Acta of Bioengineering and Biomechanics
Vol. 14, No. 4, 2012

Original paper
DOI: 10.5277/abb120412

Estimation of muscle torque in various combat sports

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The purpose of the research was to compare muscle torque of elite combat groups. Twelve taekwondo WTF athletes, twelve taekwondo ITF athletes and nine boxers participated in the study. Measurements of muscle torques were done under static conditions on a special stand which belonged to the Department of Biomechanics. The sum of muscle torque of lower right and left extremities of relative values was significantly higher for taekwondo WTF athletes than for boxers (16%, $p < 0.001$ for right and 10%, $p < 0.05$ for left extremities) and taekwondo ITF (10%, $p < 0.05$ for right and 8% for left extremities). Taekwondo ITF athletes attained significantly higher absolute muscle torque values than boxers for elbow flexors (20%, $p < 0.05$ for right and 11% for left extremities) and extensors (14% for right and 18%, $p < 0.05$ for left extremities) and shoulder flexors (10% for right and 12%, $p < 0.05$ for left extremities) and extensors (11% for right and 1% for left extremities). Taekwondo WTF and taekwondo ITF athletes obtained significantly different relative values of muscle torque of the hip flexors (16%, $p < 0.05$) and extensors (11%, $p < 0.05$) of the right extremities.

Key words: *muscle torque, taekwondo WTF, taekwondo ITF, boxers*

1. Introduction

Muscle torque is one of the most important physical factors describing general athlete's fitness and deciding about sports result [1]. It has good influence on locomotion speed, jumping ability, mechanical power which is achieved with the little outer resistance [2] and its optimal level determines correct movement technique. To a large degree, maximal muscle torques describe the level of force that could be gained during dynamic motion.

The kind of sport discipline practiced and training components have an influence on athlete's muscle torques and topography that is percentage distribution of the muscle torques for main muscle groups in the main sum of muscle torque [3]–[11]. JANIAK et al. [5] confirmed that the values of muscle torques are different for boxers, fencers and judokas. OSTROWSKA and SADKOWSKI [6] examined swimmers and found significant differences in topography and muscle torques. They found the main muscle groups to be decisive as regards force in each swimming style (elbow and shoulder extensors for backstroke, knees and trunk flexors for butterfly stroke, knee and hip extensors and shoulder flexors for breast-stroke, shoulder extensors for free style stroke). Handball players were characterized by higher percentage distribution of muscle torque of the upper extremities than basketball and volleyball players [3]. Wrestlers had higher percentage distribution of elbow muscle torque and lower muscle torque of hip flexors than team sports athletes. Significant differences were also found in the topography between fencers and boxers [5]. Fencers had higher muscle torque of knee extensors and hip flexors and lower muscle torque of elbow and shoulder extensors and flexors than boxers.

Due to the lack of literature regarding muscle torque of combat sportsmen the aim of this study was to determine main muscle groups used in these disciplines. It is necessary to emphasize that groups represented different styles of sport fight. The taekwondo WTF athletes executed mainly kicks (90%) and sporadically punches (10%) during fight [12]. The taek-

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Received: July 29th, 2011
Accepted for publication: July 23rd, 2012

wondo ITF athletes [13] use kicks (60%) as well as punches (40%). However, amateur boxers executed, of course, only punches and considering the ability to deliver punches effectively for both maximum force and also with speed is of importance [14].

2. Materials and methods

Twelve taekwondo WTF and twelve ITF athletes and nine boxers took part in the study (table 1). All competitors had mastery class and a long practice required (from five to eleven years).

