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Comparison of muscle strength profiles in taekwondo and judo elite athletes

Michał Górski[1*], Rafał Kubacki[2], Krzysztof Buśko

[1]Department of Biomechanics, Institute of Sport – National Research Institute, Warsaw, Poland

[2]Faculty of Physical Education and Sport, Wroclaw University of Health and Sport Sciences, Wroclaw, Poland

[3]Department of Biomedical Basis of Physical Culture, Faculty of Health Science and Physical Culture, Kazimierz Wielki University in Bydgoszcz, Bydgoszcz, Poland

[*]Corresponding author: Michał Górski, Department of Biomechanics, Institute of Sport – National Research Institute, Warsaw, Poland, e-mail address: michal.gorski@insp.waw.pl

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Abstract

Purpose: Sports training, of which muscle strength development is a part, should be aimed at optimally preparing athletes for competition. Differences in the demands of judo and taekwondo sports combat will lead to different results in developing the strength potential of athletes. The aim of this study was to assess the strength capabilities of athletes training taekwondo and judo.

Methods: The study included 14 taekwondo and 17 judo elite athletes. Measurements were taken of the maximum muscle torques developed under static conditions of 20 muscle groups responsible for flexion and extension of the limbs, at the shoulder, elbow, knee, hip joints and trunk flexion and extension. Based on the results, the topography of muscle torques was calculated as the percentage of the ratio of the muscle torques developed at a given joint to the sum of all the torques tested.

Results: Judo athletes developed significantly higher values of muscle torques than taekwondo athletes during flexion and extension of the upper limb joints and extension at the hip joint ($p<0.05$). Judo athletes achieved higher topography index values in flexion of the left shoulder joint and extension of both elbow and shoulder joints ($p<0.05$). Taekwondo athletes achieved higher topography index values in flexion of the knee and hip joints of the right and left lower limbs ($p<0.05$).

Conclusions: The calculation of muscle topography allowed us to assess the differences in the strength profiles of judo and taekwondo athletes and can provide additional information for evaluating the effects of strength training.

Keywords: MVC, joint torques, topography, combat sports, martial arts

Introduction

Judo and taekwondo are combat sports included in the Olympic Games programme. Upon analysing the physiological demands placed on athletes practising these sports, certain similarities emerge. The physical effort required of athletes is intense and relatively short in duration, imposing the necessity for a high anaerobic capacity [2], [14]. High muscular strength and the ability to use it skilfully also appear to be crucial for success.

During taekwondo sport fighting, strikes performed with the lower limbs predominate [10]. They account for the vast majority of all attack and defence techniques observed during sport fighting [27]. The ability to deliver powerful strikes is often identified as a trait of successful athletes [12], [13]. In judo, on the other hand, during a sport fight, rival opponents grapple, perform throws, and the fight is conducted in both standing and ground positions [24]. Judo athletes are characterised by an above-average level of muscular strength [28]. This trait is developed already at an early stage of the sport career [19]. The proportional development of the strength of certain muscle groups may condition the technical-tactical solutions used during sports combat [29].

In order to objectively assess the strength potential available to athletes, measurements of maximum muscle torques developed under static conditions are often used [4], [31]. The method allows the assessment of strength capabilities and their changes occurring as a result of the training performed [8], [16]. The muscle topography or strength profile can be used to determine the proportion of muscle groups acting on individual joints to the sum of all measured muscle groups [5]. It is subject to modifications according to the training loads applied [3] - [4]. The different demands placed on athletes by taekwondo and judo combat may result in different changes in the muscular topography of athletes training in these combat sports. However, there is little research comparing the muscular topography of taekwondo and judo athletes as determined by measurements of maximal muscular torques [4], [8].

The aim of this study was to assess the strength capabilities of athletes training in taekwondo and judo. The following hypotheses were verified during the study: 1) Judo athletes have a greater strength potential than taekwondo athletes. 2) The topography of muscle torques among judo athletes indicates that muscular strength of the upper limb joints has a greater contribution to the overall muscular strength, whereas, in the case of taekwondo athletes, muscular strength of the lower limbs has a greater contribution.

