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Comparison between jumping *vs.* cycling tests of short-term power in elite male handball players: the effect of age

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Abstract. **Purpose:** The aim of the present study was to examine the effect of age on the relationship between jumping and cycling tests of short-term power in team handball (TH) players. **Methods:** A cross-sectional study was conducted, in which adolescent and adult TH players ($n = 96$, age 19.6 ± 6.9 yrs, body mass 75.8 ± 14.1 kg, height 1.78 ± 0.10, mean ± standard deviation) performed four jumping tests (*i.e.*, squat jump, countermovement jump, Abalakov jump and a 30-s Bosco test), and two tests on cycle ergometer (*i.e.* force-velocity (F-v) test and Wingate anaerobic test (WAnT)). Heart rate (HR) was monitored during Bosco test and WAnT. Participants were classified into four age groups (12.1–15.0 yrs, U15; 15.1–18.0 yrs, U18; 18.1–25.0 yrs, U25; and 25.1–35.0 yrs, O25). **Results:** Differences of moderate to large magnitude among groups were observed with regards to all variables of the F-v test, WAnT and jumping tests, in which the older groups had higher scores in all variables than their younger counterparts ($p < 0.05$). Correlation between mean power in WAnT (8.0 ± 1.0 W.kg^{-1}) and Bosco test (29.3 ± 7.1 W.kg^{-1}) was $r = 0.70$ ($p < 0.001$) in the total sample (ranging from $r = 0.43$, $p = 0.075$ in O25 to $r = 0.72$ in U15, $p < 0.001$). Correlation between HR in WAnT (179 ± 12 bpm) and Bosco test (162 ± 14 bpm) was $r = 0.75$ ($p < 0.001$) in the total sample (ranging from $r = 0.65$, $p < 0.001$ in U18 to $r = 0.81$ in O25, $p < 0.001$). **Conclusions:** These findings might help TH coaches and fitness trainers to monitor short-term power of their athletes and to use properly cycling and jumping tests.

Key words: Growth, development, sport, physical fitness, age groups

Résumé. **Comparaison entre des tests de détente verticale et de puissance en cyclisme chez des handballeurs de haut niveau.**

Objectif : Le but de la présente étude était d'examiner la relation entre des tests de détente verticale et de puissance en cyclisme chez des handballeurs de haut niveau. **Méthodes :** Une étude transversale a été réalisée chez des handballeurs, adolescents et adultes ($n = 96$, âge $19{,}6 \pm 6{,}9$ ans, masse corporelle $75{,}8 \pm 14{,}1$ kg, taille $1{,}78 \pm 0{,}10$ m). Les sujets ont réalisé quatre tests de détente verticale (détente verticale sans contre-mouvement, SJ ; une détente verticale avec contre-mouvement, CMJ, détente verticale Abalakov (AJ) et test de Bosco de 30 s) et deux tests sur des cycloergomètres (force-vitesse (F-v) test et Wingate (WAnT)). La fréquence cardiaque (FC) a été enregistrée pendant toute la durée du test Bosco et du WAnT. Les participants ont été répartis en quatre groupes d'âge (12,1–15,0 ans, U15 ; 15,1–18,0 ans, U18 ; 18,1–25,0 ans, U25 ; and 25,1–35,0 ans, O25). **Résultats :** Des différences entre les groupes, de modérées à larges, ont été observées en fonction des variables des tests F-v, WAnT et de détente verticale. Les groupes les plus âgés ont obtenu des meilleurs résultats dans tous les tests ($p < 0{,}05$). La corrélation entre la puissance moyenne du WAnT ($8{,}0 \pm 1{,}0$ W.kg^{-1}) et du test Bosco ($29{,}3 \pm 7{,}1$ W.kg^{-1}) était $r = 0{,}70$ ($p < 0{,}001$) pour tous les joueurs (variant de $r = 0{,}43$, $p = 0{,}075$ pour O25 à $r = 0{,}72$ pour U15, $p < 0{,}001$). La corrélation entre la FC du WAnT (179 ± 12 bpm) et du Bosco test (162 ± 14 bpm) était

$r = 0{,}75$ ($p < 0{,}001$) pour tous les joueurs (variant de $r = 0{,}65$, $p < 0{,}001$ pour U18 à $r = 0{,}81$ pour O25, $p < 0{,}001$). **Conclusions :** Ces résultats pourraient aider les entraîneurs à analyser la puissance explosive de leurs joueurs et à utiliser convenablement les tests de puissance en cyclisme et de détente verticale.

Mots clés : Développement, sport d'équipe, puissance maximale, groupes d'âge

Abbreviations: SJ = squat jump; CMJ = countermovement jump; AJ = Abalakov jump; WAnT = Wingate anaerobic test; F-v = force-velocity; P_{peak} = peak power; P_{mean} = mean power; FI = fatigue index; P_{max} = maximal power; F_0 = theoretical maximal force; V_0 = theoretical maximal velocity.

