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Relationship of maximal isometric torque produced in flexors and extensors rate to technique by judo athletes

STANISŁAW STERKOWICZ[1], GRZEGORZ LECH[1], KATARZYNA STERKOWICZ-PRZYBYCIEŃ[2], WIESŁAW CHWAŁA[3]*, TADEUSZ AMBROŻY[1], TOMASZ PAŁKA[4]

[1] The Department of Theory of Sport and Kinesiology, University of Physical Education, Kraków, Poland.
[2] The Department of Gymnastics and Dance, University of Physical Education, Kraków, Poland.
[3] The Department of Biomechanics, University of Physical Education, Kraków, Poland.
[4] The Department of Physiology, University of Physical Education, Kraków, Poland.

Purpose: Development of strength is one of essential elements of motor preparation of judo athletes. The aim this study was to examine the influence of body composition and the joint torques on successful performance of various judo techniques. *Methods:* Twenty-five judo athletes participated in 175 judo bouts, which were video-recorded during the All-Polish competitions. Biomechanical classification of technical actions was used. The age and athletic experience of the subjects were 18 and 8.8 years, respectively. Their body height was 179.4 cm (Martin's type anthropometer) and body mass was 80.3 kg (Sartorius F 1505 – DZA scales). Percentage of fat (10.6%) was estimated using skinfold result measurements. BMI (24.9 kg·m^{-2}), fat-free mass index (21.9 kg·m^{-2}) and fat mass index (3.0 kg·m^{-2}) were calculated. Maximum torques measured under static conditions were evaluated 2–3 days after the tournament. Descriptive statistics and ANOVA were conducted ($p \leq 0.05$). *Results:* Balancing of maximum torques in the muscles of the pelvic and *illiac* regions caused more frequent performance of physical lever-type throwing techniques, compared to couple of force-type throwing techniques. A negative correlation was found between body fat and value of force recorded for knee flexors and between the frequency of using techniques during groundwork and torques measured in hip extensors. High correlation of fat-free mass index and relative elbow flexor torque was found. *Conclusions:* The relationship between body composition and frequency of techniques used in a tournament, and joint torques developed by athletes were found.

Key words: *athletic performance, body composition, biomechanics, martial arts*

1. Introduction

The conventional concept concerning the interactions between the two basic human systems, i.e., "locomotor" (both lower limbs and pelvis) and "passenger" (body trunk, arms, neck, head) [16] has been successfully used for analysis of human gait [12]. The characterization of muscle balance when considering conditioning and injury risk has been emphasized [17]. A judoka attempts a throw and stops the opponent, holding his or her sleeve and collar. A precondition for performing a successful throw is to build a distance from the opponent, which brings an advantage to the athlete. When the competitor holds the clothes and intends to increase the distance, it is necessary to extend the elbow joint through action of the extensors in this joint. Furtherly, in order to reduce the distance from the opponent, it is necessary to bend the elbow through the contraction of the flexors of the elbow joint [12].

When performing a throw, after gripping the opponent with hands, which is necessary to transfer the force, both opponents form a closed kinetic chain. The interaction of both athletes who act simultaneously to cause a fall of the rival determines mutual position of body parts. Therefore, a judo bout requires good tactical, technical and motor preparation, especially in terms of strength. Moreover, authors have underlined that muscle strength is a determinant factor in judo [9]. However, the maximum force is rarely used dur-

* Corresponding author: Wiesław Chwała, Department of Biomechanics, Institute of Biomedical Sciences, University of Physical Education in Kraków, al. Jana Pawła II 78, 31-571 Kraków, Poland. Phone: 504303896, e-mail: wieslaw.chwala@awf.krakow.pl
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ing the judo match [8]. Isotonic and isometric testing is used in order to ensure a reliable measurement of the maximum force. The results of measurement of maximum force, conducted using these methods, have been found to be significantly intercorrelated [20]. Nevertheless, both methods are rarely used simultaneously for the diagnostics of fitness preparation in judo athetes [24]. The researchers focus more on isokinetic [17], [9] or isometric measurements [25], [3], particularly on hand grip force [21].