Material and Methods

Participants

Thirty-one elite male athletes participated in the study: 14 men training taekwondo and 17 men training judo. The athletes tested were members of senior, youth or junior national teams. The study group included athletes who were multiple medallists of the country, international tournaments abroad and participants of the Olympic Games. At the time of entry into the study, the athletes were healthy, or at least 3 months after treatment for any injuries. The characteristics of the athletes are shown in Table 1. This study was conducted in accordance with the principles of the Declaration of Helsinki. The research was approved by the Research Ethics Committee at the <INSTITUTION NAME> (approval numbers: KEBN-16-20-MG and KEBN-17-32-KB). Prior to the study, all athletes were informed about the research purpose and test procedures as well as the possibility to discontinue participation in the study at any time. Participants gave written consent to take part in the research.

Table 1. Anthropometric characteristics of the tested athletes (means ± SD; 95%CI)

	TKD (n=14)	JUDO (n=17)	t	p	d
Age [years]	21.64 ± 4.07 (19.29 ÷ 23.99)	23.29 ± 3.72 (21.38 ÷ 25.21)	-1.18	0.248	0.43
Body mass [kg]	76.19 ± 10.87 (69.92 ÷ 82.47)	88.41 ± 19.96 * (78.15 ÷ 98.67)	-2.05	0.049	0.74
Body height [cm]	182.66 ± 7.08 (178.58 ÷ 186.75)	180.49 ± 10.54 (175.08 ÷ 185.91)	0.66	0.516	0.24
Training experience [years]	13.07 ± 3.47 (11.07 ÷ 15.08)	14.53 ± 3.56 (12.70 ÷ 16.36)	-1.15	0.260	0.41

Legend: TKD – taekwondo, * – statistically significant difference, $p<0.05$

Measurement of muscle torques under static conditions

Measurement of the 20 muscle groups responsible for flexion and extension of the limbs, at the shoulder, elbow, knee and hip joints, as well as flexion and extension of the participant's trunk, was carried out at the two self made torque meter measurement stations: upper limbs was measured at SMS1 (<DEVICE MANUFACTURER, CITY, COUNTRY>) and lower limbs and trunk was measured at SMS2(<DEVICE MANUFACTURER, CITY, COUNTRY>) [7], [16]. The total error associated with the measurement of maximum muscle torques on the stands used does not exceed 4% [3], [17]. Torques of the muscle groups flexing and extending the limb at the elbow joint were measured in the sitting position. The arm was rested on a support and the angle at the shoulder joint was 90 degrees. The forearm was positioned perpendicular to the shoulder. The torso was supported and stabilised. The muscle torques flexing and extending the limb at the shoulder joint were measured in the sitting position. The angle at the shoulder joint during extension was 70 degrees and 50 degrees during flexion. The torso was adjacent to the stand and was stabilised by the participant's chest being pressed against the backrest by the qualified person performing the measurement. Muscle torques flexing and extending the limb at the knee joint and flexing and extending the trunk were tested in the sitting position as well. The angles at the hip and knee joints were 90 degrees. The participant was stabilised at the level of the anterior superior iliac spines and during knee flexion at the distal part of the thigh. The upper limbs rested on the chest. When the hip extensor muscles were tested, the participant was lying face down. During the hip flexor muscles test, the participant was in the supine position. The angle at the hip joint was 90 degrees. The subject stabilised the trunk by holding the stance with the hands. The maximum extension of the limb at the elbow, knee and hip joints was defined as 0 degrees. For the shoulder joint, the position of the limb along the trunk was 0 degrees. The position of the trunk in the supine position was also 0 degrees. The axis of rotation at the tested joint coincided with the axis of rotation of the torque lever. Both upper and lower limbs were measured, right and left limbs separately, always in flexion-extension order. The participants were instructed to perform the measurement with full commitment in order to develop the maximum torque value, and were given verbal encouragement during the effort by those performing the measurement. All torques values were analysed relative to the subjects' body weight.

On the basis of the results of measurements of the muscle groups responsible for flexion and extension of the limbs, at the shoulder and elbow joints, indices characterising the strength potential of the upper limbs were calculated as follows:

where:

$$RUE = REF + REE + RSF + RSE,$$

$$LUE = LEF + LEE + LSF + LSE,$$

RUE is the sum of right upper extremity, LUE is the sum of left upper extremity, REF is right elbow flexors, LEF is left elbow flexors, REE is right elbow extensors, LEE is left elbow extensors, RSF is right shoulder flexor, LSF is left shoulder flexors, RSE is right shoulder extensors, LSE is left shoulder extensors.

