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Anaerobic fitness assessment in taekwondo athletes. A new perspective.

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ORIGINAL ARTICLE

ABSTRACT

We intended to determine the concurrent validity of a taekwondo specific anaerobic test (TSAT) to assess anaerobic fitness in taekwondo athletes. Seventeen elite male subjects (17.59 ± 4.34 years of age; 1.72 m ± .07 m in height; 61.3 kg ± 8.7 kg in weight and 15.6% ± 8.5% in body fat) performed a TSAT, which consisted of kicking a punching bag for 30 seconds. The standard test was the Wingate Anaerobic Test. Two trials were made for both tests and the agreement between both was tested. The variables analysed and compared were: peak power; relative peak power; mean anaerobic power; relative mean anaerobic power; fatigue index and anaerobic capacity. The number of kicks performed in the TSAT protocol and the maximum height of the counter movement jump (CMJ) were also registered. Trial I and II had significant ICC results in all variables (P = .000) ranged between 0.56 and 0.97. Both protocols were significantly correlated (r = 0.55 to 0.88; P = .000 to .05). CMJ strongly correlated with the number of techniques (r=0.59; P = .013) and the mean power (r = 0.56; P = .019) of the TSAT. The variables between the two methods correlate and are consistent, except for the anaerobic capacity that although correlated, is not consistent with constant bias, P = 0.001; CI]-705.1;-370.2[. TSAT has a level of agreement with the Wingate, and assigns specificity in the evaluation of these variables.

Keywords: anaerobic power, anaerobic capacity, taekwondo, specific test, Wingate test.

INTRODUCTION

As a martial arts and Olympic sports, taekwondo performance relies on short bursts of intense exercise in which the phosphagen system (also called the ATP-PC system) is the predominant energy system used to resynthesize ATP (Bouhlel et al., 2006; Matsushigue, Hartmann, & Franchini, 2009). Under the World Taekwondo Federation and Olympic rules, competitions consist of three semi-continuous contact rounds with two minutes each and with one minute of rest in between. Among the wide variety of techniques used in competition, all performed with extreme velocity, the kicks to the head, spinning and jumping kicks and the roundhouse kicks are frequently used. It is a sport that requires high levels of strength and anaerobic capacity (Matsushigue et al., 2009). Therefore, the lower limb muscle power is a variable of interest to evaluate the muscular mechanical characteristic of taekwondo practitioners. The literature (Olsen & Hopkins, 2003; Ravier, Grappe, & Rouillon, 2004; Sant'Ana et al., 2014) refers the counter movement jump (CMJ) as a protocol thatserves this goal, since this test has a movement pattern similar to that of the martial arts movements. Sant´Ana et al. (2014) found significant correlations between CMJ and kicks frequency, while Olsen and Hopkins (2003) link CMJ and

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similar movements with the enhancement of speed movements. Ravier, Grappe, and Rouillon (2004) conclude that karate performance depends on explosive strength.

Taekwondo players elicit near maximal heart rate (HR) responses (90 % HR peak) and high lactate concentrations (7.0–12.2mmol/l), which infer that high demands are imposed upon both aerobic and anaerobic metabolism during the matches (Bridge, Jones, & Drust, 2009; Heller et al., 1998). Hence, the assessment of anaerobic performance can provide the coach with valuable information about these athletes' fitness status as well as allowing them to monitor improvement through training (Inbar, Bar-Or, & Skinner, 1996). Individuals with improved anaerobic power are capable of generating energy at a high rate, which delays the onset of muscle fatigue and enables the continuation of high-intensity exercises (Heller et al., 1998). Currently, one of the tests used to assess the anaerobic performance of overall athletes is the Wingate anaerobic cycle test (WAnT) (Bar-Or, 1987) including taekwondo athletes (Lin, Yen, Lu, Huang, & Chang, 2006; Melhim, 2001). Bridge, Ferreira da Silva Santos, Chaabène, Pieter, and Franchini (2014) in a review article about physical profiles of taekwondo athletes, presented several studies in which the lower body Wingate anaerobic test performance was used as an instrument to measure anaerobic power. The same authors also claim that WAnT constitutes the most common method of assessing anaerobic peak power and capacity of taekwondo competitors. In that review, relative peak power for senior males has been reported with values ranging 8.4-14.7W/kg. Concerning the mean anaerobic power, investigators reported that there is limited data available, with values for males ranging between 6.6-9.2 W/kg. These values allow a favourable comparison with those produced by athletes in other intense short-duration events that elicit demands from the ATP/PC system (Aziz, Tan, & Teh, 2002; Zupan et al., 2009). The easy application, replication and scientific acceptance are factors underlying the widespread use of this laboratory test. In taekwondo the use of this popular test made it possible to confirm that the intense anaerobic nature of this combat sport and the ability of the lower limbs to generate high peak power may be essential in competition (Bridge et al., 2014).

However, there are physiological and biomechanical differences between pedaling and "kicking". As Falcó and Estevan (2014) testify, running and cycling involve isotonic contractions while kicking is a complex motor task characterized by large forces exerted in a short period of time. Consequently, according to Bridge et al. (2014) there is a need of specificity of the testing protocol, of specialized fitness tests that better reflect the mechanical actions, activity patterns and metabolic demands of the sport in a way to improve the validity of data and its application in research and training/competition.

Recently, Sant'Ana et al. (2014) recognize the WAnT limitations with regard to their ecological validity in taekwondo. The authors proposed a new method for anaerobic assessment, specific to this sport using the *Bandal chagui* kicking task over 30s. Ten subjects were asked to perform the largest number of techniques against a punching bag. The number of kicking cycles (time interval between two consecutive kicks with the same leg) was significantly correlated with a peak blood lactate concentration ($P = 0.04$; $r = .65$) and the counter movement jump (CMJ) performance ($P = 0.03$; $r = .70$). A drop in kicking cycles' time and impact magnitude during the last 20% of kicking cycles was also found when compared to the initial 20% kicking cycles ($P = 0.01$). However, no evaluation criterion of the anaerobic capacity was used (laboratory evaluation of power and anaerobic capacity) to validate this specific test for taekwondo, which made it impossible to understand the estimated level of this test to foretell the values obtained in the reference test. TSAT should evaluate the ideal observation model (anaerobic capacity) which theoretically must be related to WAnT. Thus, the correlation between the results of the laboratory test (WAnT) with the results evaluated in the field test (TSAT) has not been assessed as suggested by Bland and Altman (1986).

