ORIGINAL ARTICLE

Age-predicted vs. measured maximal heart rate in young team sport athletes

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ABSTRACT

Background: Although maximal heart rate $(HR)_{max}$ is used widely to assess exercise intensity in sport training and particularly in various team sports, there are limited data with regards to the use of age-based prediction equations of HR_{max} in sport populations. The aim of this study was to compare the measured-HR_{max} with three prediction equations (Fox-HR_{max} = 220-age and Tanaka-HR_{max} = 208-0.7×age and Nikolaidis-HR_{max} = 223-1.44×age) in young team sport athletes. **Materials and Methods:** Athletes of soccer, futsal, basketball and water polo, classified into three age groups (u-12, 9–12 years, n = 50; u-15, 12–15 years, n = 40; u-18, 15–18 years, n = 57), all members of competitive clubs, voluntarily performed a graded exercise field test (20 m shuttle run endurance test) to assess HR_{max}. **Results:** Fox-HR_{max} and Nikolaidis-HR_{max} overestimated measured-HR_{max}, while Tanaka-HR_{max} underestimated it ($P < 0.001$). However, this trend was not consistent when examining each group separately; measured-HR_{max} was similar with Tanaka-HR_{max} in u-12 and u-15, while it was similar with Nikolaidis-HR_{max} in u-18. **Conclusion:** The results of this study failed to validate two widely used and one recently developed prediction equations in a large sample of young athletes, indicating the need for specific equation in different age groups. Therefore, coaches and fitness trainers should prefer Tanaka-HR_{max} when desiring to avoid overtraining, while Fox-HR_{max} and Nikolaidis-HR_{max} should be their choice in order to ensure adequate exercise intensity.

Key words: Age groups, athletes, cardiac rate, graded exercise test, prediction equations

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INTRODUCTION

Sport training is based on the optimal prescription of exercise mode, duration and intensity. A daily task of coaches and fitness trainers is to plan an exercise program of adequate intensity. On the contrary, special care is given in order the exercise intensity not to increase the likelihood of overtraining. When working with athletes, coaches and fitness trainers often establish training heart rate (HR) intensities for aerobic exercise based on maximal HR (HR_{max}), for example Karvonen method.[1] HR_{max} is measured as the maximal value recorded in the end of graded exercise test (GXT) either in a laboratory or in field. However, occasionally it is desirable not to perform a GXT, for example to avoid the fatigue induced by maximal testing during the competitive period.

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When it is not possible to measure HR_{max}, its prediction from an age-based equation is an alternative, which is widely used by coaches and fitness trainers. Two popular equations used in the daily sport practice are those of Fox, Naughton and Haskell (Fox-HR_{max} = 220-age)[2] and Tanaka, Monahan and Seals (Tanaka-HR_{max} = 208-0.7×age).[3] The validity of these equations has been examined extensively in large samples of adults (e.g.[3-11]) and in specific categories of population, for example healthy,[3,12] sedentary,[5,10] overweight,[7] sport[8,13] and individuals with mental retardation.[6] The aforementioned studies have used a GXT in a laboratory setting to elicit HR_{max}. In contrast, only a few studies have been conducted in children and adolescents[9,14,15] and using a field protocol.[16] Few studies had a longitudinal design.[17,18]

While available studies provide important data regarding the estimation of HR_{max}, the research is by no means complete nor has it has been consistent. One particular area of concern is that athletes and adolescents are under-represented in this body of research. In a recent study, it was shown that athletes of speed/power sports had similar measured-HR_{max} with endurance athletes and both had lower values than those who were untrained.[19] This difference between trained and untrained individuals highlights the need to examine the popular prediction equations in sport samples. In addition, the various protocols of GXT in laboratory and in field may elicit different values of HR_{max}. For instance, a study on soccer players revealed higher HR_{max} in a field test (multistage shuttle run) than in a GXT on treadmill.[20] In a recent study of the validity of prediction equations in soccer players, Fox-HRmax overestimated and Tanaka-HRmax underestimated measured-HRmax, a new formula was suggested for adolescent soccer players (223-1.44×age) and the need to examine the validity of these equations in more sport populations was highlighted.[21]

Therefore, the aim of this study was to examine the validity of Fox-HR_{max}, Tanaka-HR_{max} and Nikolaidis-HR_{max} in a large sample of young team sport athletes. In addition, we investigated whether these relationships vary according to age group (U-12, 9-12 years vs. U-15, 12-15 years vs. U-18, 15-18 years).

