Muscle strength in young judo contestants *vs.* untrained subjects

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Abstract

Background and Study Aim: (1) to evaluate the level of relative strength in judoists compared to untrained peers; (2) identification of dominant muscle groups in strength preparation profile of judo contestants.

Material/Methods: The study was carried out in 11 judoists (J) who took at least fifth place in national judo tournaments. Average age of the subjects was 17 years, average body mass 79.8 kg. Their fight was registered during national-level championships: all successful actions in standing and on the ground were recorded. A comparative group (N) consisted of fifteen boys at similar age and body mass, recruited from randomly assigned schools.

In the Department of Biomechanics, measurements of muscle torques were taken in study participants for extensor and flexor muscles in hips, knees, elbows shoulders and trunk, in both left and right body sides. The analysis concerned relative torques. Mean values for left and right sides were calculated for upper and lower extremities.

Results: Statistical analysis revealed that statistically significant differences ($p<0.05$) between mean values of relative muscle torques concerned flexors and extensors of elbow joint (J>N), shoulders joint (J>N), knee joint extensors (J>N) and trunk flexors and extensors (J<N). The group of judoists was characterized by higher percentage of relative torques knee extensors, with lower percentage of flexors and trunk extensors compared to untrained controls.

Conclusions: Although judo contestants exhibit similar relative strength to untrained peers, many-year training causes that they demonstrate higher strength in the muscles which are active when pulling or lifting the opponent during performing throws. Antigravity muscles are able to develop particularly high force in these people: they play an essential role when throws are performed.

Key words: judo • kumite • training effects • strength • performance • untrained peers

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Strength – the ability to apply force and overcome a resistance. Strength is essential element in physical performance. Isometric strength is the force or torque of reaction achieved when the greatest possible effort is brought to bear in a voluntary isometric contraction [28]

Background

Human **strength** can be defined as an ability to overcome external resistance or counteract this resistance at the expense of muscle effort [1,2]. It depends on morphological, energetic and neuromuscular determinants [3] the most important being the type of dominant muscle fibre, muscle cross-section area, amount of stored ATP and rate of its synthesis from phosphocreatine as well as middle- and intramuscular coordination. Ontogeny is also characterized by balanced growth of absolute indexes of strength abilities, which occurs before ca. 20–21 years of age. Acceleration occurs only in the period of rapid growth during puberty. Then a period of relative stabilization occurs, followed by a short, intensive stage of involution after turning 50 years of

Peers – a group of individuals sharing the same status.

age [4]. Suitable level of strength abilities is essential to a general health status, effective motion [5], maintaining sufficient stability in joints and reduction in the risk of skeletal and muscular injuries [6]. Necessary level of muscular strength is an important factor which is not only a precondition for proper body build and physical fitness, but also for achievement of excellent results in sport [7]. Research methodologies in this domain have been developed by biomechanists, who laid the foundations for reliable experiments and measurements of strength abilities through identification of essential conditions which determine reliability of measurements [8–12]. They also carried out comprehensive studies and measured the values of muscle torques typical of the athletes from a variety of sports [13,14].

The underlying idea of judo declares the possibility of winning with opponents with greater physical strength. According to this principle, technical excellence means using the strength and inertia of the opponent against them [15]. However, under conditions of sport competition, this is typically manifested in the form of counterattacks. It is generally accepted that the victory over individual opponents is conditioned by similar level of strength abilities.

The importance of maximal static strength in this sport is emphasized by the fact that, among elite level athletes from a variety of sports, judoists take third position, after weightlifters and wrestlers [16]. However, due to the work performed by muscular system of a judoist in the gravitational field, including overcoming the resistance from opponent's body and the judoist's own body, the level of developed muscle torques (typically evaluated per kilogram of body mass) is of vital importance. These values predominantly determine the dynamics of an athlete who performs a particular technique. Judo belongs to the sports where both variables are very important. In consideration of global and relative strength abilities a local strength should be emphasized: it might be connected with each of the two manifestations of human strength abilities. A specific autonomy of local strength, which exists in men, was also emphasized. The men are typically characterized by slightly higher values of parameters in lower extremities compared to the values which would result from the total of all measured muscle groups [17]. However, distribution of maximal and relative muscle torques, optimal for each athlete with a particular technical preparation seems to be more important than their total, since it was demonstrated that it is connected with the effectiveness of utilized techniques [18]. Yet, there are no studies in available literature which would have focused on this problem in younger age groups.