1 Introduction

Team handball (TH) is a team sport characterized by high intensity and short duration actions (*e.g.* shoot, jump, pass, sprint) interspersed by actions of low to moderate intensity (*e.g.* walk, jog, stand) (Abade, Abrantes, Ibáñez, & Sampaio, 2014). It is played dynamically and rapidly, both in attack and defense (Bilge, 2012). Elite TH players are characterized by increased height and body mass (Ghobadi, Rajabi, Farzad, Bayati, & Jeffreys, 2013) and these anthropometric characteristics are related with increased physiological characteristics (Moncef, Said, Olfa, & Dagbaji, 2012; Srhoj, Rogulj, Papić, Foretić, & Čavala, 2012). Because of the importance of high intensity actions for performance, monitoring of short-term muscle power is a main concern in TH training. To assess short-term muscle power in a laboratory setting, jumping and cycling tests are commonly used (Praagh, 2007). Jumping tests include single jumps such as squat (SJ), countermovement (CMJ) and Abalakov jump (AJ), and continuous jumps such as 30 s Bosco test (Álvarez-Herms, Julià-Sánchez, Corbi, Pagès, & Viscor, 2014). Cycling tests include all-out sprints on a cycle ergometer such as 30 s Wingate anaerobic test (WAnT) and force-velocity (F-v) test (Driss & Vandewalle, 2013). A major question that rises is whether these tests can be used interchangeably to monitor performance. A secondary question is whether the relationship between these tests varies depending on the age of TH players.

Very few studies have been conducted about the relationship between cycling and jumping tests (Çakir-Atabek, 2014; Dal Pupo *et al.*, 2014; Driss, Vandewalle, & Monod, 1998; Hoffman, Epstein, Einbinder, & Weinstein, 2000). For instance, the relationship between mean power (P_{mean}) in the WAnT and the Bosco test was examined in male volleyball players ($n = 21$) (Dal Pupo *et al.*, 2014), where a large positive correlation was observed. The correlation of peak power (P_{peak}) and P_{mean} of the WAnT with SJ and CMJ were studied in female and male track-and-field athletes ~16 yrs ($n = 24$) (Çakir-Atabek, 2014), which found large to very large correlations. The relationship of F-v test with AJ was examined in male volleyball players ($n = 18$) (Driss *et al.*, 1998), where large correlations were observed between AJ, maximal power (P_{max}) and maximal force (F_0). The relationship of F-v test with vertical jump was confirmed also in the case of CMJ in volleyball players and physical education students (Rouis *et al.*, 2015). In addition, the relationship of P_{peak} and P_{mean} (Kendall tau rank) with CMJ and power during 15 s continuous jumping were examined in basketball players 17 yrs ($n = 9$) (Hoffman *et al.*, 2000), and these parameters were found to correlate largely. The sample size which was used in these studies was relatively low for correlation studies, because, according to the table of critical values for Pearson's r, a sample size of at least 29 was needed in order a correlation $r = 0.30$ to be significant at $p = 0.05$ (Cohen, 1988).

The abovementioned studies have enhanced our understanding of the relationship among cycling and jumping tests; however, none of them has addressed the effect of age on this relationship. Short-term muscle power, like the other components of sport-related physical fitness (*e.g.* speed, aerobic capacity), is influenced by growth and biological maturation (Van Praagh & Doré, 2002). Although the importance of maturation, chronological age is widely used in sport practice (*e.g.* it is taken into account in order to classify adolescents into age groups for official events) instead of biological age. The effect of chronological age on short-term muscle power has been well-established (Van Praagh & Doré, 2002), with older adolescents showing better performance than their younger counterparts. However, whether the relationship among short-term muscle power tests was influenced by age was not clear. Moreover, most of previous research on age-related differences has focused more on comparisons among adolescent groups or between adolescent and adult groups, and less on comparisons among adult groups (Nikolaidis, Ingebrigtsen, Povoas, Moss, & Torres-Luque, 2015). The knowledge about the relationship among cycling and jumping tests would contribute to an optimal monitoring of short-term muscle power, which would be of great practical value for TH coaches and fitness trainers. Therefore, the aim of the present study was to examine the effect of age on the relationship among cycling and jumping tests of short-term muscle power

2 Methods

2.1 Study design and participants

Male handball players ($n = 96$), classified into four age groups (under 15 yrs, U15; under 18 yrs, U18, under 25 yrs, U25; over 25 yrs, O25), who were recruited from

Table 1. Playing experience and training volume of participants according to age group.

	Total ($n = 96$)	U15 ($n = 32$)	U18 ($n = 26$)	U25 ($n = 17$)	O25 ($n = 21$)	ANOVA
Experience (yrs)	8.2 ± 6.6	$3.0 \pm 1.3^{\dagger\ddagger\S}$	$5.3 \pm 1.6^{*\ddagger\S}$	$9.4 \pm 2.8^{*\ddagger\S}$	$18.8 \pm 4.5^{*\dagger\ddagger}$	$F_{(3,92)} = 165.6$, $p < 0.001$, $\eta^2 = 0.84$
Weekly TU	4.4 ± 1.0	$3.7 \pm 0.7^{\dagger\ddagger\S}$	$4.4 \pm 0.9^{*\S}$	$4.9 \pm 0.9^{*}$	$5.2 \pm 0.8^{*\dagger}$	$F_{(3,92)} = 16.1$, $p < 0.001$, $\eta^2 = 0.34$
TU duration (min)	93 ± 14	$83 \pm 13^{\dagger\ddagger\S}$	$93 \pm 10^{*}$	$100 \pm 14^{*}$	$100 \pm 14^{*}$	$F_{(3,92)} = 10.2$, $p < 0.001$, $\eta^2 = 0.25$
Weekly volume (min)	416 ± 135	$314 \pm 91^{\dagger\ddagger\S}$	$411 \pm 107^{*\S}$	$491 \pm 126^{*}$	$518 \pm 116^{*\dagger}$	$F_{(3,92)} = 18.7$, $p < 0.001$, $\eta^2 = 0.38$

TU = training units. The symbols *, †, ‡ and § denoted difference from U15, U18, U25 and O25 group, respectively.