On the basis of the results of measurements of the muscle groups responsible for flexion and extension of the limbs, at the knee and hip joints, indices characterising the strength potential of the lower limbs were calculated as follows:

$$RLE = RKF + RKE + RHF + RHE,$$

$$LLE = LKF + LKE + LHF + LHE,$$

where:

RLE is right lower extremity, LLE is left lower extremity, RKF is right knee flexors, LKF is left knee flexors, RKE is right knee extensors, LKE is left knee extensors, RHF is right hip flexor, LHF is left hip flexors, RHE is right hip extensors, LHE is left hip extensors.

Knowing the values of the indices characterising the strength of the right and left upper and lower limbs separately, the indices for both upper and lower limbs were calculated as follows:

$$SUE = RUE + LUE,$$

$$SLE = RLE + LLE,$$

where:

SUE is the sum of upper extremity torques, SLE is the sum of lower extremity torques, RUE is the sum of right upper extremity, LUE is the sum of left upper extremity, RLE is right lower extremity, LLE is left lower extremity.

Based on the results of measurements of the muscle groups responsible for the trunk's flexion and extension, the index characterising the strength potential of the trunk muscles was calculated as follows:

$$\mathrm{ST} = \mathrm{TF} + \mathrm{TE},$$

where:

ST is the sum of trunk muscle torques, TF is trunk flexors, TE is trunk extensors.

The overall level of muscular strength was expressed as the sum of the results of all measurements taken at the joints of the upper and lower limbs and flexing and extending the trunk:

$$\mathrm{SUM} = \mathrm{SUE} + \mathrm{SLE} + \mathrm{ST}$$

where:

SUM is sum of all muscle torques, SUE is the sum of upper extremity torques, SLE is the sum of lower extremity torques, ST is the sum of trunk muscle torques.

Determination of the topography of muscle torques

The topography of the muscle torques developed at each joint was calculated as the percentage ratio of the torque developed at that joint to the sum of all 20 muscle torques. The calculation is described below using the flexors of the elbow joint of the right limb as an example:

$$\mathrm{TREF} = \frac{REF}{SUM} \cdot 100\%$$

TREF is the percentage topography of right elbow flexors, REF is right elbow flexor torque, SUM is the sum of all muscle torques.

Statistical analysis

Descriptive statistical analysis consisted of determining the maximum (MAX), minimum (MIN), mean (M), median (Me), standard deviation (SD), 95% confidence intervals

(95%CI) of the means and interquartile ranges (IQR) of the indicators studied. The normality of the distribution of variables was verified using the Shapiro-Wilk test. Homogeneity of variance was assessed using Levene's test. Student's t-test for independent groups was used to analyse differences in the values of muscle torques developed by taekwondo and judo athletes. The effect sizes of the comparisons were assessed using Cohen's d, classified as trivial ($d \le 0.2$), small ($0.2 < d \le 0.5$) medium ($0.5 < d \le 0.8$) and large ($d > 0.8$) [11]. The Mann-Whitney U test was used to analyse differences in symmetry index values and muscle topography. Effect sizes were assessed using η^2, classified as small ($0.01 < \eta^2 \le 0.06$), medium ($0.06 < \eta^2 \le 0.14$) and large ($\eta^2 > 0.14$) [11]. For the above analyses, a p-value of 0.05 was defined as significant. Analyses were performed using STATISTICA v. 13.1. (TIBCO Software Inc., 2017, California, U.S) and Microsoft Excel 2016 (Microsoft Corporation, 2016, Washington, U.S.).

Results

Table 2 shows the results of the measurements (means) of the maximum muscle torques with respect to the body weight of taekwondo and judo athletes. The table includes indices characterising the strength potential of the right and left upper and lower limbs.