The aim of the present study was to evaluate the level of relative force in judoists compared to untrained **peers** and identification of dominant muscle groups in strength preparation profile of judoists.

Material and Methods

Subjects

Eleven judoists (J) were examined during competitive period. The subjects took at least fifth position in national-level judo tournaments in Poland, where course of fight was registered through recording actions performed in standing (S) and on the ground (P). This allowed for calculation of the index of throw frequency (S/S+P). The subjects trained judo 6 to 11 years, 4–5 times a week, 8–10 hours a week. Fifteen boys at the same age, characterized by similar body mass and height, were assigned to the comparison group (marked in analysis as N). The consent for participation in the study was obtained from school principals, parents and the subjects. They were informed they might withdraw from this study at any time, they wish. Compulsory physical education lessons took 2 hours and 15 minutes a week. Before the examinations, the subjects were qualified by a sport doctor. Of the students initially qualified for the study, 6 persons did not participate because of the illness. Eventually, measurements of 9 subjects were documented. Descriptive characterization of the judoists and the untrained peers is presented in Table 1.

Measurements

In the Department of Biomechanics, measurements of muscle strength for hip, knee, shoulder and elbow extensors and flexors in left and right body side, trunk and on the basis were calculated muscle torques.

Registration of muscle force during isometric contraction was carried out in measurement stations in standard positions in consideration of mutual position of body segments (Table 2). Before maximal isometric contractions were started, the subjects were immobilized in measurement station by means of special holding devices in order to exclude muscles other than those measured in the study and ensure reliable measurement conditions.

Registration of force was carried out using a measurement circuit which featured Hottinger strain gauges, an analog-digital (AD) card and a PC. Data were stored and analysed by means of Analog Digital Acquisition ADA application, licensed for the Department of Biomechanics University School of Physical Education in Krakow. Furthermore, based on the values of registered forces,

Table 1. Descriptive characterization of judoists and their peers who do not practice any sports.

Variables	Judoists (n=11)		Untrained (n=9)		Significance of differences	
	Mean	SD	Mean	SD	Test	p
Age (years)	17.0	0.9	17.2	1.0	U=0.53	0.595
Experience (years)	7.8	1.3	.	.	.	.
Body mass (kg)	78.9	13.6	81.1	12.5	t=0.37	0.716
Body height (cm)	178.5	5.0	182.6	7.0	t=1.53	0.144

Table 2. Characteristics of standard measurement positions for maximal muscle torques.

Measured muscle group (Fmax)	Measurement position	Angles in joints between adjacent segments		
SF & SE	Standing	R – 0°	Elbow joint – 0°	PN – 0°
EF & EE	Standing	R – 90° (flexion)	Elbow joint – 90° (flexion)	PN – 0°
BF & BE	Lying on back	B – 90° (flexion)	Knee joint – 90° (flexion)	GS – 0°
KF & KE	Standing	B – 90° (flexion)	Knee joint – 90° (flexion)	GS – 0°
TF & TE	Standing	B – 90° (flexion)	Knee joint – 90° (flexion)	GS – 0°

Fmax – maximal strength; F – flexors; E – extensors; S – shoulder joint; E – elbow joint; PN – brachiocarpal joint; H – hip joint; K – knee joint; GS – talocrural joint (0° means that a foot of the measured extremity was in neutral position, i.e. at right angle to the lower leg); T – trunk.

maximal muscle torques were evaluated for the measured muscle groups. according to the formula (1):

$$M_{max}=F_{max}d \quad (1)$$

where: M_{max} [N·m] – maximal muscle torque in the measured muscle group, F_{max} [N] – maximal force developed during isometric contraction in the measured muscle group, d [m] – lever arm of external force (distance from biomechanical rotation axis in the joint to the line of dynamometer's operation).

Next, relative values of developed muscle torques were calculated based on the formula (2):

$$M_w=\frac{M_{max}}{m} \quad (2)$$

where M_w [Nm•kg^{-1}] – relative muscle torque, m [kg] – body mass of a subject.

