ENERGY ABSORBED BY ELECTRONIC BODY PROTECTORS FROM KICKS IN A TAEKWONDO COMPETITION

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ABSTRACT: Objective: Although some scientific information on electronic body protectors in taekwondo is available, no research has been done to assess the impact of kicks in a competitive situation. The purpose of this study, then, was to assess the energy absorbed by these protectors from kicks performed in an actual taekwondo competition. Methods: Subjects consisted of junior (14-17 years) and senior (≥18 years) male taekwondo-in, who participated in an open tournament. Data on the energy imparted by valid kicks in Joules (J) were collected from a public visual electronic monitor. Results: Energy was higher for the seniors: 264.31 ± 56.63 J versus 224.38 ± 48.23 J for the juniors ($eta^2 = 0.121$). The seniors scored lower in percent impact but the effect was trivial: 123.46 ± 24.77% versus 136.70 ± 26.33% ($eta^2 = 0.087$). Conclusions: The difference between senior and junior taekwondo-in in absolute energy generated was small, while the difference in relative energy impact was trivial in favour of the junior taekwondo athletes.

KEY WORDS: taekwondo, evaluation, athletic performance

INTRODUCTION

Taekwondo is a combat sport which is part of the modern Olympic Games. Currently it awards four gold medals for each sex and has gained international recognition. Its competition system recently underwent rule changes as well as changes in the duration of matches. Valid points are scored as follows: i) three points for kicks to the head, ii) two points to the chest protector involving rotational kicks, and iii) one point for punches and kicks that do not involve rotation of the body [30].

As the power and accuracy of each blow are critical to the scoring system, they need to be measured well. Previous research has shown that 70% of points scored by the referees are validated based on agreement with colleagues, and that in 17% of the matches the results would have been different if all the points scored by at least one of the referees would have been included [19]. As a result, there are several opponents of the visual system employed in the refereeing process.

After the Athens Olympic Games in 2004, the World Taekwondo Federation (WTF) began to promote the inclusion of electronic body protectors (EBP) in their competitions. EBP are intended to protect the trunk of the athlete and at the same time allow more reliable and accurate score identification. However, points derived from blows to the head are still subject to visual assessment by the referees in the system that is currently endorsed by the WTF [14]. Although the LaJUST EBP have been in existence since 1982 [14] and used since 2007, only in October 2009 (Copenhagen, Denmark) was this technology used for the first time at the World Championships [31].

These EBP work with Bluetooth™ wireless technology and have some advantages, including: the possibility to register 5 hits per second, instantaneous presentation of the energy of the blow, electronic definition of minimal impact for a valid score, high amplitude and secure transmission (from more than 100 m and encrypted to prevent interference). Electronic sensors on footwear and gloves allow points to be scored when the body protectors are hit [15].

Research on the validation of the EBP is being conducted in Germany under the leadership of Dr. Manfred Vieten (University of Constance) and coach Markus Kohlöffel [10]. Additionally, the Korea Institute of Sport Science has also committed efforts to the proper development of EBP [11,12].

Currently, the use of EBP is recognized by several taekwondo governing bodies, such as the Swedish Taekwondo Federation since 2007, the Deutsche Taekwondo Union and, more recently, the World Taekwondo Federation [13]. In the current system, the energy absorbed is measured in Joules according to different weight categories and ages. Thus, to validate one point it is necessary that the blow reaches at least this minimum value.

Early attempts at the use of electronic protective gear to help ameliorate the subjective judging in full-contact taekwondo were reported in the mid-1990s [e.g. 1]. Similar to other EBP designs, early and recent attempts used piezoelectric sensors, although the equipment was not wireless [1,7], while descriptions of wireless protectors have also been published [5]. Contrary to the LaJUST system, scientific information is available on electronically scored head kicks by the TrueScore[TM] SensorHogu [2,4].

Strength, impact, and speed measures of blows from different combat sports have been studied under controlled laboratory conditions. This has been considered one of the major limitations to better understand the fighters' performance [6]. In a study conducted by Pieter and Pieter [21], high speeds were observed in techniques used by American elite adult *taekwondo-in* (taekwondo athletes), especially during the performance of the *pandal ch'agi* (literally 'half moon' kick but often translated as 'roundhouse' kick, although executed differently from the conventional roundhouse kick or *tollyŏ ch'agi*), with speeds ranging from 6 to 16 $m \cdot s^{-1}$ for various types of techniques, while their elite junior counterparts (15 years) registered speeds ranging from 6 to 15 $m \cdot s^{-1}$ [22].