Table 2. Mean values (±SD; 95%CI) of the relative muscle torques of the flexor and extensor muscles, right and left upper and lower limbs at the elbow, shoulder, knee, hip, and the sum of the upper and lower limb force moments of taekwondo and judo athletes.

	side	TKD	Judo	t	p	d
Elbow Flexion [$N \cdot m \cdot kg^{-1}$]	R	0.96 ± 0.12 (0.89 ÷ 1.02)	1.17 ± 0.13 * (1.11 ÷ 1.24)	-4.92	<0.001	1.78
	L	0.92 ± 0.11 (0.86 ÷ 0.98)	1.16 ± 0.12 * (1.10 ÷ 1.23)	-5.74	<0.001	2.07
Elbow Extension [$N \cdot m \cdot kg^{-1}$]	R	0.59 ± 0.08 (0.55 ÷ 0.64)	0.86 ± 0.11 * (0.81 ÷ 0.92)	-7.66	<0.001	2.76
	L	0.59 ± 0.09 (0.54 ÷ 0.64)	0.84 ± 0.09 * (0.79 ÷ 0.89)	-7.82	<0.001	2.82
Shoulder Flexion [$N \cdot m \cdot kg^{-1}$]	R	0.80 ± 0.18 (0.70 ÷ 0.90)	1.02 ± 0.14 * (0.95 ÷ 1.10)	-3.93	<0.001	1.42
	L	0.76 ± 0.15 (0.67 ÷ 0.84)	0.97 ± 0.12 * (0.91 ÷ 1.03)	-4.36	<0.001	1.57
Shoulder Extension [$N \cdot m \cdot kg^{-1}$]	R	0.92 ± 0.12 (0.85 ÷ 0.99)	1.27 ± 0.17 * (1.18 ÷ 1.35)	-6.37	<0.001	2.30
	L	0.95 ± 0.13 (0.88 ÷ 1.02)	1.23 ± 0.19 * (1.13 ÷ 1.33)	-4.77	<0.001	1.72
Knee Flexion	R	1.89 ± 0.31 (1.71 ÷ 2.07)	1.84 ± 0.29 (1.69 ÷ 1.99)	0.44	0.663	0.16

[N·m·kg^{-1}]	L	1.74 ± 0.30 (1.56 ÷ 1.91)	1.75 ± 0.34 (1.57 ÷ 1.92)	-0.08	0.937	0.03
Knee Extension [N·m·kg^{-1}]	R	4.12 ± 0.90 (3.6 ÷ 4.65)	4.78 ± 0.88 (4.33 ÷ 5.23)	-2.04	0.051	0.74
	L	3.95 ± 0.94 (3.41 ÷ 4.49)	4.63 ± 0.91 (4.16 ÷ 5.10)	-2.04	0.050	0.74
Hip Flexion [N·m·kg^{-1}]	R	1.71 ± 0.25 (1.57 ÷ 1.86)	1.73 ± 0.25 (1.6 ÷ 1.85)	-0.14	0.893	0.05
	L	1.68 ± 0.22 (1.55 ÷ 1.80)	1.62 ± 0.27 (1.49 ÷ 1.76)	0.59	0.559	0.21
Hip Extension [N·m·kg^{-1}]	R	6.48 ± 1.21 (5.78 ÷ 7.17)	7.44 ± 1.18 * (6.83 ÷ 8.04)	-2.23	0.033	0.81
	L	6.43 ± 1.39 (5.63 ÷ 7.23)	7.56 ± 1.28 * (6.90 ÷ 8.21)	-2.36	0.025	0.85
sum of upper extremity [N·m·kg^{-1}]	R	3.27 ± 0.42 (3.02 ÷ 3.51)	4.33 ± 0.34 * (4.15 ÷ 4.50)	-7.75	<0.001	2.80
	L	3.22 ± 0.36 (3.01 ÷ 3.43)	4.20 ± 0.38 * (4.01 ÷ 4.40)	-7.33	<0.001	2.65
sum of lower extremity [N·m·kg^{-1}]	R	14.21 ± 2.30 (12.88 ÷ 15.54)	15.79 ± 2.09 (14.71 ÷ 16.86)	-2.00	0.055	0.72
	L	13.79 ± 2.29 (12.47 ÷ 15.12)	15.56 ± 2.31 * (14.37 ÷ 16.75)	-2.13	0.042	0.77

Legend: R – right, L – left, TKD – taekwondo, * - statistically significant difference $p<0.05$

Judo athletes developed significantly higher muscle torques than taekwondo athletes during flexion and extension of the right and left upper limb at the elbow and shoulder joints and during extension of the lower limb at the hip joint. Judo athletes outperformed taekwondo athletes in the sum of torques developed at the measured joints of the right and left upper limb ($p<0.05$). The effect size of the comparisons was found to be large. Judo athletes also achieved significantly higher values in the sum of torques developed in the measured joints of the left lower limb. The effect size of this comparison was medium.