Table 2. Anthropometric characteristics of participants according to age group.

	Total ($n = 96$)	U15 ($n = 32$)	U18 ($n = 26$)	U25 ($n = 17$)	O25 ($n = 21$)	ANOVA
Age (yrs)	19.6 ± 6.9	$13.8 \pm 0.7^{\dagger\ddagger\S}$	$16.3 \pm 0.7^{*\ddagger\S}$	$21.6 \pm 1.8^{*\dagger\S}$	$31.1 \pm 3.6^{*\dagger\ddagger}$	$F_{(3,92)} = 376.3$, $p < 0.001$, $\eta^2 = 0.93$
Body mass (kg)	75.8 ± 14.1	$64.7 \pm 12.3^{\dagger\ddagger\S}$	$72.2 \pm 9.1^{*\ddagger\S}$	$87.4 \pm 8.1^{*\dagger}$	$87.7 \pm 8.7^{*\dagger}$	$F_{(3,92)} = 31.3$, $p < 0.001$, $\eta^2 = 0.51$
Height (m)	1.78 ± 0.10	$1.70 \pm 0.08^{\dagger\ddagger\S}$	$1.77 \pm 0.08^{*\ddagger\S}$	$1.85 \pm 0.07^{*\dagger}$	$1.84 \pm 0.07^{*\dagger}$	$F_{(3,92)} = 24.5$, $p < 0.001$, $\eta^2 = 0.44$

The symbols *, †, ‡ and § denoted difference from U15, U18, U25 and O25 group, respectively.

teams competing at the top national category of Greece, participated in the study. Their training experience and anthropometric characteristics are shown in Tables 1 and 2. Testing procedures were performed during the competitive period of the season 2011–2012. The study protocol was performed in accordance with the Declaration of Helsinki and approved by the local Institutional Review Board. All players volunteered for the study, and oral and written informed consent was received from all participants or their guardians, in the case of underage players (age < 18 yrs), after verbal explanation of the experimental design and potential risks of study. Exclusion criteria included history of any chronic medical conditions and use of any medication. All participants visited our laboratory once and underwent a series of anthropometric and physiological measures. This study was part of a research project aiming to profile the anthropometric and physiological characteristics of TH players; parts of this project were already published on the relationship between body mass index and physical fitness (Nikolaidis & Ingebrigtsen, 2013b), differences among teams with different ranking (Nikolaidis & Ingebrigtsen, 2013a) and differences among playing positions (Nikolaidis *et al.*, 2015).

2.2 Equipment and protocols

First, the participants were examined for height and body mass. An electronic weight scale (HD-351 Tanita, Illinois, USA) was employed for body mass measurement (in the nearest 0.1 kg) and a portable stadiometer (SECA, Leicester, UK) for height (0.001 m). After a 20 min standardized warm-up protocol including 9 min cycling eliciting heart rate of 120–170 bpm and stretching exercises, all participants performed the following physical fitness tests in the respective order:

(a) Single jumping tests. The participants performed two trials for each jumping exercise (SJ, CMJ and AJ) and the best one was recorded (Aragon-Vargas, 2000). Approximately 1 min of rest was given among trials. Height of each jump was estimated using the Opto-jump system (Microgate Engineering, Bolzano, Italy) and was expressed as cm.

(b) Modified 30-s Bosco test. This test was contacted on the equipment as the single jumps did. The participants were instructed to jump as high as possible, while trying to stay on the ground as little as possible (Sands *et al.*, 2004). The mean power during the 30-s test was recorded in $W.kg^{-1}$.

(c) Force-velocity test (F-v). The F-v test was employed to assess maximal anaerobic power (P_{max} expressed as $W.kg^{-1}$). This test employed various braking forces that elicit different pedaling velocities in order to derive P_{max} (Vandewalle, Peres, Heller, & Monod, 1985). The participants performed four sprints, each one lasting 7 s, against incremental braking force (2, 3, 4 and 5 kg) on a cycle ergometer (Ergomedics 874, Monark, Sweden), interspersed by 5-min recovery periods.

(d) Wingate anaerobic test (WAnT). The WAnT (Bar-Or & Skinner, 1996) was performed in the same ergometer as the F-v did. Briefly, participants were asked to pedal as fast as possible for 30 s against a braking force that was determined by the product of body mass in kg by 0.075 (Bar-Or & Skinner, 1996). Peak and mean power were calculated as the highest power over a 5 s period and the average power during the 30 s period, respectively, and were expressed as W and $W.kg^{-1}$. Fatigue index was calculated as percentage of power decrease over the 30 s period. There was a 5 min rest among single jump tests, Bosco test, F-v test and WAnT. Heart rate (HR) was monitored continuously during Bosco test and WAnT, and the peak value was recorded. HR was expressed in absolute values as beats per minute (bpm) and in relative values as percentage of maximal HR (HR_{max}). HR_{max} was assessed indirectly from Fox age-based prediction equation $HR_{max} = 220 - \text{age}$.