Jakubiak and Saunders [9] also showed similar values for kick speed (11 to 12 $m \cdot s^{-1}$) in elite Scottish *taekwondo-in*. Considering the distance from where the technique is applied in a laboratory setting, the run time of these blows is estimated to be 0.12 to 0.31 s [17], making it difficult for the referees to make an appropriate judgment.

Comparisons between competitors and non-competitors showed that national level *taekwondo-in* performed the *pandal ch'agi* with an average force of 1994.03 N and a duration of 0.254 s, while lower level colleagues recorded 1477.90 N and 0.317 s, respectively, which were significantly different [6].

As the aforementioned data were obtained under controlled conditions, the use of EBP may be valuable in terms of recording these values in real competitive situations, which occur under high stress and psycho-physical load. Thus, the purpose of this study was to assess the real-time energy absorption by EBP from kicks performed in an actual taekwondo competition.

MATERIALS AND METHODS

The male subjects for this study participated in an open competition without any pre-selection procedures. The majority of participants were of regional or state level. Within each age group (for juniors, 14-17 years and seniors, 18 years and older) data on 10 matches each were used for a total of 98 valid kicks on the body protector that resulted in a score.

Data collection took place in Buenos Aires, Argentina, during the Argentina Open Taekwondo Championship in November 2007. This competition is one of the largest events in South America. Data on the energy from valid kicks (above the level of minimal impact by weight division) in Joules (J) were collected from a public visual electronic monitor and made available instantly by a wireless system – Bluetooth™.

Data distributional characteristics were verified by the Kolmogorov-Smirnov test, while skewness and kurtosis coefficients were also calculated. Log transformations were sufficient to adjust any skewed, kurtotic or non-normal distributions. Since the weight divisions for junior (≤51 kg, ≤55 kg, ≤63 kg and ≤78 kg) and senior (≤58, ≤67, ≤78, ≤84 kg) *taekwondo-in* have different ranges and because of small cell sizes, the heaviest weight division for seniors was omitted from the comparison between juniors and seniors, while the heaviest weight division in the juniors was merged with the second heaviest. When comparisons were made within age groups, the heavyweight division for the seniors was used again, but that of the juniors was still merged with the second heaviest category. To determine differences between senior and junior *taekwondo-in*, a 2-way (Group x Division) MANOVA was employed with Group consisting of senior and junior athletes and Division comprising the weight divisions.

For comparisons within seniors or juniors, a 1-way MANOVA was used to assess the differences between weight divisions. A Tukey post-hoc test for unequal sample sizes was used to locate the exact differences within weight divisions. The level of significance for the overall analyses was set at 0.05.

RESULTS

Senior compared to junior taekwondo-in. Table 1 shows the descriptive statistics for energy and percent impact by age group and weight division. When comparing senior and junior *taekwondo-in*, there was a small multivariate interaction for Group x Division ($p<0.001$, $eta^2=0.135$). However, the univariate analyses did not show this interaction for energy ($p=0.583$, $eta^2=0.012$) or percent impact ($p=0.902$, $eta^2=0.002$).

TABLE 1. DESCRIPTIVE STATISTICS OF ENERGY AND PERCENT IMPACT OF KICKS

	Juniors	
Weight Division (kg)	Energy (J)	% Impact
≤51	211.33 ± 34.53	140.89 ± 23.02
≤55	220.67 ± 51.10	137.92 ± 31.93
≤78	242.80 ± 52.33	130.75 ± 17.76
	Seniors	
	Energy (J)	% Impact
≤58	246.44 ± 42.03	123.22 ± 21.02
≤67	260.18 ± 41.11	123.90 ± 19.58
≤78	262.29 ± 49.14	119.22 ± 22.34

TABLE 2. SENIOR COMPARED TO JUNIOR *TAEKWONDO-IN*: MAIN EFFECTS FOR GROUP

	Senior	Junior
Energy (J) ($p=0.001$, $eta^2=0.121$)	264.31 ± 56.63	224.38 ± 48.23
Impact (%) ($p=0.005$, $eta^2=0.087$)	123.46 ± 24.77	136.70 ± 26.33

TABLE 3. COMPARISONS WITHIN SENIOR *TAEKWONDO-IN*: PROBABILITY MATRIX OF THE WEIGHT DIVISION POST-HOC ANALYSIS FOR ENERGY

Energy (J)	≤58 kg	≤67 kg	≤78 kg	≤84 kg
≤58 kg (246.44 ± 42.03)	--			
≤67 kg (260.18 ± 41.11)		--		
≤78 kg (262.29 ± 49.14)			--	
≤84 kg (329 ± 103.26)	0.025	0.025		--

Although there were large multivariate Group ($p<0.001$, $eta^2=0.898$) and medium Division ($p<0.001$, $eta^2=0.440$) main effects, the univariate analyses only confirmed this for the Group main effect for energy (Table 2), but not for the Division main effect ($p=0.155$, $eta^2=0.042$). As for percent impact, there was a trivial univariate Group main effect (Table 2), but no univariate Division main effect ($p=0.482$, $eta^2=0.017$).