Table 3 shows the results of the measurements (means) of the maximum muscle torques of the trunk flexor and extensor muscles with respect to the body weight of taekwondo and judo athletes. The table includes the values of the indices characterising the force potential of the muscles of the trunk, upper and lower limbs and the sum of all measured muscle torques.

Table 3. Mean values (±SD; 95%CI) of the relative torso flexor and extensor muscle torques and the sum of the torso, upper limb, lower limb and all measured muscle torques of taekwondo and judo athletes.

	TKD	JUDO	t	p	d
trunk flexion [N·m·kg^{-1}]	2.73 ± 0.37 (2.52 ÷ 2.94)	2.85 ± 0.46 (2.62 ÷ 3.09)	-0.82	0.422	0.29
trunk extension [N·m·kg^{-1}]	7.68 ± 1.28 (6.94 ÷ 8.42)	9.10 ± 1.49 * (8.33 ÷ 9.87)	-2.80	0.009	1.01
sum of trunk muscles torques [N·m·kg^{-1}]	10.41 ± 1.57 (9.51 ÷ 11.32)	11.95 ± 1.82 * (11.02 ÷ 12.89)	-2.49	0.019	0.90
sum of upper extremities [N·m·kg^{-1}]	6.48 ± 0.77 (6.04 ÷ 6.93)	8.53 ± 0.70 * (8.17 ÷ 8.89)	-7.78	<0.001	2.81
sum of lower extremities [N·m·kg^{-1}]	28.00 ± 4.55 (25.37 ÷ 30.62)	31.35 ± 4.31* (29.13 ÷ 33.56)	-2.10	0.044	0.76
sum of all muscle torques [N·m·kg^{-1}]	44.89 ± 6.28 (41.27 ÷ 48.52)	51.83 ± 5.75 * (48.88 ÷ 54.79)	-3.21	0.003	1.16

Legend: TKD – taekwondo, * - statistically significant difference p< 0.05

Judo athletes developed significantly higher values of muscle torques than taekwondo athletes during trunk extension. The sum of the torque values developed at the measured upper limb, lower limb and trunk joints and the sum of the values of all measured torques in judo athletes were significantly higher than in taekwondo athletes. The effect sizes of the comparisons were found to be large, with the exception of the comparison of the sum of lower limb joint moments, which was found to be medium.

Tables 4 and 5 contain values (medians) characterising the topography of muscle torques among taekwondo and judo athletes.

Table 4. Topography (Me ± IQR; MIN÷MAX) of muscle torques of the flexor and extensor muscles of the right and left limb at the elbow, shoulder, knee, hip joint and topography of the sum of upper and lower limb torques of taekwondo and judo athletes.

	side	TKD	JUDO	U	Z	p	η^2
elbow flexion [%]	R	2.18 ± 0.37 (1.69 ÷ 2.69)	2.33 ± 0.28 (1.78 ÷ 2.67)	82	-1.45	0.147	0.26
	L	2.07 ± 0.43 (1.59 ÷ 2.62)	2.27 ± 0.40 (1.81 ÷ 2.59)	79	-1.57	0.117	0.28
elbow extension [%]	R	1.35 ± 0.32 (1.01 ÷ 1.67)	1.62 ± 0.20 * (1.36 ÷ 2.42)	27	-3.63	<0.001	0.65
	L	1.33 ± 0.37 (1.06 ÷ 1.67)	1.58 ± 0.22 * (1.37 ÷ 1.97)	32	-3.43	0.001	0.62
shoulder flexion [%]	R	1.76 ± 0.63 (1.41 ÷ 2.24)	2.03 ± 0.32 (1.33 ÷ 2.47)	78	-1.61	0.108	0.29
	L	1.63 ± 0.30 (1.36 ÷ 2.08)	1.85 ± 0.39 * (1.31 ÷ 2.68)	65	-2.12	0.034	0.38
shoulder extension	R	2.22 ± 0.64 (1.51 ÷ 2.63)	2.41 ± 0.39 * (1.91 ÷ 3.34)	58	-2.40	0.016	0.43