MATERIALS AND METHODS

A total of 147 athletes from soccer, futsal, basketball and water polo clubs in the region of Athens were recruited to participate in this study, which was conducted in 2 days. On the 1st day, the participants visited the laboratory, where they were examined for anthropometry. On the 2nd day, within a week from the first session, they performed a GXT (20 m shuttle run test, SRT) in an indoor court.

Anthropometry. Height, weight and skinfolds were measured with subjects barefoot and in minimal clothing. An electronic weight scale (HD-351 Tanita, Illinois, USA) was employed for weight measurement (in the nearest 0.1 kg), a portable stadiometer (SECA, Leicester, UK) for height (0.001 m) and a caliper (Harpenden, West Sussex, UK) for skinfolds (0.5 mm). Body mass index (BMI) was calculated as the quotient of body mass (kg) to height squared (m^2), and body fat percentage (BF) was estimated from the sum of 10 skinfolds (cheek, wattle, chest I, triceps, subscapular, abdominal, chest II, suprailiac, thigh and calf; $BF = -41.32 + 12.59 \times \log_e x$, where x the sum of 10 skinfolds).[22]

GXT. Aerobic capacity was tested with the widely used 20 m SRT.[23,24] Briefly, after a 20 min warm-up including jogging and stretching exercises, participants performed an incremental running test in an indoor court between two lines 20 m apart. Initial speed was set at 8.5 $km.h^{-1}$ and increased every minute by 0.5 $km.h^{-1}$ till exhaustion. During the late stages of the test, participants were cheered vigorously to make maximal effort. In addition, they had been instructed to adhere strictly to the speed that was dictated by audio signals. Measured-HR_{max} was defined as the highest value attained during the test. HR was recorded continuously during the test by Team2 Pro (Polar Electro Oy, Kempele, Finland).

Statistical analyses

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). One-way analysis of variance (ANOVA) was used to examine differences between the age groups (U-12, U-15 and U-18). One-way repeated measures ANOVA was used to examine differences between measured and predicted HR_{max}. To interpret effect sizes for statistical differences in the ANOVA we used eta square classified as small ($0.010 < \eta^2 \leq 0.059$), medium ($0.059 < \eta^2 \leq 0.138$) and large ($\eta^2 > 0.138$).[25] Bland-Altman[26] analysis was used to examine the accuracy and variability of prediction equations. Associations between measured HR_{max} and age were examined using Pearson's product moment correlation coefficient (r). Magnitude of correlation coefficients were considered as trivial ($r \leq 0.1$), small ($0.1 \leq r < 0.3$) moderate ($0.3 \leq r < 0.5$), large ($0.5 \leq r < 0.7$), very large ($0.7 \leq r < 0.9$) and nearly perfect ($r \geq 0.9$) and perfect ($r = 1$). The level of significance was set at $\alpha = 0.05$.

RESULTS

The basic characteristics of participants can be seen in Table 1. Briefly, our sample was comprised of U-12 (34%), U-15 (27%) and U-18 athletes (39%). There were significant differences between age groups for age, weight, height and BMI. The older the age group, the heavier, taller with higher BMI and aerobic capacity were the athletes. Moreover, U-18 had lower BF than U-12 (−2.3%) and U-15 (−2.9%), while there was no

Table 1: Descriptive characteristics, shown as mean (standard deviation) values of participants by age group