Table 3. Short-term muscle power of participants according to age group.

	Total ($n = 96$)	U15 ($n = 32$)	U18 ($n = 26$)	U25 ($n = 17$)	O25 ($n = 21$)	ANOVA
Force-velocity test						
P_{max} (W)	993 ± 282	$797 \pm 250^{‡§}$	$907 \pm 185^{‡§}$	$1251 \pm 256^{*†}$	$1185 \pm 134^{*†}$	$F_{(3,92)} = 22.9$, $p < 0.001$, $\eta^2 = 0.44$
P_{max} (W.kg^{-1})	13.0 ± 2.5	$12.2 \pm 2.6^{‡}$	12.6 ± 2.6	$14.2 \pm 2.1^{*}$	13.6 ± 1.9	$F_{(3,92)} = 3.2$, $p = 0.029$, $\eta^2 = 0.10$
F_0 (N)	190 ± 53	$168 \pm 57^{‡§}$	$173 \pm 39^{‡§}$	$226 \pm 54^{*†}$	$217 \pm 35^{*†}$	$F_{(3,92)} = 8.5$, $p < 0.001$, $\eta^2 = 0.23$
V_0 (rpm)	209 ± 25	$192 \pm 21^{†‡§}$	$212 \pm 28^{*}$	$223 \pm 15^{*}$	$220 \pm 18^{*}$	$F_{(3,92)} = 10.3$, $p < 0.001$, $\eta^2 = 0.26$
WAnT						
P_{peak} (W)	793 ± 197	$628 \pm 155^{†‡§}$	$742 \pm 109^{*‡§}$	$994 \pm 126^{*†}$	$948 \pm 106^{*†}$	$F_{(3,92)} = 42.3$, $p < 0.001$, $\eta^2 = 0.59$
P_{peak} (W.kg^{-1})	10.4 ± 1.2	$9.7 \pm 1.2^{‡§}$	$10.3 \pm 1.3^{‡}$	$11.4 \pm 0.8^{*†}$	$10.9 \pm 0.6^{*}$	$F_{(3,92)} = 11.5$, $p < 0.001$, $\eta^2 = 0.28$
P_{mean} (W)	610 ± 149	$467 \pm 116^{†‡§}$	$592 \pm 84^{*‡§}$	$738 \pm 80^{*†}$	$734 \pm 77^{*†}$	$F_{(3,92)} = 45.9$, $p < 0.001$, $\eta^2 = 0.62$
P_{mean} (W.kg^{-1})	8.0 ± 1.0	$7.2 \pm 1.2^{†‡§}$	$8.2 \pm 0.7^{*}$	$8.5 \pm 0.5^{*}$	$8.4 \pm 0.4^{*}$	$F_{(3,92)} = 12.9$, $p < 0.001$, $\eta^2 = 0.31$
FI (%)	43.4 ± 8.3	44.5 ± 10.6	$40.7 \pm 6.6^{‡}$	$47.8 \pm 6.4^{†}$	41.2 ± 6.0	$F_{(3,92)} = 3.2$, $p = 0.029$, $\eta^2 = 0.10$
Jumping tests						
SJ (cm)	30.1 ± 6.1	$26.4 \pm 5.2^{‡§}$	$29.4 \pm 5.6^{§}$	$33.7 \pm 6.0^{*}$	$34.1 \pm 3.8^{*†}$	$F_{(3,92)} = 11.9$, $p < 0.001$, $\eta^2 = 0.29$
CMJ (cm)	31.4 ± 6.5	$27.7 \pm 5.4^{‡§}$	$30.2 \pm 5.8^{‡§}$	$35.7 \pm 6.7^{*†}$	$36.0 \pm 4.0^{*†}$	$F_{(3,92)} = 12.8$, $p < 0.001$, $\eta^2 = 0.30$
AJ (cm)	38.1 ± 7.7	$32.8 \pm 6.8^{†‡§}$	$37.4 \pm 6.4^{*‡§}$	$43.3 \pm 7.2^{*†}$	$43.8 \pm 3.9^{*†}$	$F_{(3,92)} = 16.5$, $p < 0.001$, $\eta^2 = 0.36$
Bosco (W.kg^{-1})	29.3 ± 7.1	$23.6 \pm 5.1^{†‡§}$	$29.7 \pm 5.2^{*§}$	$34.0 \pm 7.7^{*}$	$34.6 \pm 4.1^{*†}$	$F_{(3,92)} = 21.2$, $p < 0.001$, $\eta^2 = 0.42$

P_{max} = maximal power output estimated by the Force-velocity test, P_{mean} = mean power during the Wingate anaerobic test (WAnT), SJ = squat jump, CMJ = countermovement jump, Abalakov = jump. The symbols *, †, ‡ and § denoted difference from U15, U18, U25 and O25 group, respectively.

