Talent detection in taekwondo: which factors are associated with the longitudinal competitive success?

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Abstract

Background & Study Aim: Several morphological and functional characteristics are associated with the performance of taekwondo (TKD) adult athletes. However, we did not find any longitudinal study associating these features to the future performance of young athletes, and thereby, identifying the best variables to use in a battery of tests to talent detection. Therefore, the aim of this study is answer the question which factors are associated with the longitudinal competitive success of TKD young athletes over five competitive years (2008 to 2012).

Material & Methods: Six taekwondo athletes (13.06 ± 1.07 years, 43.6 ± 6.6 kg, 157.9 ± 8.3 cm), who trained three to six hours per week, for more than three years, were assessed on 32 maturational indicators, of body composition, anthropometric and functional, using anthropometric techniques, dual energy x-ray absorptiometry, carpal radiography and contact platform. To determine the competitive ranking, the competitive results of athletes from 2008 to 2012 were analysed, and these values were correlated with the other 32 indicators for determining the Longitudinal Predictors of Performance in TKD (LPPT). Moreover, one of the athletes achieved results notably higher than the other, being medalled at Junior World Championships. Therefore, all variables were transformed into *z–scores* and all those in which this athlete presented superior performance in 1 *z–scores* were considered as LPPT.

Results: The athlete of reference (the first in Longitudinal Competitive Ranking 2008-2012) distinguished, in accordance with the criteria, in nineteen LPPT indicators . The ranking was correlated with 6 LPPT parameters, including one from the maturation group of indicators and five from the functional group.

Conclusion: Our results allowed us to identify several factors that are related to longitudinal competitive success in taekwondo young athletes. These factors should be considered by coaches to the proper selection of training programs, as well as for the pre-selection of young talents in competitive taekwondo. However, these results apply only to the Portuguese taekwondo adolescent athletes, being of limited generalizability.

Keywords: anthropometry • biomechanical variables • body composition (DEXA) • indicators • WTF taekwondo

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Anthropometry – area of study that is concerned with the determination of characteristics and properties of the locomotor system.

Indicator (in the methodological meaning) – "the rate of some Z phenomenon is a W phenomenon which observing allows (in the absolute way or only with the certain probability) to state that the phenomenon happened" [37].

Factor (in the methodological meaning) – the phenomenon, which either remains in the cause-and-effect relationship with some other phenomenon (it influences it or is under the influence), or remains indifferent towards other or of other phenomena.

Body Composition – term used to describe the percentage content of fat, muscle, water and bone.

DEXA – kineanthropometric method for determining body composition.

WTF Taekwondo – World Taekwondo Federation

Introduction

Taekwondo (TKD) is an Olympic sport that involves punches and kicks, in which most of the points (98% to 100%) derives from kicks [1-3]. *Bandal chagui* (semi-circular kick performed with foot dorsum on the abdomen height of the adversary) is the most used technique in competition [4]. The choice of kick technique is related to the possibility of obtaining points with less effort and greater efficiency [5]. Moreover, the kicks in competitive TKD should be performed quickly with high muscle power [6, 7] and in adequate time to seize the tactics opportunities provided by the adversary [8-10]. For this reason, one ideal body type associated with certain functional and maturational characteristics may be required [7, 11]. Achieving suitable weight and body composition is one of the main goals for most sportsmen, especially those who compete in well-defined weight classes, as in TKD [12]. In fact, several maturational, anthropometric, body composition and functional characteristics are associated with competitive success in various martial modalities [13-16] and specifically in TKD [6, 7, 17, 18].

The biological maturation, for example, has been associated with athletic performance [19, 20]. However, any study associating this biological indicators with the performance of young athletes in TKD was not found. Another fact is that despite the height of TKD Olympic athletes having not been statistically different between medallists and non-medallists on Olympic Games of Beijing 2008 [3, 21], some researchers suggest a trend of TKD Olympic champions to be taller and with lower body mass indices than non-champions [3, 2]. This same trend has been suggested by Markovic et al. [6] on the performance of Croatian elite TKD athletes However, this inconsistency of results indicates that more studies on success factors in competitive TKD should be carried out, especially about the predicted final height of young athletes. Furthermore, it is observed that bone mineral density was associated with muscular strength and running performance in recruits [22] and the performance of young athletes in various combat sports [23], as well as in young-adult athletes of TKD and judo [17]. Bone mineral content is a variable also associated with the level of training of young athletes [24]. However, any study associating this indicator with the performance of young TKD athletes was found. Moreover, the fat mass and the fat percentage are related to performance in TKD [6] and judo [16, 25]. In addition, the Index of Fat Free Mass (IFFM) combined with characteristics of somatotype is considered important to the performance of football young athletes [26] and to jiu-jitsu high level athletes [14]. And also, the sum of skinfolds was associated with the performance of Olympic TKD athletes [7].