[%]	L	2.16 ± 0.45 (1.54 ÷ 2.59)	2.32 ± 0.33 * (1.98 ÷ 2.78)	69	-1.96	0.049	0.35
knee flexion [%]	R	4.14 ± 1.00 * (3.48 ÷ 5.79)	3.43 ± 0.70 (2.50 ÷ 4.37)	49	2.76	0.006	0.50
	L	3.83 ± 1.06 * (3.15 ÷ 5.04)	3.37 ± 0.71 (2.31 ÷ 4.58)	64	2.16	0.031	0.39
knee extension [%]	R	9.37 ± 1.90 (6.78 ÷ 10.79)	9.02 ± 1.28 (5.77 ÷ 10.86)	117	0.06	0.953	0.01
	L	8.69 ± 1.72 (6.69 ÷ 12.38)	9.31 ± 1.65 (7.03 ÷ 10.49)	103	-0.62	0.538	0.11
hip flexion [%]	R	3.77 ± 0.44 * (3.57 ÷ 4.15)	3.50 ± 0.66 (2.24 ÷ 3.93)	40	3.12	0.002	0.56
	L	3.76 ± 0.41 * (3.35 ÷ 4.23)	3.13 ± 0.43 (2.34 ÷ 3.70)	23	3.79	<0.001	0.68
hip extension [%]	R	14.95 ± 2.44 (11.95 ÷ 15.97)	14.37 ± 1.14 (11.45 ÷ 16.20)	110	0.34	0.736	0.06
	L	13.80 ± 3.43 (11.05 ÷ 17.35)	14.64 ± 1.89 (11.76 ÷ 17.21)	109	-0.38	0.706	0.07
sum of upper extremity [%]	R	7.33 ± 1.26 (5.87 ÷ 8.70)	8.30 ± 0.86 * (7.48 ÷ 10.46)	46	-2.88	0.004	0.52
	L	7.44 ± 0.66 (5.78 ÷ 8.72)	8.05 ± 0.65 * (6.83 ÷ 9.93)	40	-3.12	0.002	0.56
sum of lower extremity [%]	R	31.44 ± 1.76 (29.86 ÷ 34.04)	30.45 ± 0.90 * (27.16 ÷ 32.88)	69	1.96	0.049	0.35
	L	30.86 ± 2.01 (28.62 ÷ 33.13)	29.98 ± 2.50 (25.62 ÷ 33.38)	94	0.97	0.331	0.17

Legend: R – right, L – left, TKD – taekwondo, * – statistically significant difference, p< 0.05

Judo athletes achieved higher topography index values compared to taekwondo athletes for muscles flexing the shoulder joint of the left limb and extending the shoulder joint of the right and left limbs. Also, in the case of muscle groups whose function is extension of the right and left limbs at the elbow joint, the topography values in the judo group exceeded those of the taekwondo athletes. The proportion of the sum of the values of the muscle torques of the measured joints of the right and left upper limb in the sum of all measurements taken was significantly higher in the male judo competitors. Taekwondo athletes, on the other hand, had higher values of muscle topography indices for muscle groups flexing the knee and hip joints of both limbs. The ratio of the sum of the values of the muscle torques developed in the studied joints of the right lower limb to the values of the sum of all measured joints was higher in taekwondo athletes. The effect sizes of the comparisons were found to be large.

Table 5. Topography (Me ± IQR; MIN÷MAX) of torso flexor and extensor muscle torques and topography of the sum of torso and upper and lower limb torques of taekwondo and judo

athletes.

	TKD	JUDO	U	Z	p	η^2
trunk flexion [%]	6.10 ± 0.41 * (5.29 ÷ 6.65)	5.53 ± 0.98 (4.28 ÷ 8.14)	52	2.64	0.008	0.22
trunk extension [%]	17.24 ± 1.92 (13.45 ÷ 20.14)	18.25 ± 3.30 (14.13 ÷ 21.35)	101	-0.69	0.487	0.02
sum of trunk muscles [%]	23.39 ± 1.83 (19.42 ÷ 26.39)	24.01 ± 3.47 (18.58 ÷ 27.24)	110	-0.34	0.736	0.004
sum of upper extremity [%]	14.74 ± 1.57 (11.70 ÷ 17.41)	16.39 ± 1.57 * (14.42 ÷ 20.40)	42	-3.04	0.002	0.30
sum of lower extremity [%]	61.70 ± 3.65 * (58.91 ÷ 65.96)	59.84 ± 5.62 (52.92 ÷ 65.64)	64	2.16	0.031	0.15

Legend: TKD – taekwondo, * – statistically significant difference, $p<0.05$

The contribution of trunk flexor muscle strength to the overall muscle strength of taekwondo athletes was greater than that of judo athletes. There was a statistically significant difference in muscle topography indicating that taekwondo athletes have higher ratios for the lower limbs and judo athletes have higher ratios for the upper limbs.