	Total (*n* = 147)	U-12 (*n* = 50)	U-15 (*n* = 40)	U-18 (*n* = 57)	Comparison
Age (year)	13.6 (2.5)	10.7 (0.8)	13.4 (0.8)	16.3 (0.8)	$F_{2,144}$=678.6, $P < 0.001$, η^2=0.90
Weight (kg)	56.2 (17.3)	38.7 (7.9)	58.5 (12.8)	70.0 (11.8)	$F_{2,144}$=110.5, $P < 0.001$, η^2=0.60
Height (cm)	162.8 (15.9)	144.8 (7.7)	166.3 (10.4)	176.2 (7.2)	$F_{2,144}$=193.8, $P < 0.001$, η^2=0.73
BMI ($kg.m^{-2}$)	20.6 (3.3)	18.3 (2.4)	20.9 (2.9)	22.5 (3.0)	$F_{2,144}$=30.2, $P < 0.001$, η^2=0.30
BF (%)	15.7 (4.4)	16.4 (4.7)	17.0 (3.6)	14.1 (4.2)	$F_{2,144}$=6.9, P = 0.001, η^2=0.09
SRT (min:s)	7:10 (2:14)	5:39 (1:32)	6:42 (1:44)	8:50 (1:58)	$F_{2,144}$=44.3, $P < 0.001$, η^2=0.38

BF – Body fat; BMI – Body mass index; SRT – Shuttle run test difference with regard to the measured-HR_{max} ($F_{2,144}$ = 1.2, P = 0.308, η^2 = 0.02).

The measured-HR_{max} and predicted-HR_{max} can be found in Table 2. When using an ANOVA with repeated measures with a Greenhouse-Geisser correction, the mean score for HR_{max} differed statistically significantly between measured and predicted values in the total sample ($F_{1.072,156.441}$ = 103.0, P < 0.001, η^2 = 0.41), in U-12 ($F_{1.007,49.348}$ = 51.2, P < 0.001, η^2 = 0.51), in U-15 ($F_{1.006,39.224}$ = 26.4, P < 0.001, η^2 = 0.40) and in U-18 ($F_{1.010,56.569}$ = 43.0, P < 0.001, η^2 = 0.43). Post hoc tests using the Bonferroni correction revealed that in the total sample, Fox-HR_{max} and Nikolaidis-HR_{max} overestimated measured-HR_{max} [5.5 bpm (3.7; 7.2), mean difference (95% confidence intervals) and 2.5 bpm (0.7; 4.3), respectively], while Tanaka-HR_{max} underestimated measured-HR_{max} [−2.4 bpm (−4.2; −0.7)].

In addition, we examined this relationship separately for each age group. In U-12, Fox-HR_{max} and Nikolaidis-HR_{max} overestimated measured-HR_{max} [7.1 bpm (3.8; 10.3) and 5.4 bpm (2.1; 8.6), respectively], whereas Tanaka-HR_{max} provided similar values as measured-HR_{max} [−1.7 bpm (−5.0; 1.5) -. In U-15, Fox-HR_{max} overestimated measured-HR_{max} [6.2 bpm (2.4; 10.3)], while Nikolaidis-HR_{max} and Tanaka-HR_{max} provided similar values as measured-HR_{max} [3.3 bpm (−0.6;7.1) and −1.8 bpm (-5.6;2.0), respectively]. In U-18, Fox-HR_{max} overestimated [3.6 bpm (1.2; 6.0)], Tanaka-HR_{max} underestimated [−3.5 bpm (-5.9; −1.1)], while Nikolaidis-HR_{max} provided similar values as measured-HR_{max} [−0.6 bpm (−3.0; 1.8)].

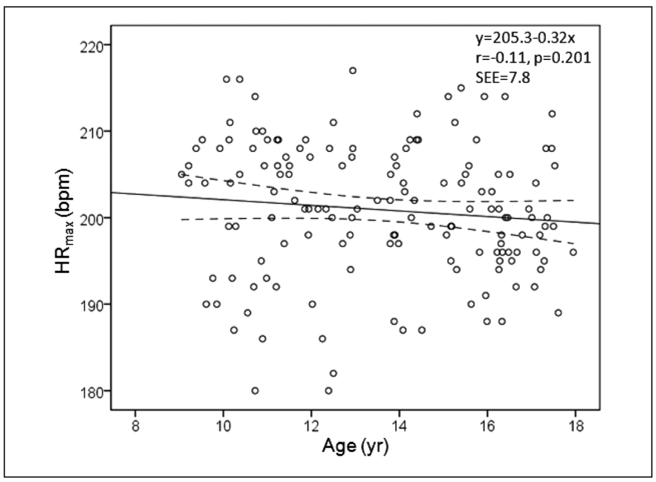

Figure 1: Relationship between age and maximal heart rate (HR_{max}) in participants