In addition to the morphological characteristics, the neuromuscular capacity is also of fundamental importance to the technical performance of combat sports athletes. For example, the muscle power of the lower limbs, estimated by vertical jumps, has been linked to competitive performance in TKD [6, 18]. However, it was observed that only performance in countermovement jump (CMJ) was higher in elite than subelite athletes, while the performance in squat jump (SJ) was similar between them [6]. This indicates that the performance of these athletes had greater influence stretch shortening cycle (SSC) than just muscle recruitment in concentric phase [27]. Moreover, about the specific variables from the kick analysis in TKD (e.g. Bandal Chagui), the reaction time [10] and kick time [28] are highlighted. The reaction time is the moment to identify a stimulus or a tactic opportunity, and start the desired action. The kick time is associated with the time allowed to the opponent start to react. When the kick time is normalized by the lower limb length, we obtain the agility coefficient that we can compare among fighters of different somatotypes.

Despite several studies having associated biotype and functional characteristics of adult fighters with performance, and few of them using young athletes, we do not found any longitudinal study associating these features with the future performance of TKD young athletes. Therefore, the aim of this study is answer the question which factors (maturational, body composition, anthropometrics and functional) are associated with the longitudinal competitive success of young TKD athletes over five competitive years (2008-2012).

Material and methods

Sample

The following criteria were used for sample selection: a) male athletes, who in the year of data collection had completed 12 to 14 years of age to belong to the cadet competitive category; b) medalled at least in the Lisbon regional championship; c) have participated in the cadet national championship. Seven athletes who have met all requirements have been invited to the analysis, of which one could not participate. The final sample was then composed by 6 taekwondo athletes (13.06 ± 1.07 years; 43.6 ± 6.6 kg; 157.9 ± 8.3 cm), who trained for three to six hours a week for more than three years on the *Sporting Soccer Club* *of Lisbon*. The participants had signed a term of consent approved by the ethics committee of the Faculty of Human Kinetics (FMH-UTL) (8/09/2009). Each athlete performed all tests in a single day, on the FMH-UTL, in the laboratory of Exercise and Health and in the laboratory of Biomechanics and Functional Morphology.

Experimental design

All evaluations were performed in a single day. In the morning, fasting for 12 hours, the athletes were evaluated in body composition by DEXA, anthropometrics and carpal x-ray to determine the bone maturation. Soon after, the athletes were allowed to feed, and in the normal training period (18:00 to 19:30), they were evaluated in functional tests (Kicks and Vertical Jumps) with contact platform, on the Taekwondo Academy of the *Sporting Soccer Club of Lisbon*. Moreover, the competitive performance of the athletes was registered between 2008 and 2012. All competitive results of major national competitions (Portuguese Championship) and international (International Open, European and World Championship) were recorded in Excel spreadsheet. Then, a score is assigned from 1 to 40 for the competitive ranking, according to the criteria in Table 1. These data were associated with the other measured indicators in order to determine which factors (indicators) were associated directly or indirectly with longitudinal competitive result.

Procedures

Anthropometrics

All measurements were collected in duplicate by a single evaluator, credited by ISAK (International Society for the Advancement in Anthropometry) with level 4. The technical error of measurement was acceptable because it followed the ISAK pattern, not exceeding 7.5% for skinfolds and 1.5% for all other measures. Body mass was measured on a Weight Scale, Vogel & Halke (Germany) model 761 7019009, and height with a stadiometer – Siber Hegner Machines S.A. Zurich (accuracy 1 mm). The dominant leg length (LL) was measured using a caliper to the slide – Siber Hegner Machines SA. Zurich (accuracy 1 mm). The skinfolds were measured with adipometer Slimguide (accuracy 1 mm). The skinfolds were measured: biceps, triceps, subscapular, supraspinatus, suprailiac, abdominal, medial germinal and frontal thigh. These values were used to calculate the percentage of fat and the sum of 8 skinfold and 6 skinfold (8 skinfolds except biceptal and iliac-crest). The somatotype was calculated by the method of Heath & Carter, so that volunteers receive a score for endomorphism, another for mesomorphism and another to ectomorphism, in amounts ranging from 1 to 7.

Body Composition

Data on body composition were measured by Radiologic Densitometry of Dual Energy (DXA), using a QDR-4500 model (Hologic, Watham, USA, version 8.21) device through the methods described by Moreira et al. 2012 [12].

Maturation

Bone maturation was evaluated with accuracy of year and month, through a radiological exam of the hand and left wrist using a portable Rx apparatus model Ascot 110, chassis model Kodak Min-R 2 and films Min-R also Kodak. The bone age and predicted final height were determined according to the method of Tanner-Whitehouse (TW3) [29].

Reaction Time, Movement Time and Agility coefficient (bandal chagui)

The function *First Step Quickness* of the *Kinematic Measurement System* (KMS; Optimal Kinetics, Muncie, IN, USA) was used to generate the random visual stimuli and measure times of reaction and movement (kick). It was installed on a laptop and connected to a contact platform fixed to the ground, under the dominant foot of volunteers. Each athlete was asked to perform the kick *bandal chagui* immediately after the appearance of visual stimuli on the computer screen located in front of the athlete and 0.5 m behind the target (Daedo racket) as in Figure 1. To not disturb the athletes' vision, the evaluator who held the target was positioned crouched immediately ahead of the table. The athletes were also instructed to perform the movement as quickly as possible. The reaction time (RT) was the time between the stimulus appearance and the foot withdrawal from the ground. The kick movement time (KMT) was considered as the elapsed time among the foot withdrawal from the ground and its return to the same place. Three attempts have been made and the attempt with the lowest total movement time (reaction time + movement time) was used for statistical analysis. The visual stimuli were randomly generated in any time period between 4 to 10 seconds after the function to prepare be started, showing the inscription "Get Ready!!!" on the computer screen. This function was restarted at each 30 seconds after finishing the previous test until performing three valid kicks. As the horizontal distance travelled by kicking foot has been standardized by the lower limb length (LLL), the influence of LLL on kick time is reverse, therefore, to obtain the agility coefficient of kick (AC) the time of movement was determined by the following standards: (AC =KMT/LLL).

