increase the risk of injury under normal circumstances (Table 5).

Discussion

Muscle strengths[5] of the knee, thigh, and shoulder are some of the most important factors for the success of judo athletes who compete at the elite level. These strengths should be high, particularly for performing throw techniques specific for judo and maintaining balance[4,6-9,11,14].

The results of our study revealed two major findings. First, in elite judokas, PLs showed higher strength than NPLs in the Ex phase of at the angular velocity of 60° sec^{-1}. Second, there was a bilateral strength difference between the Q and H muscle groups the angular velocity of 60° sec^{-1}.

Although there were no significant differences in isokinetic knee peak torque values between Rs and Ls of elite judokas at angular velocities of 60° sec^{-1} and 180° sec^{-1}, peak torque values between PLs and NPLs were significantly different in the Ex phase at the angular velocity of 60° sec^{-1}. In addition, both strengths on Rs and Ls and of PLs and NPLs decreased with increased angular velocity. Studies of upper[4,9,22,28] and lower extremity strengths[9,23,27,29] of judokas have demonstrated different results between the right and left sides and dominant and non-dominant sides of judokas. For example, in a study including elite, national judokas, Ghrairi et al.[22] measured knee Ex and Flx strengths of at angular velocities of 90° sec^{-1}, 180° sec^{-1}, and 240° sec^{-1} and reported significant differences between dominant and non-dominant sides in the Ex phase at angular velocities of 90° sec^{-1} and 180° sec^{-1}. In a study including half-heavyweight category national team athletes, Drid et al.[9] found no significant difference between right and left sides, although they did not differentiate between dominant and non-dominant sides. Results of both these studies are consistent with results of our study, and we speculate that different results between PLs and NPLs and RS and Ls knee peak torque values are due to upper extremity strength differences or upper extremity dominance in judokas. This speculation is further supported by reports of Drid et al.[9] and Ghrairi et al.[22] that there were significant differences in shoulder internal and external rotation strengths between Rs and Ls as well as between PLs and NPLs; however, they noted similar results in terms of knee extension and flexion strengths as we did in our study. In addition, judokas should reportedly have a good balance while performing movements such as pushing and pulling during competitions; thus, lower extremity muscle groups should generate strength with high levels of contraction[22,23,27]. In addition, during repetitive muscle strength measurements, decreased PT can result from the contributions of type 1 and type 2 muscle groups to strength, and since movement is primarily acquired from type 1 muscle fibers rather than type 2, strength and fatigue decrease as angular velocity increases[46].

Unlike previous studies, the present study demonstrated differences between Rs and Ls as well as between PLs and NPLs and outlined reasons underlying these differences.