Therefore, the aim of this study is to provide valid evidence to support the effectiveness of a taekwondo specific anaerobic test (TSAT) to assess anaerobic power and anaerobic capacity in athletes. It was hypothesized that: i) WAnT underestimates the anaerobic performance of taekwondo players; ii) the limit of agreement (LoA) between variables for both test protocols are in a range that allows the use of the two measurement methods interchangeably.

METHOD

This is a concurrent validity study with the purpose to provide evidence to support the effectiveness of a TSAT to assess anaerobic fitness of taekwondo athletes. A concurrent validation model was applied in the form of a statistical correlation between the TSAT and the criterion data obtained during the WAnT.

Participants

A Seventeen male elite subjects (age 17.59 ± 4.34; body height 1.72m ± .07m; body mass 61.3kg ± 8.7kgand body fat 11.9 ± 5.7 %s) of the Portuguese taekwondo national team participated in this study. According to the characterization survey, all subjects were high-level junior and senior taekwondo athletes over 5 years of experience (black belts) and trained 8.7 ± 1.4 sessions per week. Each athlete's federal license was also verified to confirm the absence of any impediment to the practice of taekwondo.

All subjects and the parents (of under-18-year-old subjects) were informed in advance about the procedures and asked to sign a term of consent that had been approved by the University of Beira Interior and carried out according to the Helsinki Declaration.

Instruments

Anthropometric measures

The anthropometric assessment was carried out according to the International Working Group of Kinanthropometry methodology (Ross & Marfell-Jones, 1991). To evaluate height (m) we used a stadiometer (SECA, model 225, Germany) with a range scale of 0.10 cm. Weight and body fat were assessed using a Tanita body composition analyser (model TBF-200, Tanita Corporation of America, Inc. Arlington Heights, IL).

Maximum kicking impact force and power

The maximum kicking impact force was evaluated by performing the *Bandal chagui* technique (roundhouse kick) to a boxing bag. This technique is a turning kick and happens to be the most commonly used kick during competition (Lee, 1996).

The impact force of the kick was measured using a *piezo* sensor (LDT4-028K/L, Measurement Specialties Incorporation) built-in into a strike shield (Mega-Strike, IMPTEC, United Kingdom). The result is expressed in units ranging between 0 and 255. Subjects were encouraged to exert their maximal force in three trials. The rest intervals between the consecutive measurements lasted 3 minutes. The maximum, value was chosen for analysis. These units, resulting from the impact force are determined by the degree of deformation of the sensor; its corresponding value in SI units is not known or disclosed by the manufacturer. Therefore, it was necessary to establish a relationship between the force of impact registered by the *piezo* sensor and the corresponding kicking power in an SI unit (in *watts*,). For that purpose, a 3D motion tracking technology (Xsens, MTi 1-series) was used to analyze body movement in order to determine the peak kicking power of each athlete. Seventeen sensors were placed throughout the entire body, particularly in lower limbs in precise locations (hip, knee and ankle). Each sensor consists of a small gyroscope, an accelerometer and a magnetometer in its interior.

The MVN Studio Pro software was used to treat the data enabling its use in Visual 3D software, in a way that allowed defining the segment to be analyzed through the Compute Model Based Tool.

The option to calculate the power was set up and then the segment of interest (ankle) and the reference segment (leg) were defined. For this calculation, power was the result of the multiplication between the angular velocity (rad/s) and the moment of inertia.

Counter movement jump

The Optojump Next System (Microgate, SARL, Italy) was used to access maximum height mean in CMJ test, (Bosco, 1994).

Wingate Anaerobic 30 Cycle Test.

The WAnT was performed by all participants for determining anaerobic power and capacity using a cycle ergometer (Monark, Ergomedic 939E, Vansbro, Sweden). Reliability and validity information for the WAnT have been reported across some studies (eg, Bar-Or, 1987; Nicklin, O´Bryant, Zehnbauer, & Collins, 1990).

The performance indices are peak power (PP), mean anaerobic power (MAP), anaerobic fatigue or fatigue index (FI) and anaerobic capacity (AC). Peak power is the highest mechanical power elicited from the test taken as the average power over any 5 seconds' period, usually the first 5 seconds. Mean anaerobic power is the average power maintained throughout the six segments of 5 seconds. Fatigue index is the amount of the decline in power during the test expressed as a percentage of peak power (Inbar et al., 1996) and anaerobic capacity is recorded over the entire 30 seconds of the test (Zupan et al., 2009) and an average is measured.

TaekwondoSpecific Anaerobic Test (TSAT)

The TSAT consists of performing the *Bandal chagui* technique for 30 seconds at maximum speed and power against a boxing bag with a strike shield, using both legs alternately. Before testing, the boxing bag was set for each athlete´s optimal kicking height and distance to target (strike shield center). A single *piezo* sensor (LDT4-028K/L, Measurement Specialties Incorporation), located in the centre of the strike shield was used to assess the impact force demonstrated in each kick, expressed in units ranging between 0 and 255.

During the TSAT, the amount of performed techniques was recorded, as well as the kicking impact force, in units. These units were then converted to *watts* based on a conversion factor that was previously calculated during the maximum kicking impact force and power test. Consequently, the following variables were calculated as follows:

(i) Peak Power Output (PP) observed during the first five seconds of TSAT

$$\text{PP (watts)} = \frac{mean\ bandal\ chagui\ force\ in\ the\ first\ 5\ secs\ x\ number\ of\ tecniques\ in\ the\ first\ 5\ secs}{time(5\ secs)}$$

(ii) Relative Peak Power Output (RPP), concerning body weight :

$$\text{RPP (watts/kg body weight)} = \frac{PP}{Body\ weight}$$

(iii) Mean Anaerobic Power (MAP),:

$$\text{MAP (watts)} = \frac{mean\ power\ of\ tehcniques\ for\ 30\ secs\ x\ total\ number\ of\ techniques\ in\ 30\ secs}{time\ (30\ secs)}$$

(iv) Relative Mean Anaerobic Power (RMAP), concerning body weight:

$$\text{RMAP (watts/kg body weight)} = \frac{MAP}{Body\ weight}$$

(v) Fatigue índex (FI):

$$\text{FI (\%)} = \frac{highest\ 5\sec PP - lowest\ 5\sec PP}{higest\ 5\sec PP}\ \text{x}\ 100$$

(vi) Anaerobic Capacity (AC),:

$$\text{AC (watts)} = \sum of\ each\ 5\sec PP$$

Procedures

Participants were tested on four sessions (days) for two consecutive weekends. All athletes had been competing regularly, exhibiting, at the time of this study, a good overall performance.