Dividing of the relative values of muscle torques in extensors by the respective values of torques flexor muscles allowed for obtaining ratios which characterize strength abilities of antagonistic pairs in lower extremities. In the case of upper extremities, relative values of muscle torques in flexors were divided by the respective values in extensors. This allowed for obtaining values over 1 in both cases, which reflects different topography of dominance of antagonistic groups of muscles in lower and upper extremities.

Statistics

The Shapiro-Wilk test was employed for evaluation of normality of distribution of the results for particular parameters in groups at $p<0.05$. Data are presented as mean, SD and standard error (SE$\bar{x}$). In order to obtain intergroup comparisons, the two-way Student's two-sided t-test (in the case of normal distribution of the results) or the Mann-Whitney's U-test (if normal distribution was not obtained) were used. During verification of the hypotheses concerning differences, the significance level was adopted as $p<0.05$. Moreover, the authors attempted to find a correlation between ratios of relative torques in antigravity muscles and the frequency of performed throws (S/S+P) in group J.

Results

Table 3 present the results of comparison of the both relative flexors and relative extensor muscle torques in judo contestants (J) and untrained controls (N).

The total of relative muscle torques in ten muscle groups measured under static conditions did not differ ($p>0.05$) between J and N groups. Furthermore, it was demonstrated that statistically significant differences ($p<0.05$) between the means for relative muscle torques concern

Table 3. Relative muscle torques in flexors and extensor muscles in the group of junior judoists (J) and untrained controls (N).

Muscle torque ($Nm\cdot kg^{-1}$)	Judoists (n=11)			(%)	The untrained (n=9)			(%)	Test value	Significance level
	Mean	SD	SEx		Mean	SD	SEx			
ElbowF	1.18	0.237	0.071	5.5	0.93	0.092	0.031	4.1	t=3.21	0.0065**
ElbowE	0.86	0.153	0.046	4.0	0.60	0.064	0.021	2.6	t=5.12	0.0002***
ShölulderF	1.65	0.217	0.065	7.7	1.22	0.198	0.066	5.4	t=4.61	0.0002***
ShoulderE	1.10	0.136	0.041	5.1	0.97	0.121	0.040	4.3	t=2.34	0.0310*
KneeF	1.54	0.227	0.068	7.2	1.34	0.308	0.103	5.9	t=1.62	0.1187
KneeE	3.72	0.502	0.151	17.4	2.58	0.244	0.081	11.3	t=6.24	0.0000***
HipF	1.64	0.591	0.178	7.7	1.86	0.400	0.133	8.2	t=-0.94	0.3558
HipE	3.77	0.843	0.254	17.6	4.29	0.846	0.282	18.8	t=-1.36	0.1919
TrunkF	1.90	0.766	0.234	8.9	2.87	0.477	0.159	12.6	U=-2.55	0.0109*
TrunkE	4.08	0.605	0.182	19.0	6.10	0.918	0.306	26.8	t=-5.93	0.0000***
TOTAL	21.44	1.631	0.492	100	22.76	2.569	0.856	100	t=-1.40	0.1801

F – flexors; E – extensors; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

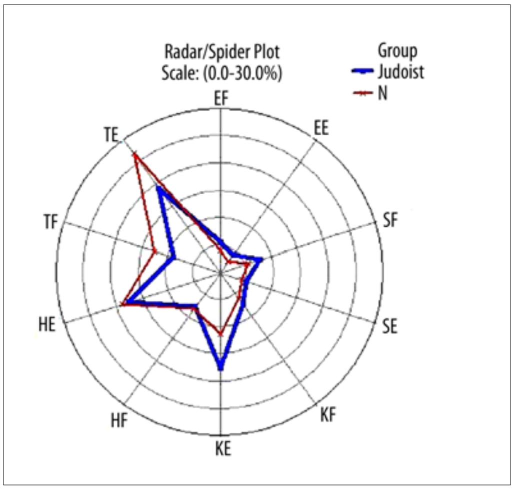

Figure 1. Ratio of muscle torques in judoists and untrained students (%).

flexors and extensors in elbow joint (J>N), shoulder joint (J>N), knee extensors (J>N) as well as trunk flexors and extensors (J<N). No significant differences between group means for knee flexors and hip flexors and extensors were found. Strength profiles for judoists and the untrained students are presented in Figure 1.

