



## ESTIMATING MAXIMAL HEART RATE WITH THE ‘220-AGE’ FORMULA IN ADOLESCENT FEMALE VOLLEYBALL PLAYERS: A PRELIMINARY STUDY

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### ABSTRACT

**Purpose.** Although maximal heart rate ( $HR_{max}$ ) is used widely to assess exercise intensity in training, there are limited data with regards to the validity of age-based prediction equations of  $HR_{max}$  in volleyball players. Therefore, the aim of the present study was to compare the measured- $HR_{max}$  of two prediction equations ( $Fox-HR_{max} = 220 - \text{age}$  and  $Tanaka-HR_{max} = 208 - 0.7 \times \text{age}$ ) in young female volleyball players. **Methods.** The study involved 47 volleyball players (age  $13.39 \pm 2.01$  years, body mass  $54.0 \pm 10.8$  kg, height  $162.7 \pm 10.2$  cm) who performed a graded exercise field test (20 m shuttle run endurance test) to assess  $HR_{max}$ . Measured- $HR_{max}$  values were compared with the Fox and Tanaka prediction equations. **Results.** The results showed that mean scores for  $HR_{max}$  significantly differed between measured and predicted values ( $p < 0.001$ ,  $\eta^2 = 0.49$ ). Post-hoc tests revealed that  $Fox-HR_{max}$  overestimated measured- $HR_{max}$  (mean difference 5.7 bpm; 95% CI [3.0, 8.5]), whereas  $Tanaka-HR_{max}$  was similar to measured- $HR_{max}$  (-2.2 bpm; 95% CI [-4.9, 0.4]).  $HR_{max}$  did not correlate with age ( $r = 0.16$ ,  $p = 0.291$ ). **Conclusions.** The results of this study failed to validate the widely used ‘220-age’ formula in volleyball players. Coaches and fitness trainers should take into account that the overestimation of  $HR_{max}$  by the Fox equation might lead to prescribing exercise at a higher intensity than what is targeted. Therefore, the Tanaka equation appears to offer a more accurate prediction equation of  $HR_{max}$  than the Fox equation in young female volleyball players.

**Key words:** age groups, graded exercise test, cardiac rate, metabolic demand, prediction equations, shuttle run, training intensity

### Introduction

Prescribing optimal mode, duration, and intensity of exercise is a prerequisite for effective sports training. A daily concern of coaches and fitness trainers is whether their exercise program has the adequate intensity in order to stimulate targeted physiological adaptations. However, the prescribed exercise intensity should not exceed threshold levels as the likelihood of overtraining is increased. Heart rate (HR) is often used to assess exercise intensity, where an athlete’s actual HR is compared with exercise zones based on maximal HR ( $HR_{max}$ ), e.g. Karvonen method [1]. Therefore, knowing  $HR_{max}$  is useful in determining exercise intensity.  $HR_{max}$  can be either assessed directly (measured) or indirectly (estimated). In the first case, a graded exercise test (GXT) is performed either in a laboratory or in the field to elicit  $HR_{max}$  [2], whereas for the latter,  $HR_{max}$  is predicted from an age-based equation.

When it is not possible to measure  $HR_{max}$  (e.g. to avoid the fatigue induced by maximal testing during the competitive season), its prediction from an age-based equation provides an alternative to coaches and fitness trainers. Two popular equations are those of Fox, Naughton, and Haskell ( $Fox-HR_{max} = 220 - \text{age}$ ) [3] and Tanaka, Monahan, and Seals ( $Tanaka-HR_{max} = 208 - 0.7 \times \text{age}$ ) [4]. The validity of these equations has been examined extensively in large samples of adults [4–10] and in specific populations, e.g. healthy [4, 11], sedentary [6, 10], overweight [8], athletic [12] and individuals with intellectual disabilities [7]. The aforementioned studies used a GXT in a laboratory setting to elicit  $HR_{max}$ . In contrast, only few studies have been conducted in children and adolescents [9, 13, 14] or with a field protocol [2].

Although the contribution of the abovementioned literature to our understanding of  $HR_{max}$  prediction is important, there are several aspects that have not been fully examined and require further research. For instance, athletes and adolescents are underrepresented in this body of research. In a recent study, it was shown that athletes of speed/power sports presented similar measured- $HR_{max}$  as endurance athletes and that both

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had lower values than the untrained [15]. This difference between trained and untrained individuals highlights the need to examine these popular prediction equations in an athlete population. In addition, the various GXT protocols in laboratory and field conditions may elicit different values of HR<sub>max</sub>. For instance, a study on soccer players revealed higher HR<sub>max</sub> in a field test (i.e. multistage shuttle run test) than in a treadmill GXT [16]. Therefore, the aim of the present study was to examine the validity of Fox-HR<sub>max</sub> and Tanaka-HR<sub>max</sub> in a sample of young volleyball players.

### Material and methods

We recruited 47 female volleyball players from the region of Athens, Greece to participate in this study, which was conducted on two non-consecutive days during the same time of day (between 09:00 and 11:00) at the end of the 2012–2013 competitive season (Table 1). Inclusion criteria were: i) participation in at least 90% of their training sessions and ii) regular participation in official matches in the previous competitive season, iii) holding a valid athletic medical clearance, and iv) present a good state of health (pain and injury free and not undergoing medical treatment). Participants were instructed to refrain from drinking alcohol or caffeine-containing beverages for 24 h and eating 2 h before HR<sub>max</sub> testing in order to reduce any measurement interference. All experimental procedures were approved by the local institutional review board and were conducted according to the ethical principles laid out in the 2013 revision of the Declaration of Helsinki.