In the 48 hours prior to the first session, subjects were instructed to refrain from physical activity and underwent one familiarization session. During this session, all athletes were counseled on proper exercise technique, as well as stretching and appropriate warm up in order to prevent the large gains that tend to occur as the subjects learn the testing procedure and also to verify the protocol acceptance and applicability to this group.

The first data collection, session 1, included the anthropometric measures, the kicking impact force (leg strike on the boxing bag) and the WAnT. Session 2 (at the same hour of the day on the following day) included the CMJ and the TSAT. In addition, all the procedures (except the anthropometric evaluation) were repeated the following weekend (sessions 3 and 4) for reliability measurement. During this period and up to 48 hours before session 3, participants were instructed to maintain their normal diet and training patterns.

Before testing, the participants were asked to perform 15 minutes of standardized warm-up consisting of running, dynamic joint mobility exercises and 8 sub maximal jumps. Prior to the WAnT, each subject performed a 5 minutes warm-up period on a cycle ergometer (Monark, Ergomedic 939E, Vansbro, Sweden). Static stretching exercises were also performed at the end of the sessions. All tests were conducted in an indoor facility to avoid weather changes during the pre- and post-test sessions (at a temperature of 19-21ºC).

The data collection started with the measurement of weight and height and body mass percentage. Subjects were tested whilst wearing shorts and t-shirts (shoes were removed). After the participants carried the warm up, in a random order they began the tests. The maximum kicking impact force (MKIF) test was the first, after the boxing bag having been previously adjusted according to the body height of each athlete (the center of the shield was placed in height between the navel and nipples).

After one hour, the WAnT was performed. Prior to testing, the seat height was adjusted individually for all athletes in order to find a knee flexion angle of less than 5 degrees when the leg was fully extended. The load was the result of multiplying the athlete's body weight by a constant (0.075 kg per kg/body described by Jackson, Pollock, & Ward, 1980). The test consisted of cycling, i.e. the athlete tried to keep the number of revolutions as high as possible in an attempt to complete the highest number of revolutions per 30 seconds.

As mentioned before, each subject was allowed a warm-up period on another cycle ergometer (Monark, Ergomedic 939E, Vansbro, Sweden) at a self-selected cadence (at 50 *Watts*) including two sprints, each lasting 3 seconds at the end of the third and fifth minutes (Beneke, Pollmann, Bleif, Leithäuser, & Hütler, 2002). The test began with the start command, which released the resistance. Verbal support was given during the entire test and after finishing the participant continued pedaling for three minutes, with a very light load in order to avoid dizziness and syncope due to testing.

On the second day of evaluation, at the same time of the day, after the standardized warm up, the counter movement jump (CMJ) was performed, wherein each athlete performed 3 trials with 3 minutes in between for each attempt. The maximum height expressed in centimetres (cm) was considered for analysis. After one hour, the taekwondo specific anaerobic test (TSAT) was accomplished- trial I. The re-test, trial II, for WAnT and for TSAT, took place one week later, in the same order.

Statistical Analysis

All data were analysed using SPSS 20.0 (Chicago, IL). Standard statistical methods were used for the calculation of means and standard deviations. The Shapiro-Wilk test was used to verify the normal distribution of variables. A t-test for paired measures was applied to compare the mean values obtained in both test situations (WAnT and TSAT) and to verify any difference between WAnT and TSAT test and re-test, correlated by intra-class correlation coefficients (ICC). Also the strike shield reliability was measured through the internal correlation coefficient. Pearson product-moment correlation coefficients were used to verify the association among all variables between WAnT and TSAT, and between CMJ and TSAT. The effect size was evaluated through Cohen´s d. The extent to which WAnT and TSAT produced the same values, by means of the strength of relation as well as the extent of agreement, was examined by the Bland-Altman graphics, using XLSTAT Addinsoft^{TM}. For a quantitative analysis, it was deemed that the values projected by TSAT would be correct if at least 80% of the dots were inside the limits of agreement. To establish statistical significance $P \leq 0.05$ criterion was used.

RESULTS

Through 3D analysis, we verify that each unit charged by the strike shield is equivalent to 3.93 *watts,* therefore we register that the mean value of the *Bandal chagui* impact force is 418 ± 85.1 *Watts*. Figure 1 represents the output of two *Bandal chagui* impacts. The grey shadow shows the standard deviation of the athlete's data while the line is the average of all athletes' data.

Table 1 shows the mean values (± standard deviation) for all recorded variables in both test and re-test during the WAnT and the TSAT.

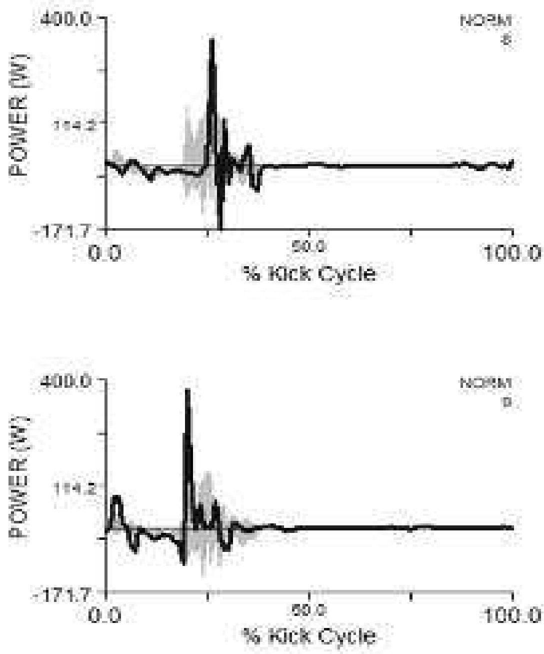

Figure 1. 2D plots from segment power scalar – right foot.