Considering the peak torque values of leg muscles, the lateral asymmetric ratio can be hindered by the individual dominance of the right or left leg; therefore, the average values for both legs may not reflect the characteristics specific for the branch[30]. It is important to be able to comment on the results after a successful test[45]. In the present study, asymmetric indices among judokas were calculated to determine such characteristics. Ipsilateral (H/Q) muscle strength ratios reached 11.93% and 15% between PLs and NPLs at angular velocities of 60° sec^{-1} and 180° sec^{-1}, respectively (Table 5). At both angular velocities, NPLs yielded a lower H/Q ratio than PLs, although the differences were not statistically significant at both 60° sec^{-1} and 180° sec^{-1}. The H/Q ratio has been reported to increase with increased velocity, and this ratio can differ depending on the test velocity[36,37]. For example, at 60° sec^{-1}, the ratio was 0.6, below which the risk of ipsilateral hamstring weakness increase compared with that of quadriceps weakness, leading to increased risk of injury. However, this depends on both ratio as well as hamstring tension and anterior cruciate ligament damage[47,48]. Some researchers have reported that the H/Q ratios of 0.6-0.8 at angular velocities between 60° sec^{-1} and 240° sec^{-1} can be considered normal[38-50]. If the lateral strength difference between Q and H at the same test velocities is >15%, the risk of injury increases, with ratios >20% representing a high risk of injury[40,51,52]. H/Q strength ratios of the present study were 10-15%, as stated in the literature, indicating there was no asymmetry between the H and Q muscle groups of judokas and that the risk of injury was minimal under normal conditions. Similar H/Q ratios between PLs and NPLs were also found in previous studies including judokas, and these studies reported results similar to the present study[29-31]. In the present study, bilateral differences between Q/Q and H/H reached 9.86% at the angular velocity of 60° sec^{-1} and decreased to 0.64% at the angular velocity of 180° sec^{-1}; the differences were significant only at the angular velocity of 60° sec^{-1}. In contrast, the bilateral asymmetric ratio decreased as angular velocity increased (Table 4), indicating that excessive and short-term load while applying a force at low angular velocities, especially bilateral asymmetry, can reach high values depending on the muscle fatigue index. Researchers have stated that 10% bilateral deficit could be accepted as normal[52]. In judo, the lateral asymmetry ratios have been proven to be safe in development of specific throw techniques, such as Uchi-mata, Haraigoshi, Osoto-gari, and Ouchi-gari[32-35] and movement models in terms of functional asymmetry. Our results are supported by those reported by Drid et al[30]. However, lateral asymmetric ratios in judo athletes were not similar to those in other martial arts athletes. In a study including elite kick boxers, Maly et al.[24] observed bilateral strength asymmetry at the angular velocity of 60° sec^{-1} and ipsilateral strength asymmetry at angular velocities of 60° sec^{-1} and 180° sec^{-1}. These differences were assumed to have resulted from the dominant sides specific to kickboxing and used intensively in hit techniques. In judo, leg strength plays an important role in maintaining balance in various stages, such as pushing, pulling, and throwing. Thus, judokas develop balance to help the upper extremities apply strength at the maximum level.

Based on the results of this and previous studies, both upper and lower extremity lateralization and symmetry are crucial for judokas due to specific movement models applied in judo and the requirements of this branch. Studies in this regard are limited and report variable results in lower and upper extremities[9,22,23,27,28]. Therefore, patterns of strength asymmetry in extremities of judokas can differ according to states such as weight categories, training age, body types, and athletes' levels. However, to succeed in judo, in addition to regular training, athletes are recommended to develop both lower and upper extremity strengths and symmetries and to apply specific training models if any asymmetry or strength difference is detected to eliminate these differences. Nonetheless, the present study has limitations in that we measured knee Ex and Flx strengths at angular velocities of 60° sec^{-1} and 180° sec^{-1}, assessed concentric contractions, and applied study design to focus on Ex and Flx strengths in lower extremities only. This study was thus planned for two main reasons. First, muscle fibrils generate more strength at low angular velocities[22], and judokas do not require high angular velocities of strength during competitions. Second, during joint movements, antagonist muscles show eccentric contraction to lengthen the muscle and to prevent supraphysiological joint loading, whereas agonist muscles show concentric contraction. Asymmetry in concentric agonist/eccentric antagonist movement can cause injury in the corresponding muscle groups[44,45]. In addition, H muscles are weak in eccentric contraction; therefore, they are more prone to injury than quadriceps muscles, which show strong concentric contraction. Moreover, as the movement velocity increases, the rate of injury increases in eccentric contraction[43]. Therefore, our study was conducted only with concentric contraction and at angular velocities of $\leq$180° sec^{-1} in order to minimize the risk of injury.

Conclusion

In conclusion, bilateral asymmetric ratios in the present study, which are used to determine injury risks and strength differences in similar muscle groups on different sides, were between percentage intervals stated in the literature at angular velocities of 60° sec^{-1} and 180° sec^{-1}, although the difference was significant at 60° sec^{-1} only. Moreover, these differences did not pose a risk of injury. There was no difference in ipsilateral strength between PLs and NPLs at angular velocities of 60° sec^{-1} and 180° sec^{-1}. The ipsilateral ratio of H and Q was 10-15%, representing low injury risk under normal conditions. However, trials performed at high angular velocities can increase this ratio. Our results indicate that while applying training methods specific to judo, strength ratios of both legs should be regularly followed up and loading should be applied based on H/Q ratio to decrease the risk of injury. Thus, we recommend that strength asymmetry be assessed at different angular velocities. Finally, short-term isokinetic strength tests and excessive load measurements are warranted to examine the associations among anaerobic strength, muscle strength, and lateral asymmetry.

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