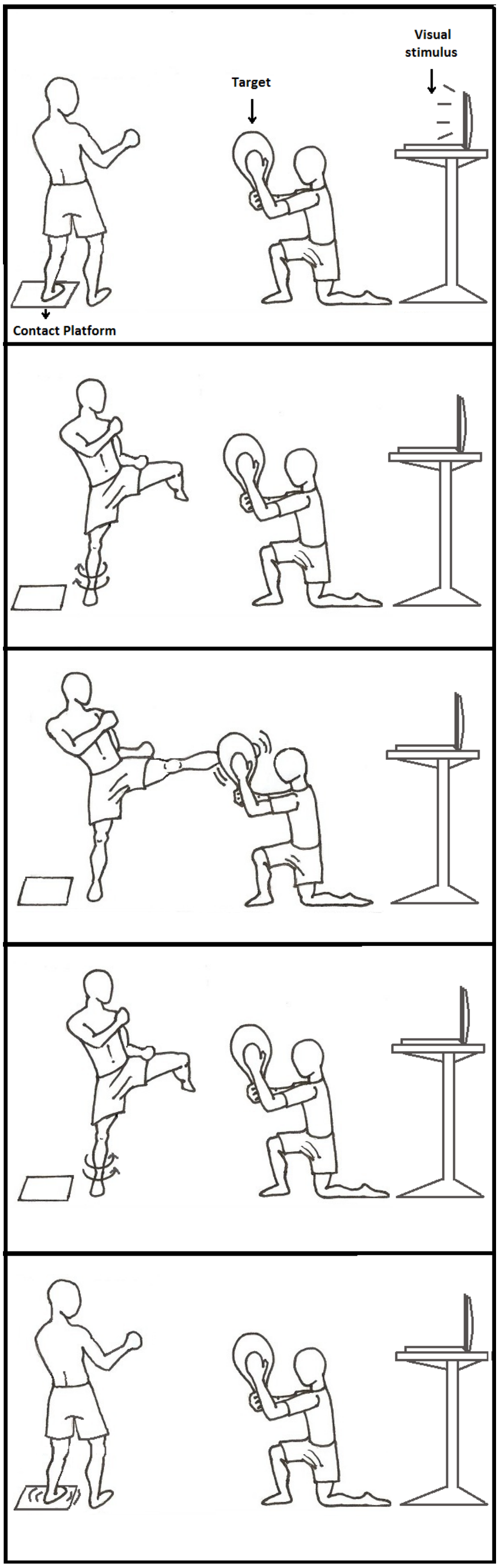

Figure 1. Assessment of *bandal chagui*

Vertical Jumps

Counter movement jump (CMJ) and squat jump (SJ) were performed to determine the height of the vertical jump and bilateral power of lower limbs. The vertical jump height, mean of absolute power (PM) and relative power (PM%; PM% = PM / Body Mass) produced during the jump were measured by the contact platform interface with the computer system by KMS®. The KMS®, that uses the total time of flight (in milliseconds) to calculate the absolute and relative powers, has been a sensitive equipment to indicate the jump performance [29]. The average power, calculated using the time of flight by contact platform, has a high coefficient of determination (r^2 = 0.82), with the power obtained by a force platform [30]. Moreover, the test-retest reliability of jump in contact platform to determine the power in bilateral vertical jumps has been previously investigated (r = 0.95) [31]. The highest jump of all attempts, body mass and height of each athlete were used to calculate the average absolute power of the SA and the SCM, through the equation of the Johnson & Bahamonde [29]:

$$PM = [41.4 \cdot \text{jump height (cm)}] + [31.2 \cdot \text{body mass (kg)}] - [13.9 \cdot \text{height (cm)}] + 431 \quad \text{(Eq. 2)}$$

In carrying out the jumps, volunteers were instructed to keep their arms on their hips to eliminate the moments caused by the upper limbs [32].

Ranking

The competitive ranking was conducted assuming the criterion of difficulty shown in Table 1 (for age category, level of competition and classification), where competitions with less difficulty were the national championships and the one with highest degree of difficulty was the world championship. The score ranking increased proportionally to the age category. It was assumed as the highest degree of difficulty ranking the 1st place in the competition, followed from getting other medals (of 2nd or 3rd place).