Table 4. Heart rate responses to Wingate anaerobic test and Bosco test of participants according to age group.

		Total	U15 ($n = 32$)	U18 ($n = 26$)	U25 ($n = 17$)	O25 ($n = 21$)	ANOVA
WAnT	bpm	179 ± 12	$186 \pm 10^{†§}$	$177 \pm 11^{*}$	177 ± 12	$169 \pm 11^{*}$	$F_{(3,92)} = 9.8$, $p < 0.001$, $\eta^2 = 0.26$
	%	89 ± 6	90 ± 5	87 ± 5	89 ± 6	90 ± 6	$F_{(3,92)} = 2.1$, $p = 0.107$, $\eta^2 = 0.07$
Bosco	bpm	162 ± 14	$169 \pm 13^{†§}$	$156 \pm 13^{*}$	163 ± 14	$155 \pm 13^{*}$	$F_{(3,92)} = 5.8$, $p < 0.001$, $\eta^2 = 0.17$
	%	81 ± 7	$82 \pm 7^{†}$	$77 \pm 6^{*}$	82 ± 7	82 ± 7	$F_{(3,92)} = 3.7$, $p = 0.014$, $\eta^2 = 0.12$

The symbols *, †, ‡ and § denoted difference from U15, U18, U25 and O25 group, respectively.

2.3 Statistical and data analysis

Statistical analyses were performed using IBM SPSS v.20.0 (SPSS, Chicago, USA). Data were expressed as mean and standard deviations of the mean (*SD*). The Kolmogorov-Smirnov test was used to assess normality for all variables. One-way analysis of variance (ANOVA), with a sub-sequent Tukey post-hoc test if difference between the groups was revealed, was used to examine differences in anthropometric characteristics and anaerobic power among age groups. To interpret the effect size for statistical differences in the ANOVA we used eta square classified as small ($0.01 < \eta^2 \leq 0.06$), moderate ($0.06 < \eta^2 \leq 0.14$) and large ($\eta^2 > 0.14$) (Cohen, 1988). Pearson correlation coefficient r was used to examine the relationships among jumping and cycling tests. To interpret the magnitude of correlations the following criteria were adopted: $r \leq 0.1$, trivial; $0.1 < r \leq 0.3$, small; $0.3 < r \leq 0.5$, moderate; $0.5 < r \leq 0.7$, large; $0.7 < r \leq 0.9$, very large; and $r > 0.9$, almost perfect (Hopkins, Marshall, Batterham, & Hanin, 2009). The level of significance was set at $\alpha = 0.05$.

3 Results

Training characteristics of participants can be seen in Table 1. Differences among age groups were observed with regards to years of training experience, number of weekly training units, duration of each training unit and total training volume. These differences had large magnitude. For all training characteristics, higher values were recorded in the older groups.

Anthropometric characteristics of participants can be found in Table 2. Differences among age groups were shown for all variables. The older age groups were heavier and taller than the younger groups. These differences had large magnitude.

Short-term muscle power of participants can be seen in Table 3. Differences among groups were observed with regards to all variables of the F-v test, WAnT and jumping tests. These differences had large magnitude, except P_{max} (W.kg^{-1}) of the F-v test, and FI of the WAnT (moderate magnitude). The older groups had higher scores in all variables than their younger counterparts. HR responses to the WAnT and Bosco test can be found in Table 4. Differences among groups were observed for

Table 5. Correlations among cycling and jumping tests of short-term muscle power in participants.

	SJ				CMJ				AJ				Bosco test			
	U15	U18	U25	O25	U15	U18	U25	O25	U15	U18	U25	O25	U15	U18	U25	O25
Force-velocity test																
P_{max} (W)		0.52‡ (0.30†)				0.55‡ (0.34†)				0.51‡ (0.26*)				0.42‡ (0.18)		
	0.29	0.43*	0.06	0.58*	0.34	0.43*	0.11	0.44	0.19	0.54†	–0.10	0.44	0.04	0.28	–0.28	0.51*
P_{max} (W.kg^{-1})		0.56‡ (0.45‡)				0.54‡ (0.45‡)				0.50‡ (0.38‡)				0.36† (0.26*)		
	0.64‡	0.51†	0.19	0.56*	0.61‡	0.49*	0.24	0.53*	0.50†	0.58†	0.06	0.36	0.42*	0.37	–0.19	0.35
F_0 (N)		0.32† (0.12)				0.34† (0.15)				0.27* (0.04)				0.18 (–0.04)		
	0.24	0.07	–0.05	0.28	0.26	0.03	0.01	0.25	0.09	0.14	–0.23	0.18	–0.02	0.01	–0.40	0.11
V_0 (rpm)		0.53‡ (0.40‡)				0.53‡ (0.40‡)				0.62‡ (0.53‡)				0.59‡ (0.54‡)		
	0.13	0.58†	0.32	0.35	0.20	0.61†	0.28	0.22	0.36	0.60†	0.46	0.38	0.26	0.41*	0.52*	0.60*
WAnT																
P_{peak} (W)		0.51‡ (0.25*)				0.55‡ (0.30†)				0.55‡ (0.28*)				0.51‡ (0.24*)		
	0.11	0.42*	0.26	–0.01	0.19	0.45*	0.30	–0.05	0.07	0.53†	0.16	0.03	–0.12	0.35	0.03	0.14
P_{peak} (W.kg^{-1})		0.67‡ (0.55‡)				0.67‡ (0.57‡)				0.69‡ (0.58‡)				0.59‡ (0.45‡)		
	0.51†	0.68‡	0.64†	0.14	0.53†	0.63†	0.64†	0.23	0.52†	0.74‡	0.62†	–0.06	0.36*	0.56†	0.40	0.20
P_{mean} (W)		0.60‡ (0.39‡)				0.62‡ (0.40‡)				0.65‡ (0.44‡)				0.61‡ (0.41‡)		
	0.36	0.39	0.17	0.13	0.43*	0.46*	0.20	0.04	0.39*	0.45*	0.10	0.19	0.23	0.23	0.02	0.24
P_{mean} (W.kg^{-1})		0.74‡ (0.68‡)				0.71‡ (0.65‡)				0.79‡ (0.75‡)				0.70‡ (0.63‡)		
	0.71‡	0.81‡	0.52*	0.56*	0.68‡	0.83‡	0.49*	0.53*	0.79‡	0.88‡	0.58*	0.37	0.72‡	0.51*	0.45	0.43
FI (%)		–0.22* (–0.23*)				–0.16 (–0.16)				–0.22* (–0.24*)				–0.21 (–0.23*)		
	–0.62‡	–0.30	0.48	–0.29	–0.56†	–0.32	0.54*	–0.25	–0.62‡	–0.23	0.45	–0.40	–0.69‡	–0.21	0.29	–0.15