We assumed that when a competing judo athlete wants to lift the other competitor, the major role is played by antigravity muscles that flex the elbow joint (in the segment of "passenger" body) and hip extensors (in the segment of "locomotor" body). Muscle mass is one of the key elements that affect their strength and is reflected by fat-free mass that represents a principal element of body composition. Thus, it seems justified to formulate the following research questions: (1) Which throwing and gripping techniques (Sacripanti's biomechanical criterion [18]) are most often used by judo athletes at national competitive level? (2) Is there a relationship between body composition or frequency of techniques used in a tournament and joint torques developed by athletes? (3) Does maximum value of hip flexor to extensor joint torque ratio determines performance of various techniques used in a judo bout during tournaments? The main aim of this study was to examine the relationship of body composition and the joint torques with successful performance of various judo techniques.

2. Material and methods

2.1. Participants

The research meets the requirements of the Declaration of Helsinki on the experimental setup and procedures for the use of human subjects in research. The athletes and their legal guardians were also informed about the benefits of obtaining the results of examinations and limited risk during performance of tests in the laboratory. The coaches expressed their interest in the experiment and agreed for participation of the athletes. Participants gave written informed consent (or their legal guardians in the case of the minors).

Based on the documentation of judo tournaments, 25 male judo athletes were qualified for the non-invasive tests. The subjects were healthy and had won places 1 to 5 in national-level competition (at least class I athletes). An interview was also carried out in order to collect information about the age and athletic experience of the subjects. Their body height was measured by means of Martin's type anthropometer with accuracy of readings of 1 mm; body mass was measured by Sartorius F 1505 – DZA scales (Germany) with the accuracy of 1 g. Percentage fat (PF) content was estimated using triceps and subscapular skinfold results measurements (Harpenden Skinfold Caliper) [19]. Body mass index (BMI), fat-free mass index (FFMI) and fat mass index (FMI) were obtained from computation [10].

Characterization of 25 judo athletes studied is collected in Table 1.

2.2. Judo match observation and analysis

Video digitizing process was employed. The study was based on authors' own digital video recording of technical and tactical actions of judo athletes during official judo tournaments. In total, the athletes used 373 techniques (there were included 188 effective techniques scoring from 3 to 10 points), with throws and grappling techniques accounting for 91.4% and 8.6%, respectively. All actions were evaluated by two experienced coaches who used biomechanical criteria for classification of techniques recommended by Sacripanti [18]. This classification first time was used during the Olympic Judo Tournament in London for analysis of the following techniques: 1) Physical lever-type throwing techniques (PL).

Table 1. Descriptive statistics (mean, SD or median and min-max values) of 25 judo athletes

Statistics	Age [years]	Experience [years]	Height [cm]	Weight [kg]	BMI [kg·m^{-2}]	FFMI [kg·m^{-2}]	FMI [kg·m^{-2}]	PF [%]
Mean or median	18.0	8.8	179.4	80.3	24.9	21.9	2.6	10.6
SD or min-max	2.5	2.8	5.1	10.5	2.6	1.5	1.0–8.1	4.5–26.5

Legend: BMI – body mass index, FFMI – fat-free mass index, FMI – fat mass index, PF – percentage of fat in whole body mass. Remark: Because of non-normality distribution of some variables medians and min-max values were presented.

From biomechanical point of view, the force with the same magnitude and direction that acts on the greater lever causes greater effect (moment of force). Moreover, with equal resistance, when the arm of the lever used in a lever technique increases, the applied force decreases on the same maximal joint torque. This means that lever techniques of maximum arm are energetically most effective among lever techniques group. 2) Couple of force-type throwing techniques (C). Normally, it is well know that couple techniques are energetically more convenient compared to lever techniques; (3) Grappling (GRAP) during mat work, pinning techniques, joint techniques of the bending and pressing against elbow joint type, and vascular chocking techniques are allowed [23].

2.3. Isometric torque measurements

In the competitive period, maximum torques in flexors and extensors were measured under static conditions described by Buśko and Nowak [4]. They included measurements in standard positions of the maximum muscle force generated during isometric contraction in flexors and extensors of the trunk, knee, hip, elbow and shoulder joints. Force measurements were carried out in a measuring setup composed of a Hottinger tensometric sensor (accuracy of 0.5%), AD card and a PC.

On their basis, the values of maximum torque were calculated. The analysis evaluated maximum torques developed under static conditions in extensor (E) and flexor (F) muscles relative to body mass ($N \cdot m \cdot kg^{-1}$). In the case of upper and lower limbs, the mean values of relative maximal torques were analyzed for right and left limbs.