Table 1

Mean values (± SD) of performance variables measured during the test and re-test of both the WAnT and the TSAT (n=17).

	Variables	Trial 1	Trial 2	Cohen´s d	t-test	*p*- value	ICC (95% IC)	*p*- value
WAnT	PP(W)	575.5(88.7)	663.8(89.3)	1.1	-8.871	.000	0.75 (-.16-.94)	.000
	RPP(W/Kg)	9.3(1.1)	10.7(1.3)	1.0	-8.781	.000	0.66(-.18-.91)	.000
	MAP(W)	386.2(71.9)	470.6(75.1)	1.2	-9.782	.000	0.70 (-.15-.93)	.000
	RMAP(W/Kg)	6.2(0.9)	7.6(0.9)	1.2	-9.936	.000	0.56 (-.15-.87)	.000
	FI(%)	36.8(9.7)	36.9(7.1)	-----	-.133	.895	0.95 (.87-.98)	.000
	AC (W)	2449(431.8)	2529(427.7)	0.32	-2.637	.018	0.97 (.89-.99)	.000
TSAT	PP(W)	558.5(127.7)	599.9(119.3)	0.27	-2.225	.041	0.87 (.62-.96)	.000
	RPP(W/Kg)	8.9(1.6)	9.7(1.6)	0.28	-2.265	.038	0.80 (.42-.93)	.000
	MAP(W)	371.4(69.7)	414.9(86.3)	0.46	-3.756	.002	0.83 (.23-.95)	.000
	RMAP(W/Kg)	6.0(1.2)	6.7(1.4)	0.47	-3.781	.002	0.84 (.25-.95)	.000
	FI(%)	37.4(7.2)	37.7(5.9)	-----	-.34	.757	0.86 (.60-.95)	.000
	AC (W)	1911(310.5)	1958(354.7)	-----	-1.220	.250	0.93 (.84-.98)	.000
	Nº TECHNIQUES	73.3(7.2)	73.4(6.8)	-----	-.223	.826	0.99 (.98-.99)	.000

PP- peak power; RPP – relative peak power; MAP-mean anaerobic power; RMAP – relative mean power; FI – fatigue index; AC – anaerobic capacity; Nº TECHNIQUES – number of the total *Bandal chagui*´s in 30 seconds. Statistically significance, $p < .05$

Towards trial II we observed a trend for higher values in both protocols, especially in WAnT protocol.

The test-retest reliability was assessed with the mean values of every variable which paired trial I with trial II using the intra-class correlation coefficient (ICC), ranging for all measures between 0.56 and 0.97 (P = .000) in the WAnT and between 0.89 and 0.99 (P = .000) in the TSAT. In WAnT, in what concerns the FI variable, from trial I to trial II, there were no differences (P =.895; ICC = 0.95). For the remaining variables, there was a difference with a large effect size (from 1.0 to 1.4).

In the TSAT, the differences in trial I and II had an effect size ranged between small and medium (0.33-0.55) for PP, RPP, MAP and RMAP. We observed a trend towards trial II for higher values in all measure variables, although, for FI, AC and number of techniques the difference was not statistically proved, P = .757; P = .240; P = .826, respectively. A significant correlation between CMJ performance and the number of techniques (r = 0.59; *P* =.013) and the MAP (r = 0.56; P =.019) was registered in the TSAT.

The reliability for the strike shield had an internal correlation coefficient of 0.87. One can note in table 2 that variables in WAnT and TSAT were significantly correlated, FI being the strongest correlation (P =.000, r =.88).

Table 2

Results of paired sample t-test, correlations and Cohen´s effect size, between the Wingate Anaerobic Test (30 seconds, WAnT) and the Taekwondo Specific Anaerobic test (TSAT) (n=17).

	Wingate (WAnT) Vs Taekwondo Specific Test (TSAT)				
	Correlation	p-value	t-test	p-value	Cohen´s d
PP (W)	0.64	.006	.719	.482	-----
RPP (W/Kg)	0.55	.05	.808	.431	------
MAP (W)	0.65	.004	1.033	.317	------
RMAP (W/Kg)	0.62	.008	.857	.404	-----
FI (%)	0.88	.000	-.533	.602	-----
AC (W)	0.66	.004	6.808	.000	0.85

PP- peak power; RPP – relative peak power; MAP-mean anaerobic power; RMAP – relative mean power; FI – fatigue index; AC – anaerobic capacity. Statistically significance, p <.05

Results also show a trend for higher values in WAnT (table 1), however, only the AC variable demonstrates being statistically different (P = .000), with a large Cohen´s d, 0.85 (table 2).

In the Bland-Altman analysis, we checked if the mean of the differences between the results of the two methods were different from zero (0). According to our data, only the anaerobic capacity variable showed a significant difference, P = 0.0001; CI [-705.1;-370.2].

Using a scatter plot graphic, figure 2, we compared the reference test (WAnt) with TSAT and we can observe that for the PP, RPP, MAP, RMAP and FI the data are on both sides of the identity line and are not distant from it, which means that both methods/tests (WAnT and TSAT) provide us with similar consistent outcomes.. The TSAT seems to underestimate the AC variable values, once the data is under the identity line.