Statistical analysis

Statistical analyses were performed with the *Statistical Package for the Social Sciences* (SPSS) *software* ver. 17.0 (SPSS Inc., Chicago, IL, USA). To calculate the potency of the test, *effect size* and sample size was used the *G*Power software* 3.1.3 (Universitaet Kiel, Germany). After the descriptive statistics, the distributions of values of each variable were tested for normality by the *Shapiro-Wilk* test. Only the data distribution of the competitive ranking, mesomorphism and SJ did not achieve normality. To determine which

Table 1. Scoring criteria for longitudinal ranking (Longitudinal Competitive Ranking)

Category	Competition	Classification	Score
	National	Medallist (silver or bronze)	1
		Champion	2
	International not Class A	Medallist (silver or bronze)	3
		Champion	4
Cadets	International Class A	Medallist (silver or bronze)	5
		Champion	6
	European	Medallist (silver or bronze)	7
		Champion	8
	World	Medallist (silver or bronze)	9
		Champion	10
	National	Medallist (silver or bronze)	11
		Champion	12
	International not Class A	Medallist (silver or bronze)	13
		Champion	14
Junior	International Class A	Medallist (silver or bronze)	15
		Champion	16
	European	Medallist (silver or bronze)	17
		Champion	18
	World	Medallist (silver or bronze)	19
		Champion	20
	National	Medallist (silver or bronze)	21
		Champion	22
	International not Class A	Medallist (silver or bronze)	23
		Champion	24
Sub-21	International Class A	Medallist (silver or bronze)	25
		Champion	26
	European	Medallist (silver or bronze)	27
		Champion	28
	World	Medallist (silver or bronze)	29
		Champion	30
	National	Medallist (silver or bronze)	31
		Champion	32
	International not Class A	Medallist (silver or bronze)	33
		Champion	34
Senior	International Class A	Medallist (silver or bronze)	35
		Champion	36
	European	Medallist (silver or bronze)	37
		Champion	38
	World	Medallist (silver or bronze)	39
		Champion	40

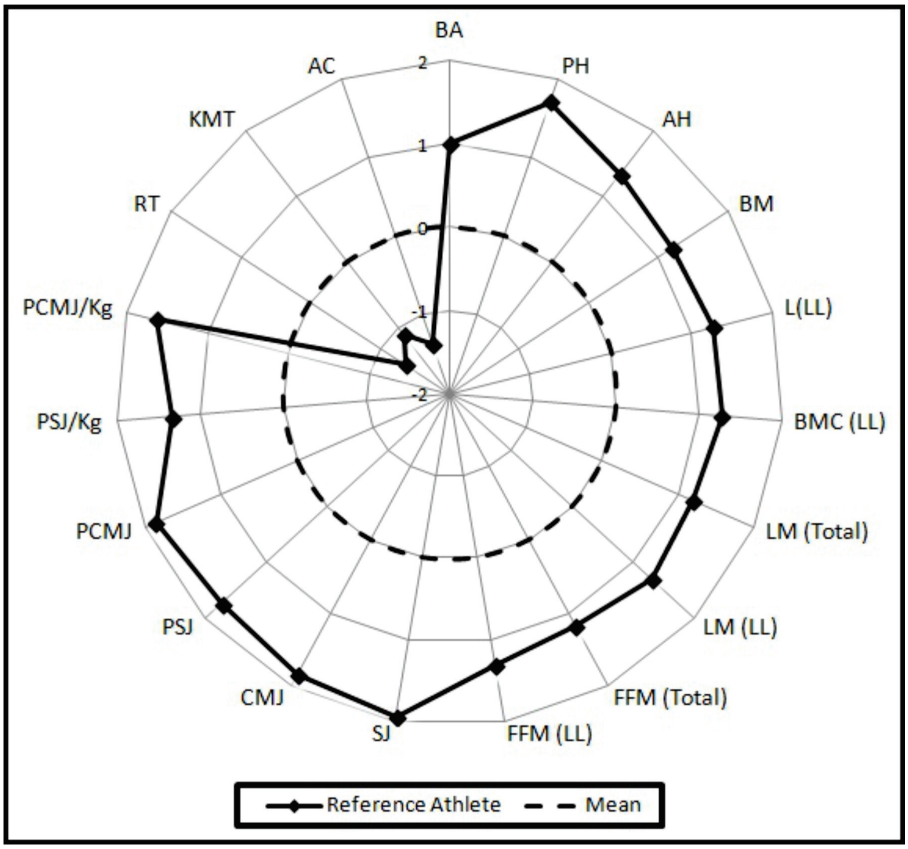

Figure 2. *z-scores* of Longitudinal Predictors of Performance in Taekwondo. **BA:** Bone Age; **PH:** Predicted Height; **AH:** Actual Height; **BM:** Body Mass; **L:** Length; **LL:** Lower Limbs; **BMC:** Bone Mineral Content; **LM:** Lean Mass; **FFM:** Fat Free Mass; **SJ:** Squat Jump Height; **CMJ:** Counter Movement Jump Height; **PSJ:** Power in Squat Jump; **PCMJ:** Power in Counter Movement Jump; **PSJ/Kg:** PSJ normalized by BM; **PCMJ/Kg:** PCMJ normalized by BM; **RT:** Reaction Time; **KMT:** Kick Movement Time; **AC:** Agility Coefficient. The data are presented in *z-scores* from the reference athlete in relationship to the mean values (dotted line) of the six athletes. Were included only the indicators where the reference athlete was different from the mean in at least 1 Standard Deviation.

variables were "Predictive of Performance", correlations of *Pearson* or *Spearman* were performed at first to evaluate the association of all selected variables, with and without normality, respectively, with those considered as "functional variables" which were "SJ", "CMJ", "PSJ", PCMJ", "PSJ/Kg", "PCMJ/Kg", "RT", "KMT" and "AC", and with competitive "ranking".