2.4. Statistical analysis

Frequency of PL and C throws and grappling techniques (GRAP) performed during a judo bout was re-calculated into percentage values (individual values are not presented). The ratio of the frequencies of PL to C throws was also computed. The data are presented as means and standard deviations (SD) or medians (Me) and min-max values, depending on the normality of distribution of the results. Furthermore, rank correlation coefficients were computed based on morphological, technical and biomechanical indices which characterized the athletes being under study. The factor of relative frequency of techniques used in a judo bout (PL/C) was constructed using a quartile criterion at three levels of value in the whole group of athletes (L – lower Me = 0.7 (IQR = 0.7); M – medium Me = 2.5 (IQR = 0.8); U – upper Me = 8.6 (IQR = 3.0). Joint torques and ratio of antigravity-to-antagonist joint torques in relation to body mass were considered as dependent variables. The sample of in each category is small (6, 13 and 6), so in ANOVA effect size η^2 – value were interpreted using the following criteria: large effect size ($\eta^2 > 0.14$), moderate effect size ($0.06 < \eta^2 < 0.14$) and small effect size ($\eta^2 < 0.06$). All statistics were analyzed using Statgraphics Centurion 17.2 software, and a significance level of $p \leq 0.05$ was used.

3. Results

3.1. Frequency of techniques

Frequency of techniques used in tournament judo bouts is presented in Table 2.

The techniques used most frequently were physical lever-type throwing techniques, with the predominant techniques in the PLmax subgroup, where the effect on the opponent occurs for the maximum lever. The typical technique was a throw with the attacker falling back (*tomoe nage*) (n = 37), where body mass is also used (lifting the opponent to the front and up and performing a risky fall back which needs supporting of a lower part of the opponent's abdominal region with the leg, pushing it upwards and throwing the opponent over the head). The dominant technique in the group of Couple of force-type throwing techniques was *harai goshi* from the subgroup of Couple of forces applied by trunk and legs CTL (n = 18). During *harai goshi,* after pushing the opponent forward, the attacker performs a rotation, pulling the opponent to hips, lifting a leg. For *te guruma* from the throw subgroup of Couple of forces applied by arm CAA, similar frequency was observed (n = 18). After lifting the opponent with both hands, the attacker rotates the opponent's body so that the latter falls on the back.

3.2. Correlations between body composition indices, strength ability and technical skills used

Relative joint torque results measured in 25 judoists are presented in Table 3.

Table 2. Frequency of techniques used during national judo tournaments by male athletes (Sacripanti's classification [18])

Classification	Count	%	Classification	Count	%
PLmaxA	120	32.2			
PLvA	93	24.9			
PLminA	24	6.4			
Physical lever-type throwing techniques (total)			PL	237	63.5
CTL	37	9.9			
CAA	32	8.6			
CAL	25	6.7			
CTA	10	2.7			
Couple of forces-type throwing techniques (total)			C	104	27.9
Osaekomi SHIHO	15	4.0			
Osaekomi KESA	9	2.4			
Kansetsu HISHIGI	6	1.6			
Shime VASC	2	1.0			
Grappling techniques (total)			GRAP	32	8.6
Total	373	100.0		373	100.0

Legend: PLmaxA – Physical lever applied with max arm; PLvA – Physical lever applied with variable arm; PlminA – Physical lever applied with min arm; CTL – Couple of forces applied by trunk and legs; CAA – Couple of forces applied by arms; CAL – Couple of forces applied by arm or arms and leg; CTA – Couple of forces applied by trunk and arms; Osaekomi SHIHO – pinning techniques of the four corner hold; Osaekomi KESA – pinning techniques of the scarf type; Kansetsu HISHIGI – joint techniques of bending and pressing against elbow joint type; Shime VASC – vascular chocking.

Table 3. Relative joint torque results measured in 25 judoists

Relative joint torque [N·m/kg^{-1}]	Mean (SD)
Elbow flexors	1.48 (0.63)
Elbow extensors	1.06 (0.35)
Shoulder flexors	2.13 (0.94)
Shoulder extensors	1.76 (1.06)
Trunk flexors	2.30 (0,80)
Trunk extensors	4.73 (1.14)
Hip flexors	2.35 (1.16)
Hip extensors	5.29 (2.85)
Knee flexors	1.87 (0.62)
Knee extensors	5.57 (1.79)

Note: Mean value of body mass was 80.3 (10.5) kg.