In the Bland-Altman plot graphic, figure 3, we can infer the following: for PP the bias is -17.1, with a 95% CI of [-67.7;33.4], the limit of agreement (LoA) is [-210.1;175.8]; for RPP the bias is the value of -0.3 with a 95% CI [-1.1;0.4], the LoA is [-3.3;2.7]; for MAP, there is a bias of -14.7 with a 95% CI of [-45.0;15.5] and LoA of [-130.2;100.7]; for RMAP the bias is -0.2 with a 95% CI of [-0.6;0.3] and a LoA [-0.2;0.7]; with regard to FI and AC, there is a bias of 0.6 and -537.6, a 95% CI of [-1.8;3.0] and [-705.0;-370.1] and a LoA of [-8.7;9.2] and [-1175,9;100.7], respectively. Summing up, the 95% CI of bias for the first five variables includes the zero (0) value. This can confirm that the risk of concluding that WAnT and TSAT are different when they are not is high and should be avoided. The LoA suggests that any difference between the two measures should lie in this CI, and allows understanding that at least 80% of dots are within this limits.

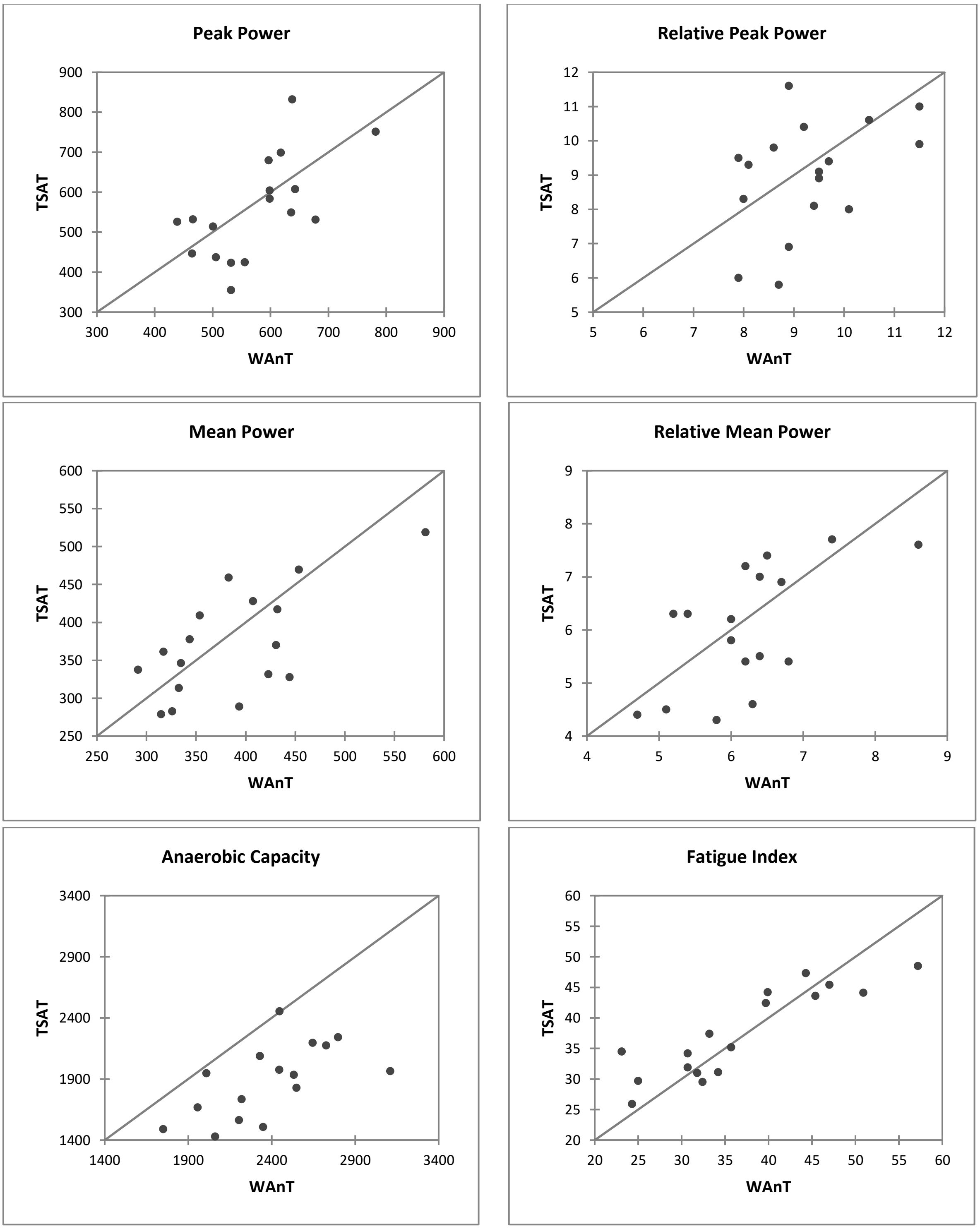

Figure 2. Scatter plot graphics for variables measured by WAnT and TSAT.