Comparisons within senior taekwondo-in. There was a small multivariate main effect for Division ($p=0.023$, $eta^2=0.153$). The univariate analysis showed that there were small differences between divisions for energy ($p=0.023$, $eta^2=0.153$), but not for percent impact ($p=0.240$, $eta^2=0.071$). Table 3 shows the probability matrix of the post-hoc analysis for energy.

Comparisons within junior taekwondo-in. There was a medium multivariate main effect for Division ($p<0.001$, $eta^2=0.376$). However, the univariate analyses did not confirm this for energy ($p=0.319$, $eta^2=0.065$) or percent impact ($p=0.692$, $eta^2=0.021$).

DISCUSSION

Although direct statistical comparisons between junior and senior *taekwondo-in* in terms of speed and force have not been reported in the literature, there is information available nevertheless to compare both groups. For instance, using the same methods of assessing speed and force, junior males (15.4 years, 165.9 cm, 53.8 kg) when collapsed over side of the body recorded a force for the roundhouse kick of 98.4 N, while their adult counterparts (21.8 years, 173.8 cm, 63.8 kg) registered 514.6 N. The Junior females (14.9 years, 158.9 cm, 47.8 kg) recorded 58.4 N and their adult colleagues (25.6 years, 170.4 cm, 67.4 kg) 405.4 N [21,22]. Variations in height, body mass and strength are suggested to have contributed to these differences in absolute terms [6,20].

For example, lean body mass was found to account for 72% of the variance in the force of the left roundhouse kick in women, while body mass explained 87% of the force in the right roundhouse kick in men [21]. In junior male *taekwondo-in* (14.5 years, 163.6 cm, 53.4 kg), isokinetic hip flexion strength at 240°/s contributed to kicking force ($\beta=0.47$), while no such relationship was apparent in the girls (14.6 years, 159.9 cm, 51.5 kg) [23].

In addition to age, experience also plays a role in impact force. For instance, Falcó et al. [6] reported experienced *taekwondo-in* to generate more force, while they were faster than less experienced counterparts as well. It is also suggested that the distance between the athlete and the target does not seem to affect kicking force, at least among experienced *taekwondo-in* [6]. Force depends on the effective mass involved in the kick: the larger the effective mass, the larger the force [26], even with decreasing acceleration [2].

Research seems to suggest that power is discriminatory in *karateka* [24,25], boxers [27] and *taekwondo-in* [8,28] of different competitive levels. For instance, elite female *taekwondo-in* recorded higher explosive leg power compared to lower ranked colleagues [16]. Similar to other sports [e.g. 18], it is suggested that those competing at a higher level are better able to synchronize the various phases of the skills they use and to rely on larger muscle fibre recruitment to mobilize a larger muscle mass in a greater angular velocity to eventually result in more force applied to the EBP.

It is noteworthy that in the present study, data were collected during real competitive taekwondo matches, which is believed to be the first time ever in this sport. In a laboratory setting, Olympic level boxers had their punches evaluated and the energy varied according to weight category. Flyweight, light-welterweight, middleweight and super heavyweight boxers produced 15.3 J, 13.9 J, 5.8 J and 28.7 J, respectively [29]. These data confirm our findings concerning the higher energy generated by heavyweight athletes in absolute terms when compared to lighter ones. Additionally, as the punch action involves a smaller muscle mass and is applied with lower displacement when compared to kicks, the aforementioned values are necessarily lower than those observed during taekwondo kicks.

As far as we know, no published research is available on the characteristics of objectivity, reliability and reproducibility of the EBP by LaJUST. Information is needed regarding the determination of the minimal values set for the LaJUST *hogu* (body protector) to score a valid point as was done for the TrueScore^{TM} SensorHogu [4], although it is recommended to also take into account age, gender and weight division.

Adult taekwondo athletes generated higher absolute energy in their opponents' body protectors compared to junior counterparts. However, in terms of percentage impact, the opposite was observed, i.e., the younger athletes generated more relative impact energy than their adult counterparts.

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