The relationship between measured-HR_{max} and age is depicted in Figure 1. HR_{max} was not correlated with age in the total sample (r = −0.11, P = 0.201). The respective correlations separately for U-12, U-15 and U-18 were also trivial to small and non-significant: r = 0.03 (P = 0.829), r = 0.22 (P = 0.181) and r = −0.16 (P = 0.242), respectively.

Figures 2, 3 and 4 show Bland-Altman plots of the difference between predicted-HR_{max} and measured-HR_{max} in total and in each age group for Fox-HR_{max} Tanaka-HR_{max} and Nikolaidis-HR_{max}, respectively. In general, we observed that there was overestimation of HR_{max} at low values of HR_{max} and underestimation of HR_{max} at high values of HR_{max}. This trend was noticed consistently for all age groups and prediction equations.

DISCUSSION

The main finding of this study was that neither Fox, Tanaka nor Nikolaidis equation provide accurate values of HR_{max} in the total sample of young athletes [Table 3]. Fox-HR_{max} overestimated measured-HR_{max} in total as well as in each age group. Tanaka-HR_{max} underestimated measured-HR_{max} in total and in U-18. Nikolaidis-HR_{max} overestimated

Table 2: Measured-heart rate $(HR)_{max}$ and age-predicted HR_{max}, shown as mean (standard deviation) values of participants by age group

	Total (n=147)	U-12 (n=50)	U-15 (n=40)	U-18 (n=57)
Measured-HR_{max} (bpm)	200.9 (7.8)^{F,T,N}	202.3 (8.2)^{F,N}	200.4 (8.5)^{F}	200.1 (6.8)^{F,T}
Fox-HR_{max} (bpm)	206.4 (2.5)^{M,T,N}	209.3 (0.8)^{M,T,N}	206.6 (0.8)^{M,T,N}	203.7 (0.8)^{M,T,N}
Tanaka-HR_{max} (bpm)	198.5 (1.8)^{M,F,N}	200.5 (0.6)^{F,N}	198.6 (0.6)^{F,N}	196.6 (0.6)^{M,F,N}
Nikolaidis-HR_{max} (bpm)	203.4 (3.7)^{M,F,T}	207.6 (1.1)^{M,F,T}	203.7 (1.2)^{F,T}	199.5 (1.1)^{F,T}
Fox-HR_{max}-Measured-HR_{max} (bpm)	5.5 (7.9)	7.1 (8.3)	6.2 (8.7)	3.6 (6.7)
Tanaka-HR_{max}-Measured-HR_{max} (bpm)	−2.4 (7.8)	−1.7 (8.3)	−1.8 (8.6)	−3.5 (6.7)
Nikolaidis-HR_{max}-Measured-HR_{max} (bpm)	2.5 (8.2)	5.4 (8.3)	3.3 (8.8)	−0.6 (6.7)

*Statistically differed from measured HR_{max} (P < 0.001). The capital letters M, F, T, N (standing for measured-HR_{max}, Fox-HR_{max}, Tanaka-HR_{max} and Nikolaidis-HR_{max}, respectively) when using as exponents denote statistical difference from the respective value within each group

Table 3: Summary of the main findings

Total	U-12	U-15	U-18
Fox-HR_{max} > Nikolaidis-HR_{max} > Measured-HR_{max} > Tanaka-HR_{max}	Fox-HR_{max} > Nikolaidis-HR_{max} > Measured-HR_{max} ≈ Tanaka-HR_{max}	Fox-HR_{max} > Nikolaidis-HR_{max} ≈ Measured-HR_{max} ≈ Tanaka-HR_{max}	Fox-HR_{max} > Nikolaidis-HR_{max} ≈ Measured-HR_{max} >Tanaka-HR_{max}