Table 1. Somatic characteristic of taekwondo WTF athletes, taekwondo ITF athletes and boxers (mean ± SD)

	Age	Body weight	Body height	BMI	Practice
	[years]	[kg]	[cm]	[kg/m^2]	[years]
taekwondo WTF (n = 12)	19 ± 1.62	75 ± 6.19	180 ± 6.93	23.1 ± 1.80	8 ± 1.0
taekwondo ITF (n = 12)	21 ± 1.2	77 ± 9.49	179 ± 5.28	24.0 ± 2.42	9 ± 0.6
boxers (n = 9)	18 ± 0.44	66 ± 10.06	175 ± 7.70	21.0 ± 1.61	5 ± 2.0

All participants were informed about the purpose of the study and signed the agreement form before tests. That study was approved by the Ethic Committee of Human Experiments in Warsaw University of Physical Education. Muscle torque were done under static conditions on the Biodex System III PRO Isokinetic Dynamometer version 3.03 (Biodex Medical Inc, Shirley, New York). Muscle strength was evaluated by muscle torque measurements for flexion (F) and extension (E) for the following joints: elbow (EL), shoulder (S), knee (K), hip (H), flexion of the ankle (A) and flexion and extension of the trunk (TR). There was also estimated the sum of muscle torque of right (UE-R) and left (UE-L) upper (elbow and shoulder joint) and right (LE-R) and left (LE-L) lower (knee, hip and ankle joints) extremities. Moreover, the maximal muscle torque distribution, so called muscle strength topography was analyzed, too. The left and right limbs were measured twice and analyzed separately. There were 2 minute intervals between each measurement. The value of the muscle torques under static conditions was determinated at an angle of 90° with measurement level adjusted to the anatomical angle in joint. The manufacturer's operating instructions were followed. A standard procedure commonly used with gauge measuring instruments was followed during calibration, which consisted in comparing the indications of the device with the known values of the measured quantity. Subjects were comfortably seated on the dynamometer chair, with the hip joint at about 85° (0° = full extension) during measurements of isometric data in: elbow, shoulder, knee and ankle joints. The isometric strength of hip joint was measured while standing, without fixation of the trunk and pelvis. To minimize extraneous body movements during muscle contractions, straps were applied. The alignment between the dynamometer rotational axis and the joint rotation axis was checked at the beginning of each trial. Torque data were recorded from the dynamometer with a sampling rate of 100 Hz.

The results were statistically analyzed by the Statistica program. ANOVA method was used to compare various dependent variables of all the groups tested. The Duncan post hoc contrast was used to identify differences between selected variables. A $p = 0.05$ probability level was used for all tests of statistical significance.

3. Results

The test groups belong to a combat with a division into different weight classes and that is why detailed data analysis concerned only relative values of muscle torques, which are values related to subject's body mass [Nm/kg]. Statistical significance of the differences presented was confirmed for body mass for all groups ($F(2.30) = 4.35$, $p < 0.05$), which might have influenced muscle torques. Boxers (66 ± 10.06 Nm) were much slighter than taekwondo WTF athletes (75 ± 6.19 Nm, $p < 0.05$) and taekwondo ITF (77 ± 9.49 Nm, $p < 0.05$).

Average ± standard deviation (SD) relative values of the sum of muscle torques of the right and left upper (UE-R, UP-L) and lower (LE-R, LE-L) extremities are presented in table 2.

The highest values of UE-R (4.84 ± 0.62 Nm) and UE-L (4.94 ± 0.62 Nm) were confirmed for boxers (table 2) and they were higher than those for taekwondo WTF athletes by about 5% of the right (4.60 ± 0.58 Nm) and about 7% of the left limb (4.58 ± 0.57 Nm). The boxers presented also higher UE-R and UE-L values than taekwondo ITF athletes by about 2% of the right (4.74 ± 0.57 Nm) and 6% of the left limb

(4.66 ± 0.52 Nm). There were no significant differences verified among all groups for UE-R and UE-L.

The sum of muscle torques of the lower right (17.71 ± 1.67 Nm) and left extremities (17.02 ± 2.16 Nm) of taekwondo WTF athletes was significantly higher than for boxers by about 16% of the right (14.81 ± 2.04 Nm; $p < 0.001$) and about 10% of the left limb (15.27 ± 1.62 Nm; $p < 0.05$), and of taekwondo ITF by about 10% of the right (15.86 ± 1.52 Nm; $p < 0.05$) and 8% of the left limb (15.64 ± 1.49 Nm).