Both profiles turned out to be similar, with distinguishing advantage of antigravity muscle groups (KE, TE) and trunk flexors (TF). However, the polygon which represents strength preparation profile for judoists is more regular. The group of judoists is characterized by higher percentage of relative muscle torques in KE, with lower percentage of TF and TE compared to the group of untrained controls.

Table 4, which presents the ratios of relative muscle torques in antagonists muscle groups, reveals significant differences ($p<0.05$) between the judoists and untrained subjects. Ratio of flexor to extensor muscle strength in shoulder joint in J group was significantly higher than in the untrained controls. However, relative values of muscle torques of knee extensors to flexors were significantly higher than in the untrained subjects. Comparison of means also revealed that ratios of muscle strength in elbow, hip and trunk flexors and extensors in judoists and the untrained controls did not show statistical differences ($p>0.05$).

Analysis of the ratio of the number of attacks performed in standing position in relation to all the attacks (S/S+P) revealed normal distribution of S/(S+P) and SF/SE indexes, because value of p in Shapiro-Wilk test amounted to 0.60 and 0.30. Regression analysis exhibited statistical relationships between the index of S/(S+P) and the ratio of relative values SF/SE at 95.0% confidence interval. The obtained model explained 46.9% of variability of the index of attack frequency in standing position, *Tachi-waza* (Figure 2).

The linear model is given by the formula (3):

$$S/(S+P) = 0.4891 + 0.2588*SF/SE \qquad (3)$$

Nearly strong correlation was observed between the means because $r=0.69$ ($p<0.05$). Standard forecast error was 0.081.

Table 4. Ratios of relative muscle torques in the group of juniors and untrained controls [Nm•kg^{-1}].

Muscle torque (Nm•kg^{-1})	Judoists (n=11)		The untrained (n=9)		Test value	Significance level
	Mean	SD	Mean	SD		
HipE/HipF	2.68	1.53	2.36	0.52	U=–0.27	0.790
KneeE/KneeF	2.46	0.40	2.00	0.38	t=2.64	0.017*
TrunkE/TrunkF	2.34	0.58	2.15	0.32	t=0.83	0.392
ShoulderF/ShoulderE	1.52	0.28	1.26	0.16	U=2.24	0.025*
ElbowF/ElbowE	1.39	0.24	1.55	0.13	t=–1.91	0.073

F – flexors; E – extensors; * p<0.05.

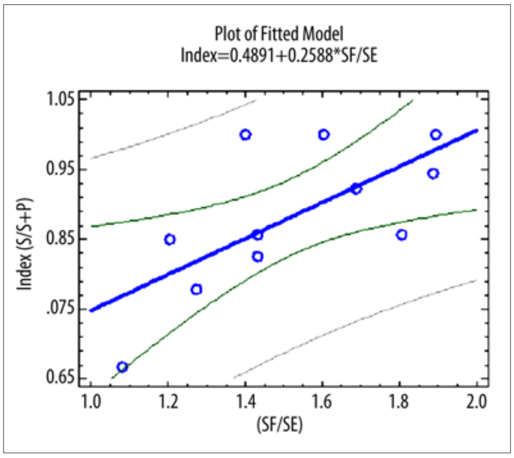

Figure 2. Correlation of SF/SE and the index of successful actions in standing position S/(S+P). Index of the number of observations at given values of SF/SE. External borders denote 95.0% confidence intervals for new observations.