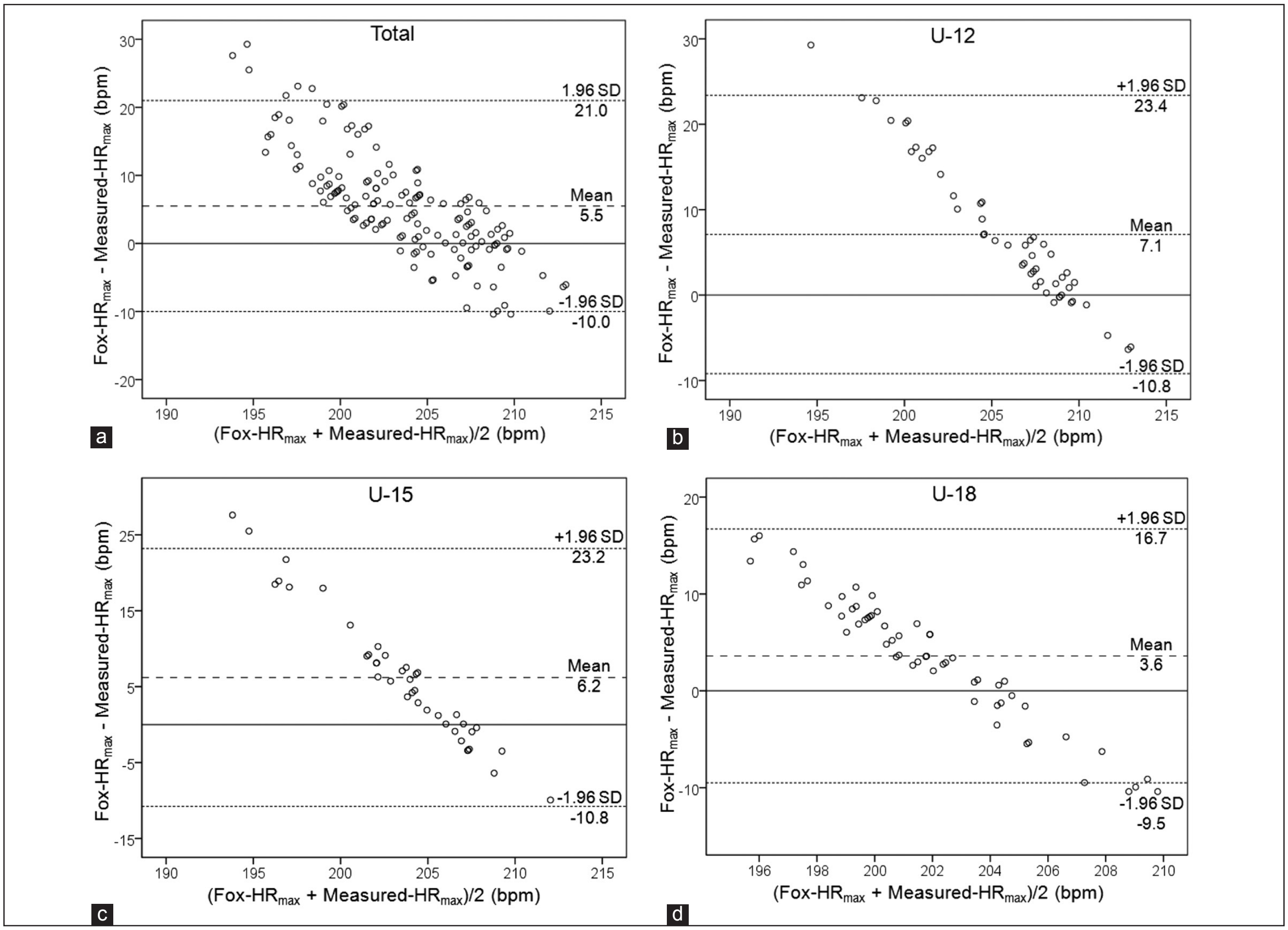

Figure 2: Bland-Altman plots of the difference between Fox-HR_{max} and measured-HR_{max} in the total sample (a), u-12 (b), u-15 (c) and u-18 participants (d)

measured-HR_{max} in total and in U-12. Thus, Tanaka-HR_{max} was valid in U-12 and U-15, while Nikolaidis-HR_{max} was valid in U-15 and U-18.