We did not notice any significant differences in the muscle torque of the trunk flexors and extensors for any of the groups.

Neither did we find any significant differences among all the groups as regards muscle torque of the elbow and shoulder flexors and extensors (table 3). Despite that fact, using the Duncan test for absolute

Table 2. Relative values of muscle torque sum for right and left upper (UE-R, UE-L) and lower (LE-R, LE-L) extremities

	Taekwondo WTF	Taekwondo ITF	Boxers
UE-R [Nm/kg]	4.6 ± 0.58	4.74 ± 0.57	4.84 ± 0.62
UE-L [Nm/kg]	4.58 ± 0.47	4.66 ± 0.52	4.94 ± 0.62
LE-R [Nm/kg]	17.71 ± 1.67	15.86 ± 1.52	14.81 ± 2.04
LE-L [Nm/kg]	17.02 ± 2.16	15.64 ± 1.49	15.27 ± 1.62

Table 3. Relative ± SD value of muscle torque for: ELF-R – elbow flexion of right limb, ELF-L – elbow flexion of left limb, ELE-R – elbow extension of right limb, ELE-L – elbow extension of left limb, SF-R – shoulder flexion of right limb, SF-L – shoulder flexion of left limb, SE-R – shoulder extension of right limb, SE-L – shoulder extension of left limb

	Taekwondo WTF	Taekwondo ITF	Boxers
ELF-R [Nm/kg]	1.0 ± 0.1	1.12 ± 0.1	1.05 ± 0.1
ELF-L [Nm/kg]	1.01 ± 0.1	1.05 ± 0.2	1.11 ± 0.2
ELE-R [Nm/kg]	0.71 ± 0.1	0.72 ± 0.1	0.73 ± 0.1
ELE-L [Nm/kg]	0.69 ± 0.1	0.74 ± 0.1	0.71 ± 0.1
SF-R [Nm/kg]	1.48 ± 0.3	1.46 ± 0.2	1.56 ± 0.3
SF-L [Nm/kg]	1.53 ± 0.2	1.57 ± 0.2	1.62 ± 0.2
SE-R [Nm/kg]	1.42 ± 0.3	1.44 ± 0.2	1.5 ± 0.2
SE-L [Nm/kg]	1.36 ± 0.2	1.3 ± 0.2	1.5 ± 0.2

Table 4. Relative ± SD value of muscle torque for: KF-R – knee flexion of right limb, KF-L – knee flexion of left limb, KE-R – knee extension of right limb, KE-L – knee extension of left limb, HF-R – hip flexion of right limb, HF-L – hip flexion of left limb, HE-R – hip of right limb extension, HE-L – hip of left limb extension, AF-R – ankle flexion of right limb, AF-L – ankle flexion of left limb, TRF – trunk flexion, TRE – trunk extension

	Taekwondo WTF	Taekwondo ITF	Boxers
KF-R [Nm/kg]	2.12 ± 0.3	1.9 ± 0.4	1.83 ± 0.3
KF-L [Nm/kg]	2.01 ± 0.2	1.85 ± 0.3	1.84 ± 0.2
KE-R [Nm/kg]	3.62 ± 0.7	3.23 ± 0.4	3.15 ± 0.5
KE-L [Nm/kg]	3.47 ± 0.6	3.23 ± 0.3	3.35 ± 0.5
HF-R [Nm/kg]	2.81 ± 0.4	2.37 ± 0.4	2.27 ± 0.5
HF-L [Nm/kg]	2.66 ± 0.4	2.4 ± 0.5	2.08 ± 0.2
HE-R [Nm/kg]	6.37 ± 0.7	5.65 ± 0.7	4.63 ± 0.7
HE-L [Nm/kg]	6.22 ± 0.3	5.52 ± 0.7	5.19 ± 0.8
AF-R [Nm/kg]	2.79 ± 0.4	2.71 ± 0.3	2.93 ± 0.6
AF-L [Nm/kg]	2.67 ± 0.6	2.64 ± 0.3	2.82 ± 0.5
TRF [Nm/kg]	3.94 ± 0.6	3.67 ± 0.5	3.78 ± 0.5
TRE [Nm/kg]	7.09 ± 0.4	7.56 ± 0.4	6.66 ± 0.8

values we confirmed that compared to boxers, taekwondo ITF athletes attained significantly higher muscle torque of elbow flexors (20%, $p < 0.05$ of right limb; 11% of left limb) and extensors (14% of right limb; 18%, $p < 0.05$ of left limb) and shoulder flexors (10% of right limb; 12%, $p < 0.05$ of left limb) and extensors (11% of right limb; 1% of left limb).