Age and experience correlated with ElbowF/ElbowE ratio (0.514, $p = 0.012$ and 0.676, $p < 0.001$, respectively). Percentage shares of PL and C type in total number of techniques correlated negatively (–0.83, $p = 0.000$). Significant correlations were also found between: fat- free mass index and relative elbow flexor torque ElbowF (0.541, $p = 0.008$), FFMI and HipE/HipF torque ratio (0.435, $p = 0.033$), fat mass index FMI and torque developed by knee extensors KneeE (–0.426, $p = 0.037$), fat-free mass index and frequency of using PL throws (0.454, $p = 0.026$), frequency of using groundwork grappling techniques and relative torque of hip extensors HipE (–0.451, $p = 0.027$). The weak correlations of PL/C with Shoulder F/E (–0.125, $p = 0.540$), Trunk E/F (–0.068, $p = 0.739$) and Knee E/F Knee (0.26, $p = 0.196$) were found. Moderate correlations of frequency of throws PL/C Ratio and torque in hip flexors HipF (0.419, $p = 0.029$), Elbow F/E (0.383, $p = 0.061$) and Hip E/F (–0.434, $p = 0.034$) were revealed. Moreover, Knee E/F highly correlated with Trunk E/F (0.577, $p = 0.005$) and HipE/F (–0.673, $p = 0.001$).

3.3. Frequency of PL/C throws vs. relative torques in different joints

Table 4 presents the relative values of joint torquess developed in the five joints with respect to PL/C levels. There were not statistically significant differences PL/C throw ratio for Elbow F/E ($F = 1.32$, $p = 0.286$, $\eta^2 = 0.107$, (moderate effect); L < M, L < U, M < U), Shoulder F/E ($F = 0.20$, $p = 0.817$, $\eta^2 = 0.018$ (small)), trunk E/F ($F = 0.51$, $p = 0.610$, $\eta^2 = 0.044$ (small)) and knee E/F ($F = 2.36$, $p = 0.118$, $\eta^2 = 0.177$, (large); L < M, L < U, M < U) ratios relative to body weight. Only, medians for HipE/HipF ratio differed statistically between PL/C levels (Kruskal–Wallis $H = 8.297$, $p = 0.016$, $\eta^2 = 0.195$ [large]; L > M, L > U, M > U). Using the Bonferroni's procedure, 2 of the comparisons are statistically significant at the 95.0% confidence level. For Hip E/F ratio, PL/C ratio rank for upper (9) was lower than middle (11.46) and upper (20.33) levels.

Table 4. Test for relative ratio of antigravity muscles and their antagonists by PL/C levels (Mean, SD or Median and min-max values)

PL/C level	Count	Elbow F/E	Shoulder F/E	Trunk E/F	Hip E/F	Knee E/F
L	6	1.2 (0.33)	1.33(0.40)	2.38(0.68)	2.94 (2.32–6.96)	0.81(0.34)
M	13	1.42(0.30)	1.36(0.25)	2.11(0.51)	2.01 (1.22–3.19)	1.04(0.35)
U	6	1.47(0.27)	1.26(0.41)	2.22(0.44)	1.89 (1.34–2.70)*	1.23(0.32)
Total	25	1.38(0.31)	1.33(0.32)	2.20(0.53)	2.32 (1.22–6.96)	1.03(0.35)

Remark: *Upper (U) was different from both lower (L) and middle (M) PL/C levels; Remark: Because of non-normality distribution of some variables medians and min-max values were presented.

The subjects at lower PL/C levels had higher values of HipE/HipF torque muscles. On the contrary, when the athletes were characterized by lower HipE/HipF values, a predominance of PL throws was observed compared to C throws. Median of HipE/HipF ratio for lower PL/C level was significantly higher than both upper and medium PL/C ratio levels (Fig. 1).

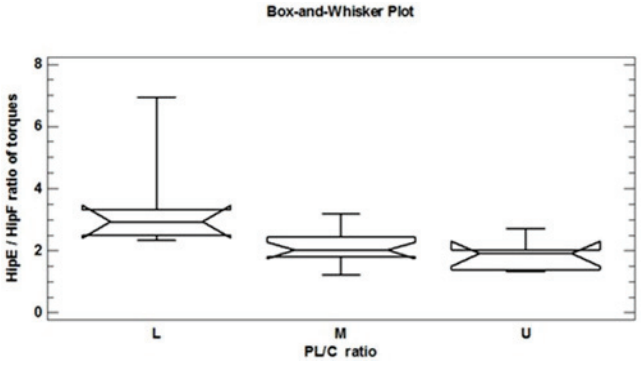

Fig. 1. PL/C throw frequency ratio expressed with respect to HipE/HipF torque ratio. The central part of the diagram is extended from the first to the third quartile, covering the central part of the results obtained for all the groups. Horizontal lines inside each box represent location of medians. Vertical lines connect the highest and the lowest values in each group

4. Discussion

The aim of this study was to evaluate the importance of body composition and joint torques for successful performance of various judo techniques. During analysis of body mass of a judo athlete, we used FFMI and FMI, which are the components of BMI [10]. We agree with the view that higher fat-free mass index (FFMI) reflects improved muscular body build of an athlete and their fat-free body mass [14]. The typical per cent fat in whole body mass characterized judokas who participated in our study in comparison to other groups [8], [22].