Our study did not confirm the findings of previous research supporting that Fox-HR_{max} underestimates HR_{max} with increasing age,[3,17] which should be attributed to the younger age of the participants in the present study. In contrast, our findings confirmed that Fox-HR_{max} overestimate HR_{max} in adolescents.[15] This finding practically implies that adopting this widely used prediction equation in young athletes leads athletes to work at higher intensities than what it is desired.

The basic characteristics of participants were similar with those reported recently[27] and the differences in weight, height, BMI and endurance between adolescent and adult players were in line with previous research.[27,28] The comparison between age groups with regard to their mean HR_{max} revealed no statistical difference, despite a trend for lower values in U15 (−1.9 bpm) and U18 (−2.2 bpm) than in the younger group, finding which was in accordance with the trivial, but not statistically significant, negative correlation between HR_{max} and age.

However, these findings on the relationship between HR_{max} and age were not in agreement with the existing literature. The variation of the span of chronological age may explain the discrepancy between this study and previous research with regard to the above mentioned correlation. In a previous study covering a relatively short span of ages (10−16 years) the correlation between HR_{max} and age was −0.10,[15] while in studies with large span we observed large to very large correlations (e.g. 15-75 years, $r = -0.56$,[8] 14-77 years, $r = -0.60$,[11] 16-71 years, $r = -0.67$,[29] 19-89 years, $r = -0.60$,[12] 16-65 years, $r = -0.60$,[10] 18-81 years, $r = -0.79$[3]). Therefore, it should not be a surprise the lack of significant and large correlation when the sample of participants, independently from its size, covers only a few years. Compared with boys of similar age (10-16 years)[15] who performed a GXT on treadmill, the athletes in the present study achieved similar HR_{max}. In addition, we found also similar values with another study on individuals aged 7-17 years.[9]