Significant differences were also verified among taekwondo WTF, taekwondo ITF athletes and boxers for values of the hip flexors of the right ($F(2.30) = 5.37$, $p < 0.01$) and left limb ($F(2.30) = 5.32$, $p < 0.01$) and hip extensors of right limb ($F(2.30) = 14.44$, $p < 0.0001$).

Moreover, significant differences (table 4) were noticed between taekwondo WTF athletes and boxers for hip extensors (27%, $p < 0.0001$ of right limb; 17%, $p < 0.05$ of left limb) and flexors (19%, $p < 0.05$ of right limb; 22%, $p < 0.05$ of left limb) and knee flexors of right limb (14%, $p < 0.05$). The highest relative muscle torque of ankle flexors was confirmed for boxers (right: 2.93 ± 0.6 Nm and left limb: 2.82 ± 0.5 Nm).

We did not find any significant differences among all the groups for muscle torque of the knee and hip flexors and extensors. But using the Duncan test we found significant differences between taekwondo WTF (2.81 ± 0.4 Nm) and ITF athletes (2.37 ± 0.4 Nm) for muscle torque of the hip flexors of the right leg (16%, $p < 0.05$). Additionally, taekwondo WTF athletes (6.37 ± 0.7 Nm) presented values of muscle torque of the hip extensors of the right leg that were about 11% higher than in taekwondo ITF athletes (5.65 ± 0.7 Nm, $p < 0.05$). Significant differences were also noted between taekwondo ITF athletes (5.65 ± 0.7 Nm) and boxers (4.63 ± 0.7 Nm) for muscle torque of the hip extensors of the right limb (18%, $p < 0.05$).

4. Discussion

The results of this study showed that the kind of sport discipline practiced, the way of sport fighting and training components can have influence on muscle torques of taekwondo WTF athletes, taekwondo ITF athletes and boxers.

Boxers attained the highest relative values of the sum of right (4.8 ± 0.6 Nm/kg) and left (4.9 ± 0.6 Nm/kg) upper extremities of muscle torques among elite groups tested. The highest differences in relative values of shoulder flexion (6% for right and 5% for left extremities) and extension (5% for right and 13% for left extremities) were confirmed between boxers and taekwondo WTF athletes and taekwondo ITF athletes. Additionally, boxers had the highest values of percentage distribution of muscle torques of upper extremities (19.5%), especially for shoulder flexion (3.2% for right and 3.2% for left extremities) and extension (3% for right and left extremities). KARPIŁOWSKI et al. [15] found significant correlation between the muscle torque of shoulder flexors and the punch force in boxers ($r = 0.486$). JANIAK et al. [5] noticed that boxers generated markedly higher muscle torque for shoulder flexion and extension than fencers. Those facts confirmed that shoulder flexors and extensors are important muscle groups for boxers. Moreover, the boxers had the highest relative values of muscle torque of ankle flexors (2.87 ± 0.6 Nm/kg) and its percentage distribution (5.7%) among the groups tested. The work of lower extremities for amateur boxers is very important because the boxer who moves very quick is elusive for opponent and is able to shorten or lengthen the distance which is needed to execute intended fight action [14].