The second step was to select the "Longitudinal Predictors of Performance in Taekwondo" (LPPT), based on at least one of two criteria: 1) to have significant correlation with the Longitudinal Competitive Ranking; 2) to be different than average performance of full sample in more than 1 standard deviation (SD), in the athlete of reference.

The third and final step was to present these values in the form of "*z-scores*" (Figure 2). When necessary for the interpretation of some results, LPPT variables were correlated with other that may theoretically be physiologically associated, supported by the literature. One-tailed tests were used for testing variables, which according to the literature, may be associated in only one direction (positive or negative), whereas for those that can be associated with both positive and negative, two-tailed tests were used. Using six athletes, this study presented a statistical power of 80% to detect a correlation coefficient greater than 0.78 and 0.84, in one-tailed and two-tailed tests, respectively. For all procedures, we considered the significance of $p < 0.05$.

Results

To determine the "Longitudinal Predictors of Performance in Taekwondo" (LPPT) of six teen competitors, 19 variables associated with performance were found (Figure 2 and Table 2). The individual values of each athlete for each indicator are also reported (Table 3), and performance in competitions during 2008-2012 (Table 4). The athlete of reference (the first in Longitudinal Competitive Ranking 2008-2012, Table 3) distinguished in accordance with the criteria – nineteen indicators (Figure 2).

Biological age (Bone age) was not directly associated with the ranking, but the model athlete had higher values (> 1 *z-scores*) in this indicator. In addition, this variable is strongly correlated with other 8 LPPT, anthropometric (Length of lower limb, Current Height and Body Mass), of body composition (Total Fat Free Mass, Total Lean Body Mass and of lower limbs) and functional (PSJ, PCMJ, reaction time and agility coefficient).

Table 2. Correlation between indicators of maturation, body composition, anthropometry, and biomechanics, with the performance indicators

	Indicators	Indicators of performance Biomechanics (functional)									
		General						Specific			Ranking
		SJ	CMJ	PSJ	PCMJ	PSJ/Kg	PCMJ/Kg	RT	KMT	AC	
Maturation	CA	–0,580	–036	0,079	–0,136	–0,535	–0,658	–0,48	–0,39	–0,66	–0,401
	BA	0,314	0,35	0,765*	0,777*	0,132	0,053	–0,95**	–0,48	–0,77*	0,148
	PH	0,371	0,673	0,695	0,576	0,557	0,337	–0,729	–0,171	–0,598	0,808*
Body composition	BMD	–0,543	–0,238	0,139	0,193	–0,191	–0,155	–0,097	–0,78	–0,571	–0,443
	BMC	–0,200	0,089	0,471	0,484	0,066	0,02	–0,454	–0,912*	–0,857*	–0,109
	Total Fat Mass	–0,543	–0,298	–0,098	–0,244	–0,368	–0,593	–0,202	–0,163	–0,515	–0,061
	FAT (%)	–0,429	–0,544	–0,683	–0,788*	–0,528	–0,617	0,549	0,493	0,396	–0,251
	Total Lean Mass	0,143	0,464	0,764*	0,776*	0,387	0,321	–0,814*	–0,712	–0,859*	0,29
	Total FFM	0,143	0,450	0,756*	0,768*	0,375	0,310	–0,804*	–0,726	–0,866*	0,274
	BMC of LL	0,086	–0,339	0,675	0,64	0,275	0,152	–0,643	–0,897*	–0,980***	0,204
	Fat Mass of LL	–0,771*	–0,587	–0,547	–0,673	–0,667	–0,825*	0,118	0,256	–0,047	–0,325
	Lean Mass of LL	0,314	0,530	0,807*	0,801*	0,459	0,367	–0,855*	–0,605	–0,834*	0,424
	FFM of LL	0,314	0,525	0,807*	0,799*	0,454	0,36	–0,851*	–0,623	–0,848*	0,417
Anthropometry	LLL	0,29	0,320	0,565	0,466	0,180	-0,032	–0,840*	–0,424	–0,87*	0,385
	Body Height	0,086	0,396	0,576	0,499	0,181	0,00	–0,931**	–0,452	–0,859*	0,342
	Body Mass	0,143	0,393	0,72	0,707	0,307	0,205	–0,815*	–0,73*	–0,926**	0,261
	BMI	–0,143	0,105	0,479	0,433	0,266	0,154	–0,155	–0,621	–0,073	0,227
	FFMI	0,200	0,306	0,404	0,473	0,501	0,578	–0,061	0,063	0,087	0,37
	Ectomorphism	0,486	0,008	–0,305	–0,392	–0,042	–0,123	0,131	0,827*	0,520	0,301
	Mesomorphism	0,928**	0,986***	0,649	0,729*	0,765*	0,856*	–0,406	–0,262	–0,029	0,454
	Endomorphism	–0,377	–0,377	–0,262	–0,308	–0,131	–0,159	0,723	–0,135	0,114	–0,161
	6 SKF	–0,600	–0,725	–0,667	–0,742*	–0,628	–0,687	0,661	0,109	0,185	–0,501
	8 SKF	–0,600	–0,565	–0,526	–0,627	–0,477	–0,577	0,586	0,061	0,099	–0,314
Functional	SJ		0,943*	0,890**	0,844**	0,916**	0,808*	–0,371	–0,29	0,086	0,937**
	CMJ			0,900**	0,891**	0,947**	0,891**	–0,555	–0,318	–0,358	0,887**
	PSJ				0,985***	0,877*	0,791*	–0,677	–0,593	–0,667	0,793*
	PCMJ					0,875*	0,832*	–0,646	–0,602	–0,609	0,727
	PSJ/Kg						0,965***	–0,341	–0,297	–0,252	0,900**
	PCMJ/Kg							–0,223	–0,255	–0,095	0,777*
	RT								0,363	0,735*	–0,432
	KMT									0,815*	–0,069
	AC										–0,259