Some researchers have experienced difficulties in explaining the level of sports achievements with respect to strength abilities since they measured exclusively muscle thickness rather than joint torquess. They expected that the differences were caused primarily by varying muscle thickness [13]. In our study, we measured joint torques and assumed that their value should depend on FFMI. The main findings of this study are: (1) in the group of PL throws, the most frequent techniques were physical lever applied with max arm or physical lever applied with variable arm; (2) in Couple of forces-type throwing techniques, the dominant group was Couple of forces applied by trunk and arms techniques and techniques applied by arms only. During international tournaments *seoi-nage* is typical technique of physical lever applied with variable moment arm, while *uchi-mata* is a typical technique of Couple forces applied by trunk and leg. The different mechanisms of the both representative throws was pictured [23]. Negative correlations obtained for PL/C levels and HIP E/F may result from high frequencies of *tomoe-nage* (PL applied with maximum moment arm) and *seoi-nage* (PL applied with variable moment arm standing on two lower limbs at execution phase of throw). Contrary to PL throws, popular C *harai-goshi* and *uchi-mata* throws are performed standing on one leg during their execution. Interestingly, high intercorrelations between HIP E/F and Knee EF, and Trunk E/F were found. It suggests that coordinated strength of these muscle groups probably were mastered in judokas who are searching the best technical/tactical solution during their training and tournament combats.

Significant correlations were observed between FFMI and joint torque ElbowF, torque ratio ElbowF/ElbowE, and frequency of using PL throws. Ratio of throwing frequency PL/C depended on HipF torques, whereas the frequency of grappling techniques was negatively correlated with the value of joint torques developed by hip extensors HipE. We found that bal-

ancing the value of maximum torques of the muscles in the regions of *pelvis* and hip joints enabled more confident maintaining of vertical position and frequency of performing PL throws with respect to C throws. The negative correlation occurred between body fat and values of torques in knee flexors and between the frequency of using grappling techniques during groundwork and torques that extend the hip joint.

In our study, the choice of the fighting technique depended on fat free mass index (FFMI) and fat mass normalized with respect to body height FMI [kg·m^{-2}]. The importance of mesomorphy has been emphasized with respect to manifestations of the isometric strength in judo athletes [15]. Furthermore, values of torques have been demonstrated to have the effect on ability to perform repeated *nage-komi* throws and performance level of special judo fitness [3]. Originality of the results obtained in present study is visible also in demonstration of the effect of frequency of using various techniques in a judo bout on the values of joint torques ratio under static conditions. The results of biomechanical analysis of *uchi-mata* throws (C group) have also been presented in literature [1], *osoto-gari* (C group) [1], [11], *seoi-nage* (PL group) [1], [5], [11]. Dominance of *shiho-gatame* holds was justified by the Sacripanti biomechanical criteria [18]. Among the throwing techniques frequently observed at national competitions by the authors of this study, only the *harai-goshi* (C group) technique was characterized in detail [11], whereas *tomoe-nage* (PL group) or *te-guruma* (C group) techniques have not been analyzed in literature.

The results obtained in this study determine further biomechanical analyses, which, in our opinion, with computer modelling, might result in improvement of technical exercises in connection with development of special strength through conventional forms of training [7]. Greater decline in isometric strength in upper limbs observed after a judo bout [6] represents a specific basis for development of local isometric strength in upper body parts. Judo coaches should focus on using training devices to improve not only strength but also the quality of performing judo throwing technique [2].

In practice, for selection of the throwing technique, the relative flexor to extensor strength ratio may be of more importance than individual values. Moreover, torque production ratio of the flexors and extensors or, in this case, ratio of torques of antigravity to antagonist muscles should be trained specifically to technique preferred by judo athletes.

5. Conclusions

Maximum value of hip extensor to flexor joint torque ratio determine performance of various techniques used in a judo bout during tournaments. The relationship between body composition and frequency of techniques used in a tournament and joint torques developed by athletes were found. But we do not consider it as the causality.

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