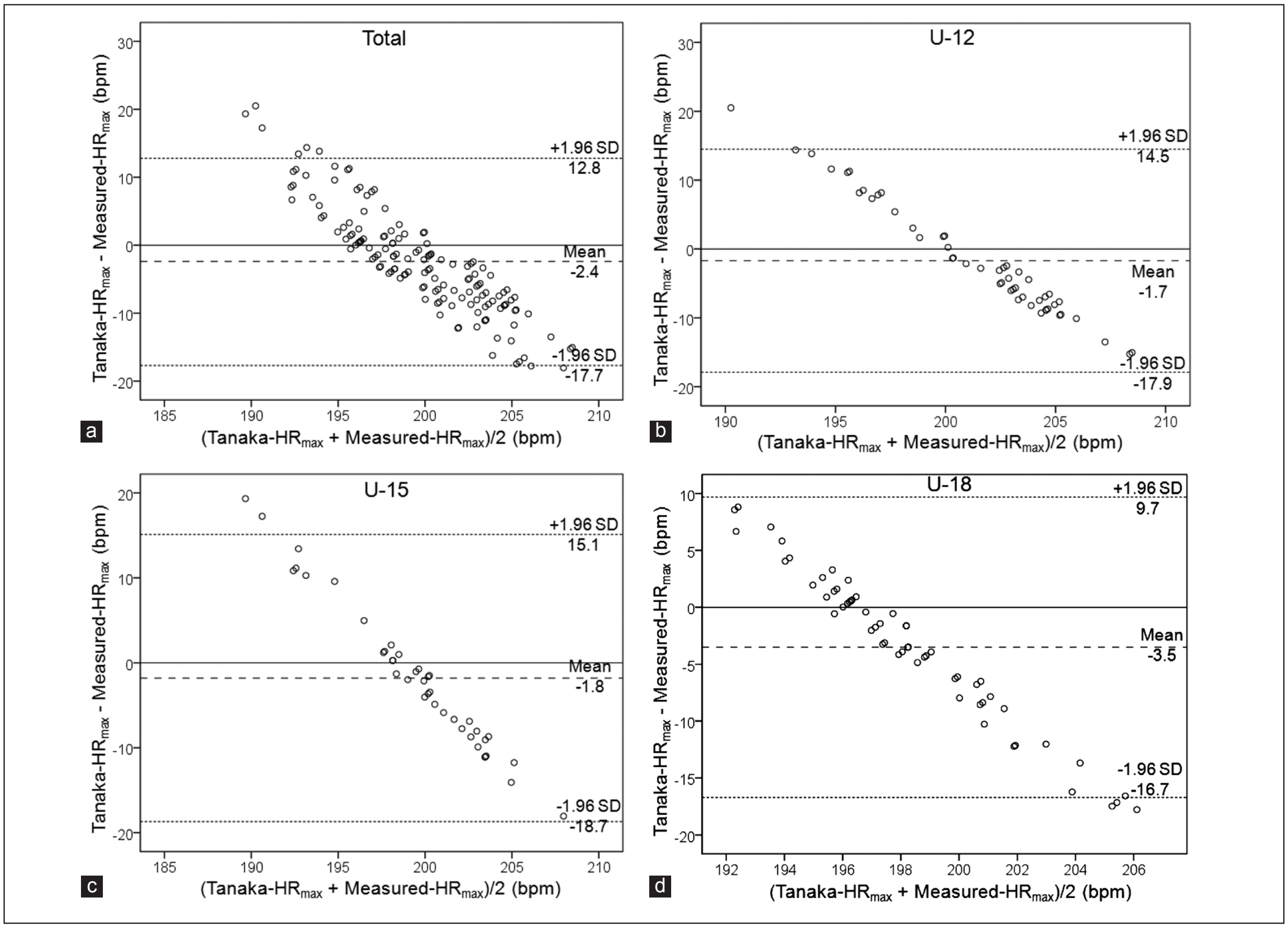

Figure 3: Bland-Altman plots of the difference between Tanaka-HR_{max} and measured-HR_{max} in the total sample (a), u-12 (b), u-15 (c) and u-18 participants (d)

The main limitation of this study was that it presents the common drawbacks of any field GXT; in opposition to the criteria of maximal effort [e.g. plateau of oxygen uptake, HR >90%-95% of HR_{max}, respiratory quotient >1.15 and lactate >9-10 mmol.L^{-1}[30]] used typically in a laboratory setting, the only criterion to evaluate participants' effort was their oral confirmation that they have run till exhaustion. In addition, we examined only the relationship between HR_{max} and age and not the effect of other confounders on this relationship. It has been suggested that the overestimation of HR_{max} might be associated with increased weight and smoking, while its underestimation with rest HR.[11]

However, an issue with important practical implications is to recognize the risks that coaches and fitness trainers undertake depending on which their choice of prediction equation is. Adopting Tanaka equation, which consistently tends to provide low values of HR_{max}, might result in prescribing exercise of lower intensity than what it is desired. In contrast, using Fox or Nikolaidis equation, which tend to overestimate HR_{max}, might result in prescribing high exercise intensity. To deal with this issue, it is recommended to apply higher intensity in the first case and lower intensity in the other two cases.

CONCLUSION

The results of this study failed to validate two widely used and one recently developed prediction equations in a large sample of young athletes, indicating the need for specific equation in different age groups. Based on the findings of the present study, coaches and fitness trainers are advised to prefer Tanaka-HR_{max} when desiring to avoid overtraining, while Fox-HR_{max} and Nikolaidis-HR_{max} should be their choice in order to ensure adequate exercise intensity.