P_{max} = maximal power output estimated by the Force-velocity test, P_{mean} = mean power during the Wingate anaerobic test (WAnT), SJ = squat jump, CMJ = countermovement jump, AJ = Abalakov jump. The symbols *, † and ‡ denoted significance at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively. Correlations were shown for each variable in two lines: in the first line, Pearson correlations were presented (with partial correlations adjusted for age in brackets) for the total sample, and in the second line, correlations for each one of the four age groups were shown.

HR (bpm) in the WAnT and HR (bpm and $\%HR_{max}$) in the Bosco test.

The correlations among cycling and jumping tests can be seen in Table 5. Correlation between mean power in WAnT and Bosco test was $r = 0.70$ ($p < 0.001$) in the total sample (ranging from $r = 0.43$, $p = 0.075$ in O25 to $r = 0.72$ in U15, $p < 0.001$) (Fig. 1).

Correlation between HR in WAnT and Bosco test was $r = 0.75$ ($p < 0.001$) in the total sample (ranging from $r = 0.65$, $p < 0.001$ in U18 to $r = 0.81$ in O25, $p < 0.001$). The relationship between HR in the WAnT and HR in the Bosco test is depicted in Figure 2 (absolute values of HR) and Figure 3 (values expressed as $\%HR_{max}$).

4 Discussion

The main findings of the present study were (a) large correlations of P_{max} (W and W.kg^{-1}) with single jumps and moderate with continuous jumps; (b) large correlations of v_0 and low to moderate of F_0 with jumping tests; (c) large to very large correlations of P_{peak} and P_{mean} with jumping tests; (d) low and negative correlation of FI with jumping tests.

With regards to the relationship among F-v test and jumping tests, the magnitude of correlations varied according to the mode of jumping being higher in single jumps than in continuous jumping. This variation might be attributed to the metabolic relevance of each test. Each sprint in the F-v test lasted 7 s, taxing mainly the alactic anaerobic metabolism (triphospate adenosine and creatine phosphate, ATP-CP); thus, the F-v test had greater metabolic affinity with single jumps than with continuous jumps (whose duration, 30 s, indicated the involvement of both ATP-CP and lactic anaerobic metabolism). The F-v test provided information not only about P_{max}, but also about the constituents of power (*i.e.* force and velocity). During the performance of both