MACHADO et al. [9] observed that regarding the peak torque measured in the isokinetic condition (60º/s), taekwondo WTF athletes presented higher peak torque values for flexors of the right (20%) and left (22%) lower limb and extensors of the right (6%) and left lower limb (6%) in comparison to kick boxers. The authors noticed that although these differences were not significant, one must take into consideration the fact that the training time of taekwondo WTF athletes was superior, compared to kick boxers (5 ± 1 versus 2 ± 1 years, respectively). PROBST et al. [10] observed karate athletes with a minimum experience of two years and found that the mean values of peak torque (60º/s) for quadriceps (190 Nm) and ischiotibials (115 Nm) were higher than in taekwondo WTF and kick boxing athletes [9]. Karate athletes training imposes significant articulation strength, especially concerning the execution of knee extension exercises – such as the frontal kick, and kick boxers and taekwondo WTF athletes attribute to their training certain strategies of blow sequences (punches and kicks), not emphasizing all the power and velocity required by the karate athletes [9]. The suitable strength conditions affect low risk of musculoskeletal injury associated to knee articulation [9], [10]. A strong quadriceps muscle along with good timing may be the key to taking advantage of the open kinetic chain and producing a forceful kick [11]. As the energy of kicking is generated and transferred by the activation of flexor and extensor muscles, the coordination of muscle contractions (timing of turning on and off between hip

flexor/extensor and knee flexor/extensor) is important to take advantage of the open kinetic chain.

In our research, taekwondo WTF athletes attained the highest relative values of the sum of muscle torque of right (17.7 ± 1.7 Nm/kg) and left (17 ± 2.2 Nm/kg) lower extremities among the groups tested. Moreover, taekwondo WTF athletes had higher relative values of muscle torque than boxers for hip flexion (19%, $p < 0.05$ for right and 22%, $p < 0.05$ for left leg) and extension (27%, $p < 0.0001$ for right and 17%, $p < 0.05$ for left leg). Besides, we found that taekwondo WTF had the highest percentage distribution of muscle torque for hip flexion (5.1% for right and 4.8% for left leg) and extension (11.6% for right and 11.3% for left leg). The highest muscle activity (EMG) was noticed for hip extensors (biceps femoris, gastrocnemius) during front kick [16]. Based on EMG analysis it was also found that knee flexors and extensors and hip extensors are first recruited during front kick [17], [18]. This is connected with raising the leg and then kicking [19]. Taekwondo WTF athletes [20] executed mostly roundhouse kicks (72.7%) and more often double roundhouse kicks (11%).

We found significant differences in muscle torque between taekwondo WTF (Olympic sport) athletes and taekwondo ITF athletes. We noticed that compared to taekwondo ITF athletes taekwondo WTF athletes had higher (8%, $p < 0.05$) relative muscle torque values of the sum of right lower extremities, especially for hip flexion (16%, $p < 0.05$) and extension (11%, $p < 0.05$) of right extremities. Taekwondo ITF athletes had little higher sum of the muscle torque of upper extremities (3% for right and 2% for left extremities) than taekwondo WTF athletes. The highest differences in relative values of muscle torque were found for shoulder flexion (12% for right and 4% for left extremities) and extension (2% for right and 7% for left extremities). It is also interesting to note that taekwondo ITF athletes had lower relative values of upper extremities (2% for right and 6% for left extremities) than boxers and higher than taekwondo WTF athletes (3% for right and 2% for left extremities).

The results of our study showed that differences among taekwondo WTF athletes, taekwondo ITF athletes and boxers exist and some of them appeared to be sport-specific and related to the long term systematic training.

5. Conclusions

1. In competitions organized by the ITF battle is carried out in the so-called light touch, and in competitions organized by the WTF in the so-called full contact, understood here as the acceptability of asking blows with full force, as opposed to the formula in full-contact boxing. Therefore, statistical significant differences in muscle torque and its percentage distribution among muscle groups in the athletes tested are attributed to specific factors of training and fight.

2. The most obvious difference between combat styles represented by the two major taekwondo organizations is that the competition rules of the ITF allow you to hit in the face with your fist (the glove), WTF rules allow only leg hits (fist to strike only in the trunk – because of that WTF mainly uses foot techniques). Therefore, muscle torques of taekwondo WTF and taekwondo ITF athletes significantly differ (mostly for hip extension).

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