* = p < 0,05; ** = p < 0,01; e *** = p < 0,001. **Abbreviation: AC** = Agility Coeficient; **BA** (Bone Age); **BMI** = Body Mass Index; **CMJ** = Counter Movement Jump; **BMC** = Bone Mass Content; **BMD** = Bone Mass Density; **FFM** = Fat Free Mass; **FFMI** = Fat Free Max Índex; **KMT** = Kick Movement Time; **LL** = Lower Limbs; **LLL** = Length of Lower Limbs; **PH** = Predicted Height; **PSJ** = Power in SJ; **PCMJ** = Power in CMJ; **PSJ/Kg** = PSJ normalized by body mass; **PCMJ/Kg** = PCMJ normalized by body mass; **RT** = Reaction Time; **SJ** = Squat Jump; **6 SKF** = Sum of 6 skinfolds; **8 SKF** = Sum of 8 skinfolds.

Table 3. Individual values, mean and standard deviation of indicators of maturation, body composition, anthropometry and biomechanics (functional)

	Indicators	Athletes						Mean	SD
		1*	2	3	4	5	6		
Maturation	CA (years)	13,08	11,5	14,25	12,42	12,83	14,25	13,06	1,07
	BA (anos)	14,02	12,05	13,32	11,75	13,7	13,59	13,07	0,94
	Predict Height (cm)	184,2	177,5	178,7	173	173,6	176,5	177,3	4
Body composition	BMD (g cm-2)	0,918	0,797	0,856	0,963	0,961	1,08	0,929	0,098
	BMC (g)	1707	1087	1330	1480	1543	1913	1510	288
	Total Fat Mass (g)	7603	6720	8521	7209	5943	8127	7354	942
	FAT (%)	15	18,2	21,3	19,7	13,5	16	17,3	3,0
	Total Lean Mass (g)	41510	29046	30191	27855	36633	40612	34308	6055
	Total FFM (g)	43217	30133	31521	29335	38176	4225	35818	6294
	BMC of LL (g)	733	432	537	546	555	713	586	115
	Fat Mass of LL (g)	3146	3257	4391	3490	2751	3596	3438	553
	Lean Mass of LL (g)	15385	10972	10857	9318	12789	14609	12322	2359
	FFM of LL (g)	16118	11404	11394	9863	13344	15322	12907	2455
Anthropometry	LLL (cm)	90,7	81,6	87,1	79	81,7	88,7	84,8	4,7
	AH (cm)	169	149,8	163	147,4	156,2	161,7	157,9	8,3
	Body Mass (Kg)	51,5	37	40,6	36,8	44,3	51,2	43,6	6,6
	BMI (Kg m-2)	18,03	16,49	15,28	16,94	18,16	19,58	17,41	1,5
	FFMI (Kg m-2)	15,13	13,43	11,86	13,5	15,65	16,26	14,31	1,65
	Ectomorphism	4,7	6,4	6,3	4,4	4,0	3,4	4,9	1,2
	Mesomorphism	4,5	4,2	2,2	4,1	4,2	4,0	3,9	0,8
	Endomorphism	1,9	2,2	1,9	2,8	1,5	2,4	2,1	0,5
	6 SKF (cm)	44	48	53,5	56	42,4	51,5	49	5
	8 SKF (cm)	58	60,5	67	70	51,9	63,5	62	7
Functional	SJ (cm)	41,5	32,1	28,1	28,5	29,9	27,1	31,2	5,3
	CMJ (cm)	42,7	34,3	29,2	31	34,2	29,3	33,5	5,1
	PSJ (W)	1407	832	595	710	880	903	888	279
	PCMJ (W)	1406	923	641	814	1058	994	981	275
	PSJ/Kg (W Kg-1)	27,32	22,49	14,66	19,3	19,86	17,63	20,21	4,34
	PCMJ/Kg (W Kg-1)	28,28	24,95	15,79	22,11	23,88	19,41	22,40	4,38
	RT (ms)	319	450	390	508	383	392	407	65
	KMT (ms)	509	576	558	526	536	517	537	26
	AC (ms/m)	561	706	641	666	656	583	635	54

Abbreviation: AC (Agility Coeficient); **AH** (Actual Height); **BA** (Bone Age); **BMC** (Bone Mass Content); **BMD** (Bone Mass Density); **BMI** (Body Mass Index); **CA** (Chronological Age); **CMJ** (Counter Movement Jump); **FFMI** (Fat Free Max Índex); **FFM** (Fat Free Mass); **KMT** (Kick Movement Time); **LL** (Lower Limbs); **LLL** (Length of Lower Limbs); **Mat (**Maturational indicators); **PH** (Predict Final Body Height); **PSJ** (Power in SJ); **PCMJ** (Power in CMJ); **PSJ/Kg** (PSJ normalized by body mass); **PCMJ/Kg** (PCMJ normalized by body mass); **RT** (Reaction Time); **SJ** (Squat Jump); **6 SKF** (Sum of 6 skinfolds); **8 SKF** (Sum of 8 skinfolds).