Discussion

Judo fight regulations today cause that coaches and athletes focus on improvement of throws and defence against throws, which, as a matter of fact, consists in a specific grappling and ***Kumite***. These actions, if they are supposed to be successful, necessitate perfect neuromuscular coordination, coordinated movements of upper and lower extremities during attack or defence. Therefore, professional preparation for judo fight calls for development of perception of forces and dynamic and explosive strength necessary for performing throws [19]. With this aim in view, special training devices are used by judoists [20]. An essential aspect in strength preparation of judoists is the maximal force developed under conditions of isometric contraction, because advantage in this parameter allows for utilization of holds which allow a contestant to dominate over the opponent in attack and to increase chances of winning. Strong holding opponent's clothes with *Hikite* and *Tsurite* might allow for performing techniques which have been arduously mastered during training. Hence hand grip force measurements are employed for examinations of judo contestants. For comparative purposes, the results of other authors studies [21–23] were converted from kgf into newtons (SI). In cadet category, at the mean age of 15.6 years and body mass 67.2 kg, right hand force amounted to 375.7 N [21], whereas in juniors aged 17.3 years with body mass of 67.2 kg this value was higher and amounted to 510.1 N; in seniors the mean value was 566.0 N [22]. A tendency for strength to develop with age is observed, but one cannot exclude natural development of this motor ability. Examination of the group of trained and untrained peers revealed that static hand grip force in boys aged 11–17 years was increasing until it reached, at the age of 17 years, the level of 562.1 N. Judoists considerably dominated over untrained controls at the age of 16–17 years in their handgrip force [23].

The focus of the present study was on static strength in ten groups of muscles: hip, knee, trunk, shulder and elbow flexors and extensors in judoists and untrained peers who participated in compulsory physical education classes at schools (we did not examine a spontaneous, unorganized physical activity of the subject). Unexpectedly, we found no evidence of differences between the groups in the total of relative muscle torques. The judoists included in our study demonstrated advantage over the untrained controls in terms of muscle force developed by elbow and shoulder flexors and extensors as well as knee extensors. Recently, the results of the study by Mazur et al. [24] demonstrated that judoists (n=20, age 17.5 years, body mass 81.5 kg) dominated over the representatives of other sports (including weightlifters) with strength of elbow, shoulder and hip extensors. Antigravity muscles perform a vital function when lifting an opponent during performing throws. The strongest muscles in our study were trunk, hip and knee extensors. In the study by Trzaskoma [7], the hierarchy of the value of relative muscle torques in athletes (n=80, age 16.5 years, body mass 72.5 kg) was dominated by hip, trunk and knee extensors. In practice, during **performance** of shoulder throws, such as *Seoi-nage*, a compensation of body posture can be observed, connected with disproportions in the state of force development. With knee extensors weaker than hip extensors, smaller knee bend is naturally observed. Lifting opponents

Kumite – the maneuvering for specific advantageous grips that take place between two judoists prior to executing of techniques. The way a judoist uses his right and left hands and the place on his opponent's label, collar, or sleeve that his grips will tend to distinguish his personal fighting style, approach, and preferences. Hikite is the hand gripping the opponent's sleeve or pulling hand; Tsurite is the hand gripping collar/label or catching hand [27].

Performance – The observable act of carrying out a process, such as motor skill which may vary according to circumstance, e.g. sport participation or not. A plot of the average level of performance of group of subjects for each of a number of practice trials or block of trials is named performance curve [28]

Training effects – the functional physiological adaptations which have been linked with training and physical exercise. Regular training tends to increase the strength [28].

will occur with unfavourable position of inclination forwards (longer lever arm for the acting force). This situation is typical of weak antigravity muscles in lower extremities, both knee and hip extensors. If an athlete's knee extensors are weaker than those in hips, this state can be compensated by higher hip bend angle, without the necessity to incline the body trunk.

Individual body build characteristics and experience cause that strength profile in elite seniors was connected with the preferred techniques of performing throws (foot and leg techniques or hand techniques) [18]. In our study, where athletes were specialized mainly in hand techniques, frequency of throws used during competitions depended on ratios of forces developed by shoulder flexors to extensor muscles. Hence it was easier for the contestants who exhibited higher advantage of arm flexors combined with the strength of knee and trunk extensors (antigravity muscles) to lift opponents. Recent studies by Boguszewska et al. [25] demonstrated the dependence of the results obtained during special judo fitness test (SJFT) on static force developed by lower extremities and trunk. These authors postulated that 'biomechanics measurements, physical fitness tests and special fitness tests characteristic for optimal training control should be used in training process'. Our opinion [26] is that the problem of factors conducive to sport success and the system of training control in judo is more complex.

Conclusions

Although judo contestants exhibit similar relative strength to untrained peers, many-year training causes that they demonstrate higher strength in the muscles which are active when pulling or lifting the opponent during performing throws. Antigravity muscles are capable of developing particularly high force in these persons and play an essential role when throws are performed.

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