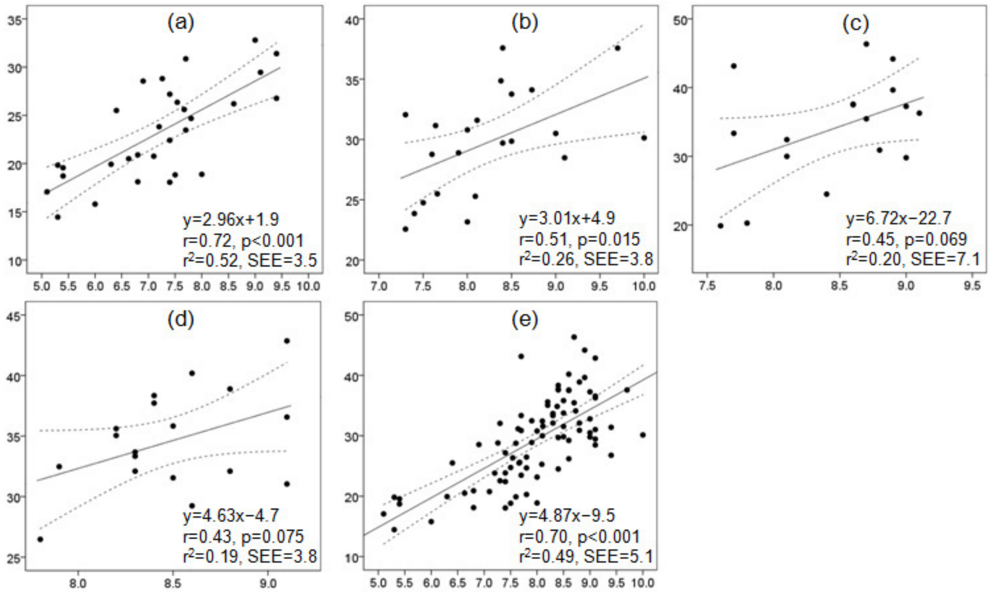

Fig. 1. Relationship between mean power in the Wingate anaerobic test and mean power in the Bosco test in U15 (a), U18 (b), U25 (c), O25 (d) and in the total sample (e). X axis represents mean power ($W.kg^{-1}$) in Wingate anaerobic test; y axis represents mean power ($W.kg^{-1}$) in Bosco test; SEE = standard error of estimate.

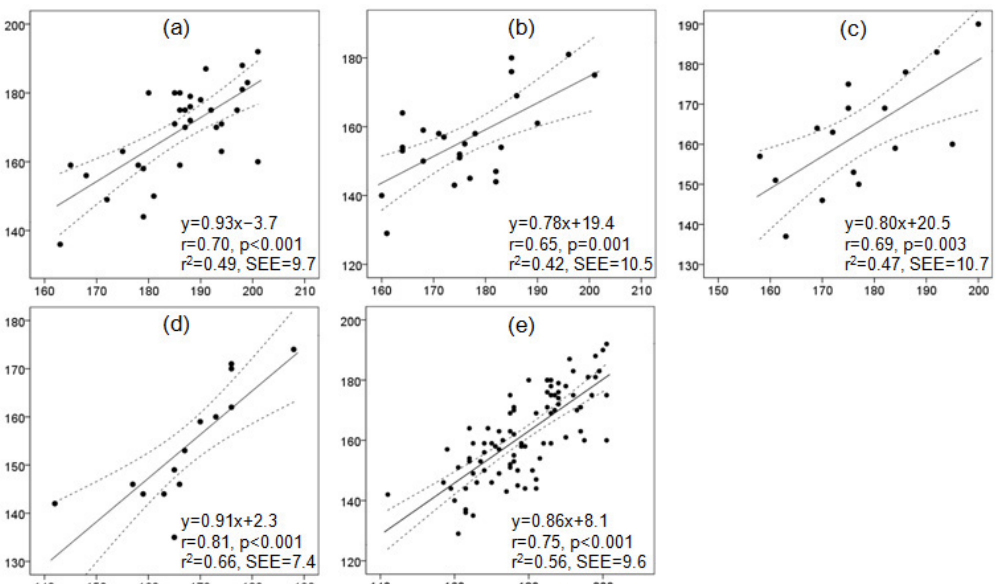

Fig. 2. Relationship between heart rate responses (beats per minute) to the Wingate anaerobic test and Bosco test in U15 (a), U18 (b), U25 (c), O25 (d) and in the total sample (e). X axis represents HR (in beats per minute) in the Wingate anaerobic test; y axis represents HR (in beats per minute) in the Bosco test; SEE = standard error of estimate.

tests, the activation of lower body muscle fast twist fibers is elicited (Fernandez-del-Olmo *et al.*, 2013), *i.e.* the metabolic requirements of these muscle contractions are quite similar as it was shown by the correlation analysis. Compared with F_0, v_0 showed higher correlations with jumping performance, which might be attributed to that jumping performance did not depend only to lower limbs' strength, but also to the speed of movements. Among the four age groups, the U25 group presented the higher values of P_{max} in the F-v test and P_{peak} in the WAnT. The higher scores in these indices of short-term power for this age group might be explained by the increased production of testosterone and dehidroepiandrosterone during this period (Campbell, 2003).