Table 4. Longitudinal Competitive Ranking (2008 – 2012) of taekwondo athletes

					Competi-tion							
Athletes	**Category**	**2008**		**2009**		**2010**		**2011**		**2012**		**TRS**
		National	**International**	**National**	**Interna-tional**	**Na-tional**	**Interna-tional**	**Na-tional**	**Interna-tional**	**Na-tional**	**Interna-tional**	
1	Cadet	3rd	- -	1st	3º O.S.(A)/ 5º Eur.	- -	- -	- -	- -	- -	- -	112
	Junior	- -	- -	- -	- -	- -	- -	1st	3º O.S.(A)	2nd	2º O.S.(A)/ 3º WRD.	
	Sub-21	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	Senior	- -	- -	- -	- -	- -	- -	- -	- -	1st	- -	
2	Cadet	2nd	- -	1st	1º B.I.O./ 2º O.S.(A)	- -	- -	- -	- -	- -	- -	69
	Junior	- -	- -	- -	- -	1st	- -	1st	- -	1st	- -	
	Sub-21	- -	- -	- -	- -	- -	- -	2nd	- -	- -	- -	
	Senior	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
3	Cadet	1st	- -	- -	- -	- -	- -	- -	- -	- -	- -	2
	Junior	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	Sub-21	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	Senior	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
4	Cadet	1st	- -	- -	- -	- -	- -	- -	- -	- -	- -	2
	Junior	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	Sub-21	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	Senior	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
5	Cadet	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0
	Junior	-- -	-	- -	- -	- -	- -	- -	- -	- -	- -	
	Sub-21	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
	Senior	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
6	Cadet	- -	- -	D	D	D	D	D	D	D	D	0
	Junior	- -	- -	D	D	D	D	D	D	D	D	
	Sub-21	- -	- -	D	D	D	D	D	D	D	D	
	Senior	- -	- -	D	D	D	D	D	D	D	D	

The rows refer to age categories (Cadet = Sub 14 years; Junior = Sub 18 years; Sub-21 = Sub 21 years; and Senior = above 18 years or above 16 years with authorization of coach and parents) of competitions participated by each athlete (1; 2; 3; 4; 5; or 6) and the columns refer to the competition level (National or International) for each year (2008-2012). The last column (TRS) refers to the total cumulative score, or *Competitive Ranking*, for each athlete over the five years analysed, according to criteria of table 1. **"- -":** Without participation or expressive results. **National:** Portuguese Championship; **(A):** Competition Classified as "Class A" by *World Taekwondo Federation*; **1st:** Champion; **2nd:** 2nd place; **3rd:** 3rd placed. **B.I.O.:** British International Open; **D:** Drop-out of taekwondo **EUR:** European Championship; **O.S.:** Open of Spain **TRS:** Total Ranking Score **WRD:** World Championship.

In addition to the associations shown in Table 2, the bone age was significantly correlated with other non-functional LPPT, which included the lean mass (0.859, ± 0,.014), the fat free mass (0.855 ± 0.015), the fat free mass of the lower limbs (0.845 ± 0.017), the lean mass in the lower limbs (0.845 ± 0.017), the length of the lower limbs (0.784 ± 0.033), the body height (0.896 ± 0.008) and body mass (0.863 ± 0.013). The body height also correlated significantly with non-functional LPPT, which were the predict body height (0.777 ± 0.035), bone mineral content in the lower limbs (0.752 ± 0.042), the length of the lower limbs (0.954 ± 0.002), the fat free mass, total (0.752 ± 0.042) and of the lower limbs (0.792 ± 0.003), total lean mass (0.756 ± 0.041), and lean mass of lower limb (0.788 ± 0.031). The bone mineral content of the lower limbs, correlated significantly with the length of the lower limbs (0.77 ± 0.037), total lean mass (0.877 ± 0.011), lean mass of lower limbs (0.829 ± 0.021), the total fat free mass (0.886 ± 0.009), fat free mass of lower limbs (0.844 ± 0.017) and total body mass (0.928 ± 0.004). The total body mass, also strongly correlated with total fat free mass (r = 0.986, $p < 0.001$), without association with the fat mass (r = 0.273, $p = 0.3$).

Discussion

There are other studies that associate maturational advance with sports performance [19, 20], because this has usually been associated with a higher predicted final height [32] and young athletes with early maturation tends to have better performance earlier than others. This can strengthen the social and psychological incentives for dedication to the sport and also, allow greater experiences in high level sport athletes than who did not had early maturation [33]. However, this does not mean that late maturing athletes are not capable of achieving similar performance levels. In practical terms, it is important that the coach has this assessment in hand, to inform the athlete and family that he will tend to achieve their best performance levels later than the others. This fact, coupled with a lack of association of chronological age with any variable analysed, opens a discussion in the sense that the age categories of sports should be separated by maturity rather than chronological age [20].