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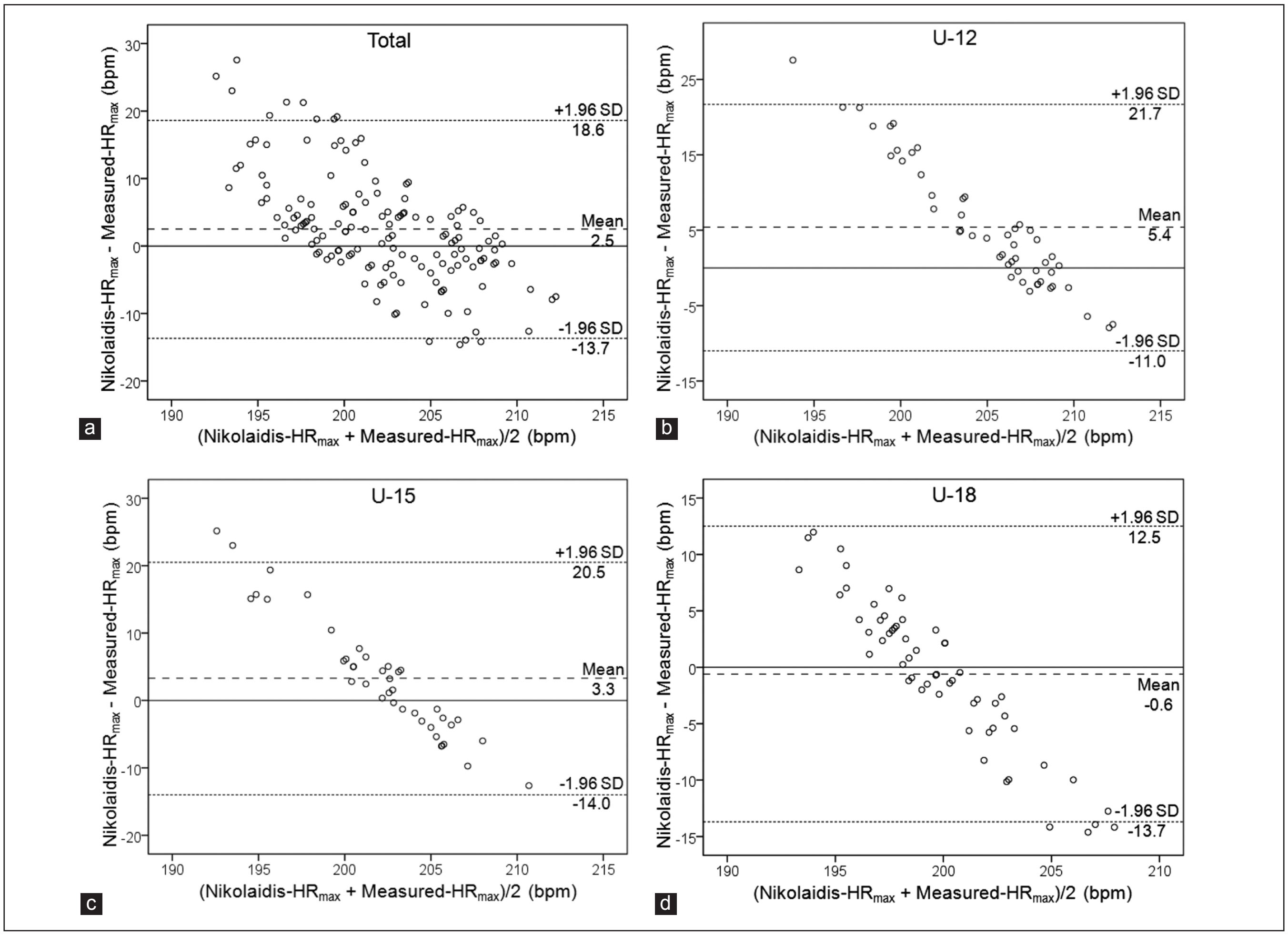

Figure 4: Bland-Altman plots of the difference between Nikolaidis-HR_{max} and measured-HR_{max} in the total sample (a), u-12 (b), u-15 (c) and u-18 participants (d)

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