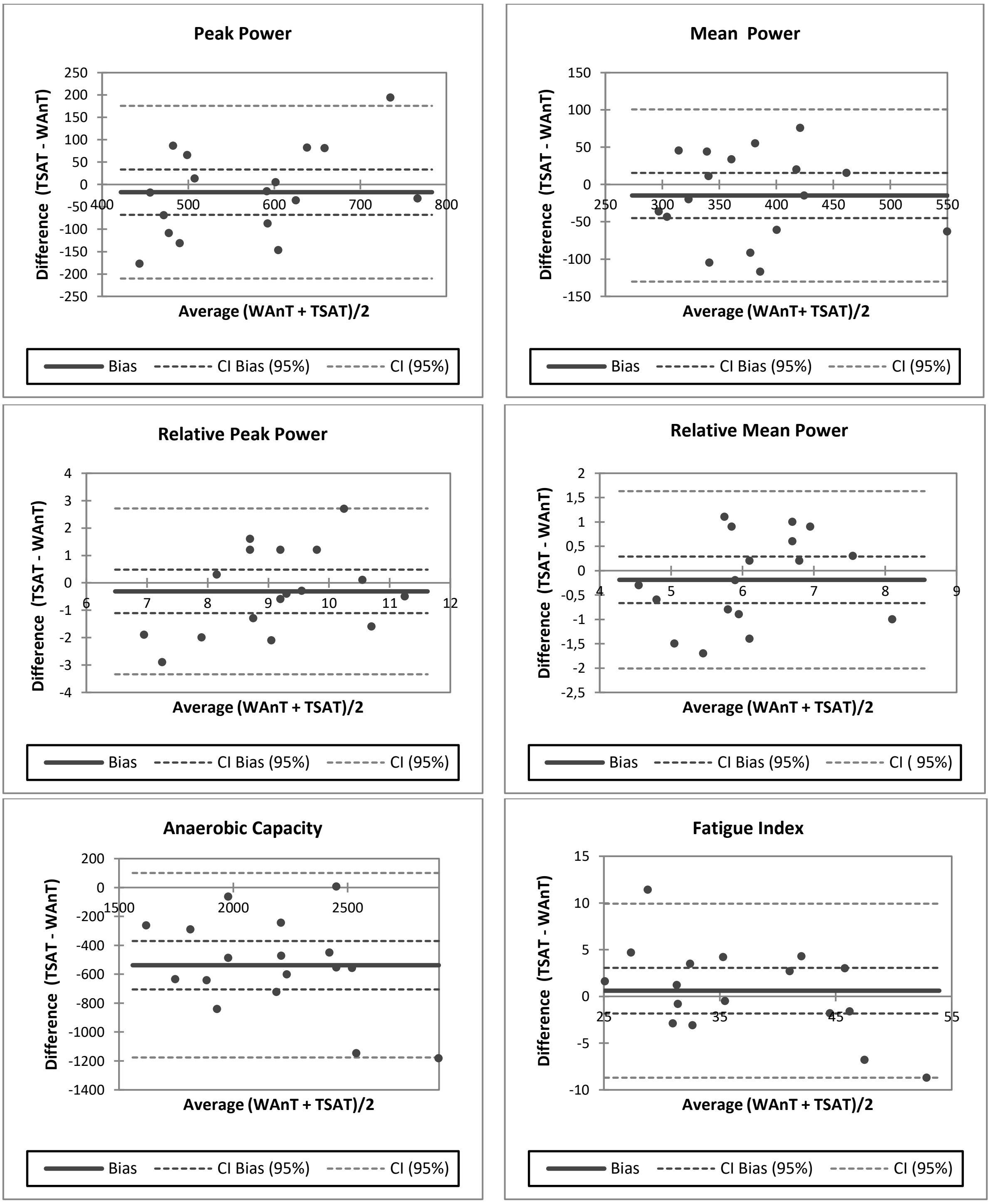

Figure 3. Bland-Altman fit differences from the variables measured by WAnT and TSAT.

DISCUSSION

The intent of this study was to evaluate the concurrent validity of TSAT using the WAnT as gold standard test and to verify how far the TSAT gives results that are similar to WAnT in an elite male taekwondo subjects.

Performing a technique with speed and strength are two important criteria for taekwondo competition (Roosen & Pain, 2006). Several studies have attempted to assess the kick impact force using measurement systems whose results are presented in Newtons (Falcó, Estevan, Álvarez, & Molina-García, 2011; O'Sullivan et al., 2009) others in Kilogram-force (Chiu, Wang, & Chen, 2007) or in joules (Del Vecchio, Franchini, Vecchio, & Pieter, 2011) and also in gravity acceleration units (g) (Sant'Ana et al., 2014). Moreover, the electronic body protector used in official taekwondo matches records the impact in joules. Del Vecchio, Franchini, Vecchio, and Pieter (2011) presented data from the energy absorbed by the electronic body protector during taekwondo official competitions and states that the energy values recorded ranges from 211 ± 34 joules in junior <51kg athletes to 262 ± 49 joules in senior 67-78kg athletes. In this study, we used the watts measurement system to quantify the *Bandal chagui* impact because we wanted to correlate the impact forces with the WAnT results and because the Mega Strike device measures the impact of a hit in units patented by the manufacturer. We verify that the *Bandal chagui* technique can produce in average an impact force of 418 ± 85.1Watts. Assuming the relationship between joules and watts by the following formula, Joules= Watts x seconds, and considering the work of Matsushigue, Hartmann, and Franchini (2009), which refers *Bandal chagui* speed values in the order of 0.31 seconds, we realize that the electronic body protector delivers higher values than those recorded in this study (680 watts vs. 418 watts). There must be several reasons for this underestimation in the presented work, and from our point of view it is clear that the difference is explained by how the impacts are assessed, the material used, contact time, and other factors.

For the WAnT evaluation, all participants were instructed about the proper methods, although, a difference in trial I and trial II was registered. Barfield, Sells, Rowe, and Hannigan-Downs (2002) reported a systematic change in peak power (14%) and mean power (5%) between two trials in WAnT, when there is not a good familiarization with the evaluation test. In our study, for WAnT, the differences are 15% for peak power and 21% for mean power. During the sport seasons, all participants are evaluated with WAnT, and even so, it is evident that any technical gesture unspecific to the sport performed in WAnT protocol can act as lack of familiarization, which in a way can explain the differences between trial I and II. This question became apparent when we recorded differences of 7% and 11% for the same variables, peak power and mean power respectively, between trial I and II for the TSAT protocol, both with an ICC above 0.83 and a small to medium effect size, suggesting that these differences in practice will not have a big impact.

Several studies have been conducted on the validity, reliability and/or replication of the 30 seconds Wingate test protocol (Beneke et al., 2002; Denadai, Gugliemo, & Denadai, 1997). Additionally, Bridge et al. (2014) in a review article reported 864.6 ± 246.2 w (peak power); 11.8 ± 2.0 w/kg (relative peak power); 671.2 ± 151.3 w (mean power) and 9.2 ± 1.2 w/kg (relative mean power) for an international US male elite taekwondo sample. Heller et al. (1998) reported values of 14.7 ± 1.3 w/kg (relative peak power); 344 ± 26.4 J/kg (anaerobic capacity) and a 42.2 ± 7.3% (anaerobic fatigue) in a sample of elite male and female taekwondo subjects. When considering our findings in WAnT we reported results in some variables lower than those considered in literature, such as the peak power, relative peak power and anaerobic capacity. The lower values can explain the value presented in FI, i.e., installed fatigue was also shorter, resulting in a lower FI.