The predicted final height was a variable strongly correlated with the ranking. This result is consistent with studies showing a trend of stature to influence the results of competitive Taekwondo adult athletes [1, 6], since the higher stature offers two advantages, one direct and another indirect. The direct is that in taller athletes, the targets (chest and especially the face) are also higher, making it more difficult to be reached by the opponent, which would require great flexibility and distance to be travelled by the feet of the attacker.

This would allow a longer time to react (defence, dodge or counterattack). The indirect advantage is that typically taller athletes have longer lengths of lower limbs (LLL), which enables a greater linear range of attack. Thus, the taller athlete can fight in a bigger distance to hit the opponent without great effort or active flexibility needs, while the opponent with lowest LLL must use movements of high need for flexibility or use displacement to approximation. LLL was also included in this model of talent detection, because the model athlete had values higher than 1 *z-scores* (+1.26) and LLL was also strongly correlated, negatively, with another LPPT, the Agility coefficient (AC). The inverse relationship among LLL and AC presented in this study indicates that athletes with greater LLL performed larger horizontal distances by the foot, in relatively lesser times.

The actual body height was also included in the model of talent detection, although it was not directly correlated with the ranking, the athlete 1 had the actual height with 1.45 *z-scores*. Moreover, this variable showed strong correlations with other functional LPPT (reaction time and agility coefficient). It was significantly correlated with bone age, final body height, with the bone mineral content of the lower limbs, and consequently, with the length of lower limbs, and also, with the fat free mass (total and lower limbs) and with the lean mass (total and lower limbs).

A strong negative correlation among the actual body height and reaction time may be related to two factors: a) the relationship among stature and maturity, because physiologically more matured athletes also have greater maturation of the central nervous system and, consequently, greater myelination of neurons [34]. b) The relationship among the stature and lean mass (LM) of the lower limbs (LL), because a greater amount of LM of LL, and consequently, muscle tissue, can result in higher rate of force production [35], resulting in increased speed of withdrawal of the foot on the contact platform.

In fact, both Lean Mass, and Fat Free Mass (Total and Lower Limb), showed high negative correlations with two specific variables of performance that were the reaction time and the agility coefficient. While lean mass was slightly stronger correlated with the reaction time than the fat free mass, the opposite happened with the agility coefficient. This can be explained by the fact that the fat free mass include bone mineral content, and the bone mineral content of the lower limbs are directly related to the length of the lower limbs. Moreover, both, lean mass, and fat free mass, were higher in more than 1 *z-scores* in the reference athlete. They were strongly correlated with the absolute power of the vertical jumps. Lean mass correlated perfectly with fat free mass. This means that the influence of variability of fat free mass in the variability of the power of vertical jump is entirely explained by the variability of lean mass. The same happened to correlate the fat free mass of the LL and lean mass of LL. The total body mass showed significant correlations with the specific parameters of the kick, that is almost entirely explained by the variability of fat free mass because the total mass correlates strongly with this variable, and it had no significant correlation with fat mass. The athlete 1 had higher values in this variable at 1.2 *z-scores*.

The bone mineral content (BMC) of the lower limbs was also included in the set of parameters for performance prediction, because the reference athlete presented values of BMC above 1 *z-scores* (1.28). Moreover, the BMC of lower limbs is strongly correlated with two specific functional variables (kick time and agility coefficient). This can be explained by the correlations among the BMC of lower limbs and body mass, fat free mass, lean mass and length of the lower limb. Because body mass, fat free mass, lean mass and LLL are inversed correlated with functional variables of the kick.

Except for the absolute power of the countermovement jump (PCMJ), all the jump variables were strongly correlated with the ranking (r = 0.777 to 0.937). These results were expected; however, studies on adults have demonstrated greater importance of the countermovement jump performance (CMJ) than squat jump (SJ) for the competitive ranking [31], meaning that the contraction of stretch-shortening-cycle (SSC) is more important to differentiate athletes of different levels than the neuromuscular recruitment only concentric. But in the current study, although the variables of CMJ have been associated with the competitive ranking, those from the SJ showed stronger correlations, meaning that the capacities for concentric power production in our adolescent athletes are more related to longitudinal performance than those of SSC. In all variables of vertical jumps, the athlete 1 also had values greater than 1 *z-scores* (1.34-1.93). This confirms the importance of these indicators in prediction of performance in taekwondo.

The reaction time (RT), kick time (KT) and, hence, the agility coefficient are associated with the efficiency of the main stroke of taekwondo, the kick; therefore, being considered essential variables for a good performance in this modality. The study of Hermann et al. [4] showed that the reaction time has the same significance for the efficiency of the attack as the kick movement time, and the study of Vieten et al. [36] demonstrated that elite athletes have shorter times than sub-elite athletes. In accordance with these findings, in the current study, the reference athlete obtained scores below 1 *z-scores* (1.36, 1.09, and 1.37) in these three indicators, respectively.

Conclusion

Our results allowed us to identify several factors (maturational, body composition, anthropometrics and functional) that are related to longitudinal competitive success in taekwondo young athletes. These factors should be considered by coaches to the proper selection of training programs, as well as for the pre-selection of young talents in competitive taekwondo. However, these results apply only to the Portuguese taekwondo adolescent athletes, being of limited generalizability.

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Competing interests

The authors declare they have no competing interests.

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