Discussion

Motor preparation, one element of which is increasing the strength potential of athletes, is an important part of sports training in both taekwondo and judo. In this study, the values of muscle torques developed by muscle groups acting on the joints of the upper limbs, lower limbs and trunk of taekwondo and judo athletes were analysed.

One of the research hypotheses concerned the strength potential available to the athletes of the combat sports studied. The results obtained partially confirm the first hypothesis. It is supported by the fact that the sum of muscle torques developed in all the examined joints of the upper limbs, lower limbs and trunk was higher in judo athletes. Judo athletes, compared to taekwondo athletes, obtained significantly higher values in measurements of muscle torques during flexion and extension of the right and left upper limbs at the elbow and shoulder joints. The values of the sums of the muscle torques of the judo athletes developed in the studied right and left upper limb joints and their sums exceeded the results of the taekwondo athletes. In addition, judo athletes obtained better results during hip extension of the right and left limbs and trunk. However, the research hypothesis was not fully confirmed, as there were no significant differences in the measurements of right and left lower limb flexion and extension at the knee joints or trunk flexion and hip flexion.

Judo athletes, during a sport fight, perform standing attacks, grapple and hold their opponent, execute throws or engage in ground grappling, and the time spent on individual technical and tactical elements during fights may vary depending on the sport level or the age of the rivals [23]-[24]. Strength preparation is one of the key elements of judo training. A high level of static strength allows athletes to gain an advantage in elements such as grappling and holding an opponent [28]. We noted that judo athletes, who use their upper limbs far more frequently during combat, outperform taekwondo athletes in their ability to develop muscle torques under static conditions at the elbow and shoulder joints. In our study, we also noted that judo athletes, compared to taekwondo athletes, have significantly higher values of muscle forces developed by the hip and trunk extensor muscle groups. This may be due to the fact that antigravity muscles, e.g. the extensors of the trunk and hip and knee joints, are highly involved in the execution of throws during judo combat [19]. Buśko and Nowak [8] observed that the specialised training of highly trained judo athletes leads to an increase in the strength potential of the lower limbs and the overall level of muscle strength, while decreasing the level of upper limb and trunk strength. Strength preparation training in combat sports should be balanced. Therefore, the muscle groups that flex these joints are no less important. The correct proportions between these antagonistically working muscle groups and their coordinated activation will determine the performance of attack techniques during a judo match [29].

Strength training in judo begins at an early stage. According to Lech et al. [19], strength training applied during the preparation of adult athletes is already applied to athletes training in younger age categories – junior or cadet. The authors claim that early specialisation results in young athletes having a high level of muscular strength, not different to athletes in the senior category, and this may interfere with naturally occurring biological mechanisms of physical development. An assessment of the strength capabilities of taekwondo athletes can be found in a number of papers. Pędzich et al. [26], compared the values developed by Olympic taekwondo athletes' muscle torques to those obtained by athletes of the non-Olympic version of this combat sport and boxers. Olympic taekwondo athletes were found to have greater lower limb strength, primarily of the hip joint. In contrast, in the study by Buśko [4], boxers and taekwondo athletes exhibited similar lower limb strength levels.

Several studies have compared the generated muscle torques in static conditions by judo and taekwondo athletes. However, the results of the comparisons were inconclusive. In the study by Buśko et al. [5], judo athletes outperformed taekwondo athletes in the strength capabilities developed at all joints of the upper and lower limbs and trunk examined. This partly agrees with the results of our study, where judo athletes developed higher values of muscle torques with the exception of the knee flexors and extensors and hip and trunk flexors. In contrast, similar strength potentials of judo and taekwondo athletes in these joints were reported subsequently by Buśko [4]. Differences between the results of different authors may be due to the adoption of different positions during the measurement of individual muscle groups [7]. Differences in the training process may also contribute to the occurrence of differences between the study groups [26].