There is a notorious difference in anaerobic capacity (about 22%) between both tests. Despite the reliability of the mega strike shield presenting a good ICC, the power decline in the techniques throughout the TSAT is evident. We suppose that this decline is partly due to the reduction of energy sources, including ATP, PC, muscle glycogen and accumulation of H^+ and inorganic phosphate (Pi) (Fitts, 2008), but it may also be due to the strike shield not having the same sensitivity throughout. As declines in physical performance can be associated with reductions in technical skill performance (Fitts, 2008; Radman et al., 2016) a decrease in technical aim for the most sensitive part of the shield may have occurred, presenting, in our view, a difference in values to the AC variables between the two tests. This observation can also justify the FI behaviour when compared with the Sant´Ana et al. (2014), although the values between WAnT and TSAT were very similar, they seem to be higher than 27.69% in the Sant´Ana' study.

Sant´Ana et al. (2014) justified the lower values of the taekwondo anaerobic test, in FI variable, when compared with other authors using the WAnT, due to the fact that in the WAnT there is a constant load for the technical gesture (cycling) while in taekwondo specific tests, there is a brief pause between the kicks which somehow allows for recovery, causing a lower drop in performance. In this study, assuming the feature mentioned above, and to justify the similarity of values in the FI variable, we would rather assume that the similar values between the two tests are due to a specific technical gesture that imposes physiological dissimilarities between cycling and kicking. Cycling involves isotonic contractions while kicking is a complex motor task characterized by large forces exerted in a short period of time (Falcó & Estevan, 2014) and therefore, there is a central and peripheral specific adaptation. The specific gesture also allows the athletes to better synchronize the various phases of the kick skills they use, thus saving energy in carrying out the test. On the other hand, this ability to synchronize also allows the athlete a larger fibre recruitment to mobilize a larger muscle mass in a greater angular velocity and this, eventually, results in more force applied (Del Vecchio et al., 2011) corresponding to increased energy consumption.

We suggested that the correlation between the mean power and number of techniques in the TSAT with CMJ is supported by the stretch-shortening cycle. When performing the *Bandal chagui* there is a knee flexion before a leg extension (when the foot hits the bag), a movement that mimics the one performed in the CMJ test. With this association, we can understand that the ability to perform the TSAT, particularly regarding the number of techniques and the average value of the impact force, depends on the maximal muscular power production by the knee extensors, a finding also described by Sant´Ana et al (2014).

We obtained results contrary to our first hypothesis, WAnT underestimates the anaerobic performance of male taekwondo o athletes, due to, in our perspective, factors related to impact measurement; nevertheless, the same results show the existence of a significant correlation, which suggests that both protocols have the ability to evaluate an identical variable.. Additionally, there is no proportional bias in all variables (except for AC), which leads us to mention that there is a level of agreement between both tests and that confirms our second hypothesis. The level of agreement is higher after normalization (peak power and mean anaerobic power) according to the body weight (Falcó, Molina-García, Alvarez, & Estevan, 2013). For the anaerobic capacity variable the first assumption is that the two methods on this variable do not consistently provide similar measures because there is a level of disagreement that may include practical important discrepancies up to 537.6 watts. In fact we have a correlated and inconsistent measure at a constant bias; however, this bias does not render TSAT meritless to assess anaerobic capacity. In this particular case, to evaluate AC we could use the value of the AC plus the bias, as an estimate of the anaerobic capacity from TSAT. It should also be added that these results are in position to assume the TSAT validation: a) there are no differences between the tests (mean data) with the exception of AC variable; b) the Bland and Altman analysis allows for realization that PP and FI have one dot each beyond the limits of agreement, while the other variables have all the dots within those limits. So, the cut-off value of at least 80% of plots within the LoA was accomplished for all variables of TSAT protocol.

We discussed earlier the sensor sensitivity issue that may have caused this constant bias. This constitutes a limitation for this study and should be further investigated through complementary experiments with an improved power assessment tool, capable of retaining a minimum level of measurement accuracy that guarantees that every major portion of the strike shield surface must include a sufficient number of sensors to ensure recording of every possible type and magnitude of hit on it.

Our findings have been limited to a group of elite male athletes. Further approaches are needed to confirm if TSAT protocol is appropriate for assessing other athletes in different levels of training, of different ages and especially in female athletes.

CONCLUSION

It was hypothesized that WAnT underestimates the anaerobic performance of taekwondo players. In fact, the results showed the opposite, especially regarding the AC variable; due to decrease of motor acuity in performing the *Bandal chagui* with onset fatigue, the techniques began to be carried out in areas farther from the center of the shield/sensor, with lower impact values than the force actually applied. Our results also have shown that TSAT has a level of agreement with the WAnT, especially in the variables PP, RPP, MAP, RMAP and FI, therefore the protocol attaches great specificity in assessing anaerobic fitness of taekwondo athletes. The importance of muscular power in the TSAT is significant when there is a relation between CMJ and mean power, CMJ and the number of techniques. An important point in this work was to quantitatively measure the performance effort, and it has produced a set of equations which can provide a practical impact to the training/anaerobic evaluation process of taekwondo athletes.

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REFERENCES

Aziz, A. R., Tan, B., & Teh, K. C. (2002). Physiological Responses During Matches and Profile of Elite Pencak Silat Exponents. *Journal of Sports Science & Medicine*, *1*(4), 147–155.

Barfield, J.-P., Sells, P. D., Rowe, D. A., & Hannigan-Downs, K. (2002). Practice effect of the Wingate anaerobic test. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *16*(3), 472–473.

Bar-Or, O. (1987). The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Medicine (Auckland, N.Z.)*, *4*(6), 381–394.

Beneke, R., Pollmann, C., Bleif, I., Leithäuser, R. M., & Hütler, M. (2002). How anaerobic is the Wingate Anaerobic Test for humans? *European Journal of Applied Physiology*, *87*(4–5), 388–392. http://doi.org/10.1007/s00421-002-0622-4

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet (London, England)*, *1*(8476), 307–310.

Bosco, C. (1994). *La valoracion de la fuerza con el test de Bosco*. Barcelona: Paidotribo.