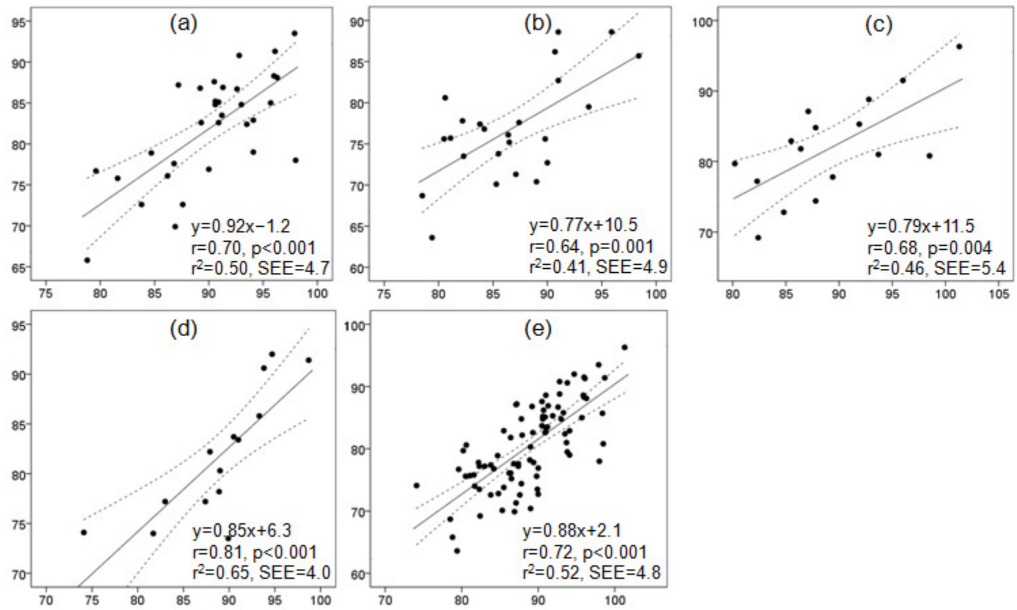

Fig. 3. Relationship between heart rate responses (% of maximal heart rate) to the Wingate anaerobic test and Bosco test in U15 (a), U18 (b), U25 (c), O25 (d) and in the total sample (e). X axis represents HR (%HR_{max}) in Wingate anaerobic test; y axis represents HR (%HR_{max}) in Bosco test; SEE = standard error of estimate.

The large correlation between P_{mean} in the WAnT and Bosco test was in agreement with a study on male volleyball players which also found $r = 0.70$ (Dal Pupo *et al.*, 2014). Also, the large-to-very large correlations of P_{peak} and P_{mean} with SJ and CMJ were in agreement with the findings in female and male track-and-field athletes ~16 yrs ($0.67 \leq r \leq 0.76$) (Çakir-Atabek, 2014). With regards to the F-v test, P_{max} had lower correlation with AJ than that reported in the literature ($r = 0.75$), and different F_0 ($r = 0.68$) and v_0 ($r = 0.24$) compared with male volleyball players (Driss *et al.*, 1998), variation due possibly to the different actions required in both team sports that elicits different muscle activation. These large correlations among cycling and jumping tests indicated that these tests reflected similar anaerobic qualities (*e.g.* muscle fiber composition, anaerobic enzymes). However, the non-shared portion of variance between these tests cannot be explained by anaerobic qualities and should be attributed to a "skill component", *i.e.* the ability to pedal fast using efficient cycling technique or jump effectively.

The effect of age on short-term power of TH players was in agreement with the correlations among jumping and cycling tests. Short-term power increased with age and both jumping and cycling tests could identify these differences. This finding highlighted the relationship of these tests.

The WAnT and Bosco test correlated not only with regards to their muscle power output, but also about the HR responses. The magnitude of the correlations of their HR responses was higher than that of their mean power. Moreover, the variation of these correlations by age groups was lower in HR responses ($0.65 \leq r \leq 0.81$) than in mean power ($0.43 \leq r \leq 0.72$). The main explanation for this large-to-very large correlation of HR responses might be the same duration of these tests. Although the WAnT and Bosco test represented different modes of exercise (*i.e.* cycling *vs.* jumping), their metabolic impact was similar. The absolute values of HR responses to the WAnT decreased in the older TH players. When HR was expressed as percentage of HR_{max} no age-related difference was observed, which should be attributed to the decrease of HR_{max} with age. A similar trend was shown in the Bosco test for all age groups except U18.

Short-term muscle power was recently identified as an important factor of success in TH. For instance, vertical jump was among the variables that differentiate between successful and less-successful adult TH players (Massuça & Fragoso, 2013), the CMJ was higher in elite U14 and U16 TH players than their non-elite peers (Matthys *et al.*, 2011), and the SJ, CMJ, AJ, Bosco and WAnT were better in an elite team than a lower ranked team (Nikolaidis & Ingebrigtsen, 2013a). Although previous studies on the relationship of age with the WAnT and vertical jump have shown large correlations and higher scores in the older age groups during adolescence (Nikolaidis, Calleja-González, & Padulo, 2014; Nikolaidis & Ingebrigtsen, 2013a, 2013b), the variation of short-term muscle power within adult athletes was not studied previously. No difference was found within the adult TH players (*i.e.* U25 *vs.* O25) in the present study, where both groups had the same scores in anthropometric characteristics (body mass and height), F-v test, WAnT and jumping tests. The similar physiological profile of U25 and O25 might be due to their similar training characteristics (number of weekly training units, duration of training unit and total weekly training volume). Whereas better scores in U25 than in O25 would be expected (Hoffman, 2006), this potential age effect might be counterbalanced by the higher sport experience of the older group. Thus, it was deduced that elite TH training elicited adequate physiological adaptations to the older TH players in order not to decrease their short-term muscle power.

5 Conclusions

The higher scores in muscle power in adult than in adolescent TH players was in agreement with the existing literature; the novel finding on the comparison among age groups was that O25 did not differ from U25. This implied that TH induced adequate anaerobic adaptations to training in older elite TH players to maintain high level of muscle power. The variation in the magnitude of correlations between jumping and cycling tests across age groups should be attributed to the variation of ranges of scores. Thus, TH coaches might be encouraged to use cycling and jumping tests interchangeably to monitor anaerobic performance of their players only with young players.

Conflict of interest. The authors declare that there is no conflict of interest regarding the publication of this paper.

Informed consent. Informed consent was obtained from all individual participants included in the study.

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