The rules of taekwondo matches are constantly being modified [25]. Over the years, the dimensions of the competition area have changed, a protector scoring system based on an electronic impact force measurement system has been introduced, and the number of points awarded for accurate punches and kicks has changed [10], [21]. The changes have modified the technical and tactical solutions used by competing athletes [18], [27]. Among other reasons, in order to score more points, strikes during taekwondo fights are mostly delivered with the lower limbs [22], [27]. In order for a kick delivered during a taekwondo fight to earn points effectively, it must be imparted with sufficient impact force. Determining the magnitude of impact forces delivered is a complex task. To date, a number of laboratory methods have been developed to measure taekwondo kicks impact forces [1], [9], [20]. During a fight, the evaluation of the impact force of the strike is performed by an electronic protector [10], [21]-[22]. Minimum kick forces are set separately for each weight category. Side and roundhouse kicks are the kicks most commonly used by athletes during taekwondo combat [10]. There is a correlation between the strength of the side kicks and lean body mass, of which muscle tissue is a major component [15]. Buśko and Nikolaidis [7] reported that the strength of the roundhouse kicks is correlated with the results of muscle torques tested under static conditions. To achieve high impact forces of the strike, taekwondo athletes should possess a high strength potential.

The second hypothesis tested concerned muscle topography, defined as the proportion of the results of muscle torques at individual joints to the sum of all measurements taken. In our study, this hypothesis was also only partially confirmed. In our results, significant differences were observed in the muscle topography of athletes training in taekwondo and judo. Analysing the results of the lower limb torques, the muscle topography of the taekwondo athletes was superior to that of the judo athletes in the case of flexion of the knee and hip joints and the sum of the torques developed at the joints of the right lower limb and both lower limbs combined. These are the muscle groups that are activated during the performance of taekwondo kicks [30]. It is also consistent with the hypothesis that judo athletes performed better than taekwondo athletes in elbow extension of both upper limbs, left shoulder joint flexion and right and left shoulder joints extension. Since the proportion of the muscle torques developed by the extensors of the knee and hip joints of both lower limbs, and the flexors of the elbow joint in the case of the upper limbs, compared to the sum of the values of the torques developed in all measured joints, did not differ significantly between the athletes of the compared combat sports, the research hypothesis cannot be fully confirmed. The results of our work illustrating the differences in the muscular topography of judo and taekwondo athletes differ from the work of Buśko [4], who did not find statistically significant differences in the distribution of muscle torques across the individual joints of the upper limbs, lower limbs and trunk.

In Olympic taekwondo, striking with the upper limbs is only allowed towards the torso of the opponent. Restrictions imposed by the rules result in athletes using the upper limbs mainly in defence – blocking and protecting themselves from the opponent's strikes. The upper limbs are also used in fighting at a short distance from the opponent in order to execute a punch combined with pushing the opponent away in order to increase the distance from the target to perform a kick. Judo fighters, on the other hand, use their upper limbs throughout almost the entire fight. They are used when holding and pushing the opponent away, throwing, locking the opponent's joints and fighting in ground positions. Differences in the use of the upper limbs during a fight contribute to the differences in muscle topography found in our work. The use of the lower limbs during combat is also different. In judo, the leg muscles are strongly used together with the back extensors during throws and ground fighting. In taekwondo, the muscles of the lower limbs are involved during kicking, which are the main way to gain a scoring advantage and win the fight. In our opinion, the specialised training in each of the combat sports studied, which aims to prepare the athlete for a sports competition that differs between the two disciplines, is the main moderator of muscle topography. The strength training of taekwondo is mainly aimed at developing lower limb muscle strength, while judo training is aimed at increasing the strength capabilities of upper limb muscles and antigravity muscles such as hip extensors and trunk extensors.

Conclusions

Differences in the strength profiles of judo and taekwondo athletes were highlighted by calculating muscle topography. These differences are the result of the selection of training loads specific to each combat sport. Muscle topography, together with values of maximum muscle torques, is a good tool for characterising the strength profiles of combat sports athletes. Observations of changes in muscle topography can provide additional information for evaluating the effects of strength training. The values of muscle torques developed in static conditions correspond to the maximum strength capabilities of the athletes. Based on the results of measurements, it is possible to select training loads individually for each athlete, optimally for his needs and capabilities. Disbalance of antagonistically working muscle groups can be an indicator of incorrect development of combat sports athletes and is considered as a one of the predictors of musculoskeletal injuries. Tracking strength potential changes with muscle topography can be useful in the selection process of elite athletes or talent identification of young athletes.

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