Bouhlel, E., Jouini, A., Gmada, N., Nefzi, A., Ben Abdallah, K., & Tabka, Z. (2006). Heart rate and blood lactate responses during Taekwondo training and competition. *Science & Sports*, *21*(5), 285–290. http://doi.org/10.1016/j.scispo.2006.08.003

Bridge, C. A., Ferreira da Silva Santos, J., Chaabène, H., Pieter, W., & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes. *Sports Medicine*, *44*(6), 713–733. http://doi.org/10.1007/s40279-014-0159-9

Bridge, C. A., Jones, M. A., & Drust, B. (2009). Physiological responses and perceived exertion during international Taekwondo competition. *International Journal of Sports Physiology and Performance*, *4*(4), 485–493.

Chiu, P. H., Wang, H. H., & Chen, Y. C. (2007). *Designing a measurement system for taekwondo training*. Poster Session 1/Sport. Poster 138, S619, Institute of Sports Equipment Technology, TPEC, Taipei, Taiwan.

Del Vecchio, F. B., Franchini, E., Vecchio, A. H. M. D., & Pieter, W. (2011). Energy absorbed by electronic body protectors from kicks in a taekwondo competition. *Biology of Sport*, *28*(1), 75–78.

Denadai, B. S., Gugliemo, L. G. A., & Denadai, M. L. D. (1997). Validade do teste de wingate para a avaliação da performance em corridas de 50 e 200 metros. *Motriz*, *3*(2), 89–94.

Falcó, C., & Estevan, I. (2014). Biomechanics in taekwondo: practical applications. Em M. Haddad (Ed.), *Performance optimization in taekwondo: from laboratory to field* (pp. 1–23). Foster City, CA: OMICS Group eBooks.

Falcó, C., Estevan, I., Álvarez, O., & Molina-García, J. (2011). Capacity to create impact forces and execution time according to weight category in taekwondo. *Revista de Ciencias del Deporte*, *7*(Suppl), 23–29.

Falcó, C., Molina-García, J., Alvarez, O., & Estevan, I. (2013). Effects of target distance on select biomechanical parameters in taekwondo roundhouse kick. *Sports Biomechanics / International Society of Biomechanics in Sports, 12*(4), 381–388. http://doi.org/10.1080/14763141.2013.776626

Fitts, R. H. (2008). The cross-bridge cycle and skeletal muscle fatigue. *Journal of Applied Physiology (Bethesda, Md.: 1985), 104*(2), 551–558. http://doi.org/10.1152/japplphysiol.01200.2007

Heller, J., Peric, T., Dlouhá, R., Kohlíková, E., Melichna, J., & Nováková, H. (1998). Physiological profiles of male and female taekwon-do (ITF) black belts. *Journal of Sports Sciences, 16*(3), 243–249. http://doi.org/10.1080/026404198366768

Inbar, O., Bar-Or, O., & Skinner, J. S. (1996). *The Wingate Anaerobic Test*. Champagn, IL: Human Kinetics.

Jackson, A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise, 12*(3), 175–181.

Lee, K. M. (1996). *Tae Kwon Do: Techniques & Training*. NY: Sterling Publishing Company.

Lin, W.-L., Yen, K.-T., Lu, C.-Y. D., Huang, Y.-H., & Chang, C.-K. (2006). Anaerobic capacity of elite Taiwanese Taekwondo athletes. *Science & Sports, 21*(5), 291–293. http://doi.org/10.1016/j.scispo.2006.04.005

Matsushigue, K. A., Hartmann, K., & Franchini, E. (2009). Taekwondo: Physiological responses and match analysis. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 23*(4), 1112–1117. http://doi.org/10.1519/JSC.0b013e3181a3c597

Melhim, A. F. (2001). Aerobic and anaerobic power responses to the practice of taekwon-do. *British Journal of Sports Medicine, 35*(4), 231–234.

Nicklin, R., O´Bryant, H., Zehnbauer, T., & Collins, M. (1990). A computerized method for assessing anaerobic power and work capacity using maximal cycle ergometry. *Journal of Strength and Conditioning Research, 4*(4), 135–140.

Olsen, P. D., & Hopkins, W. G. (2003). The effect of attempted ballistic training on the force and speed of movements. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 17*(2), 291–298.

O'Sullivan, D., Chung, C., Lee, K., Kim, E., Kang, S., Kim, T., & Shin, I. (2009). Measurement and Comparison of Taekwondo and Yongmudo Turning Kick Impact Force for Two Target Heights. *Journal of Sports Science & Medicine, 8*(CSSI3), 13–16.

Radman, I., Wessner, B., Bachl, N., Ruzic, L., Hackl, M., Prpic, T., & Markovic, G. (2016). The acute effects of graded physiological strain on soccer kicking performance: a randomized, controlled cross-over study. *European Journal of Applied Physiology, 116*(2), 373–382. http://doi.org/10.1007/s00421-015-3293-7

Ravier, G., Grappe, F., & Rouillon, J. D. (2004). Application of force-velocity cycle ergometer test and vertical jump tests in the functional assessment of karate competitor. *The Journal of Sports Medicine and Physical Fitness, 44*(4), 349–355.

Roosen, A., & Pain, M. T. G. (2006). Impact timing and stretch in relation to foot velocity in a taekwondo kicking combination. *Journal of Biomechanics, 39*(Suppl 1), S562. http://doi.org/10.1016/S0021-9290(06)85319-4

Ross, W. D., & Marfell-Jones, M. (1991). Kinanthropometry. Em J. D. MacDougall, H. A. Wenger, & H. J. G. (Ph Green (Eds.), *Physiological Testing of the High-performance Athlete*. Champagn, IL: Human Kinetics Books.

Sant'Ana, J., Diefenthaeler, F., Dal Pupo, J., Detanico, D., Gugliemo, L. G. A., & Santos, S. G. (2014). Anaerobic evaluation of Taekwondo athletes : original research. *International SportMed Journal, 15*(4), 492–499.

Zupan, M. F., Arata, A. W., Dawson, L. H., Wile, A. L., Payn, T. L., & Hannon, M. E. (2009). Wingate Anaerobic Test peak power and anaerobic capacity classifications for men and women intercollegiate athletes. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 23*(9), 2598–2604. http://doi.org/10.1519/JSC.0b013e3181b1b21b