On the first day of testing, the participants visited the laboratory for anthropometric examination. On the second day, within a week from the first session, they performed a GXT on an indoor volleyball court.

Anthropometric measures included height, body mass, and skinfold thicknesses with participants barefoot and wearing minimal clothing. An electronic weight scale (HD-351 Tanita, USA) was employed for body mass measurement (to the nearest 0.1 kg), a portable stadiometer (SECA, UK) for height (0.001 m) and a caliper (Harpenden, UK) for skinfold thickness (0.5 mm). Body mass index was calculated as the quotient of body mass (kg) to height squared (m<sup>2</sup>). Body fat percentage (BF) was estimated from the sum of 10 skinfolds (cheek, wattle, chest I, chest II, triceps, subscapular, abdominal, suprailiac, thigh, and calf; BF =  $-41.32 + 12.59 \times \log_e x$ , where  $x$  is the sum of the 10 skinfold sites) [17].

HR<sub>max</sub> was assessed with the widely used 20 m shuttle run test (SRT) [18]. All participants were familiar with testing procedures as they had already performed such a test at least once in the past. After a 20 min warm-up including jogging and stretching exercises, participants performed an incremental running test on an indoor court between two lines spaced 20 m apart. Initial speed was set at 8.5 km · h<sup>-1</sup> and increased every minute by 0.5 km · h<sup>-1</sup> until exhaustion. They were instructed to adhere strictly to the set speed, which was dictated by audio signals. During the later stages of the test, participants were vigorously motivated to exert maximal effort. HR was recorded continuously during the test by a Team2 Pro (Polar Electro Oy, Finland). Measured-HR<sub>max</sub> was defined as the highest value attained during the test.

Statistical analyses were performed using SPSS ver. 20.0 (IBM, USA). Data were expressed as mean and standard deviations of the mean (SD). One-way repeated measures ANOVA was used to examine differences between measured and predicted HR<sub>max</sub>. To interpret effect sizes for statistical differences in the ANOVA we used eta squared, classified as small ( $0.01 < \eta^2 \leq 0.06$ ), medium ( $0.06 < \eta^2 \leq 0.14$ ), and large ( $\eta^2 > 0.14$ ) [19]. Bland-Altman [20] analysis was used to examine the accuracy and variability of the prediction equations. Associations between measured-HR<sub>max</sub> and age were examined using Pearson's product-moment correlation coefficient ( $r$ ). The magnitude of the correlation coefficients were interpreted as very small ( $r \leq 0.1$ ), small ( $0.1 \leq r < 0.3$ ) moderate ( $0.3 \leq r < 0.5$ ), large ( $0.5 \leq r < 0.7$ ), very large ( $0.7 \leq r < 0.9$ ), nearly perfect ( $r \geq 0.9$ ) and perfect ( $r = 1$ ) [19]. The level of significance was set at  $\alpha = 0.05$ .

### Results

The anthropometric characteristics and aerobic capacity of participants can be seen in Table 1. The measured-HR<sub>max</sub> and predicted-HR<sub>max</sub> values are presented in Table 2. When using repeated measures ANOVA with a Greenhouse-Geisser correction, the mean score for HR<sub>max</sub> differed significantly between measured and predicted values  $F(2,92) = 43.45$ ,  $p < 0.001$ ,  $\eta^2 = 0.49$ . Post-hoc tests using the Bonferroni correction revealed that in the sample, Fox-HR<sub>max</sub> overestimated measured-HR<sub>max</sub> (5.7 bpm, 95% CI [3.0, 8.5]), while Tanaka-HR<sub>max</sub> was similar as measured-HR<sub>max</sub> (-2.2 bpm, 95% CI [-4.9, 0.4]). The relationship between measured-HR<sub>max</sub> and age is depicted in Figure 1. HR<sub>max</sub> did not correlate with age ( $r = 0.16$ ,  $p = 0.291$ ).

Table 1. Anthropometric characteristics and aerobic capacity ( $M \pm SD$ )

Variable	Age (years)	Weight (kg)	Height (cm)	BMI (kg · m <sup>-2</sup> )	BF (%)	SRT (min:s)
Mean $\pm$ SD	13.39 $\pm$ 2.01	54.0 $\pm$ 10.8	162.7 $\pm$ 10.2	20.2 $\pm$ 2.8	21.2 $\pm$ 4.2	4:51 $\pm$ 1:26

BMI – body mass index, BF – body fat, SRT – shuttle run test

Table 2. Measured-HR<sub>max</sub> and age-predicted HR<sub>max</sub> ( $M \pm SD$ )

Variable	Mean $\pm$ SD
Measured-HR <sub>max</sub> (bpm)	200.9 $\pm$ 6.9
Fox-HR <sub>max</sub> (bpm)	206.6 $\pm$ 2.0*
Tanaka-HR <sub>max</sub> (bpm)	198.6 $\pm$ 1.4
Fox-HR <sub>max</sub> – Measured-HR <sub>max</sub> (bpm)	5.7 $\pm$ 7.5
Tanaka-HR <sub>max</sub> – Measured-HR <sub>max</sub> (bpm)	–2.2 $\pm$ 7.3

\* statistically differed from measured-HR<sub>max</sub> ( $p < 0.001$ )

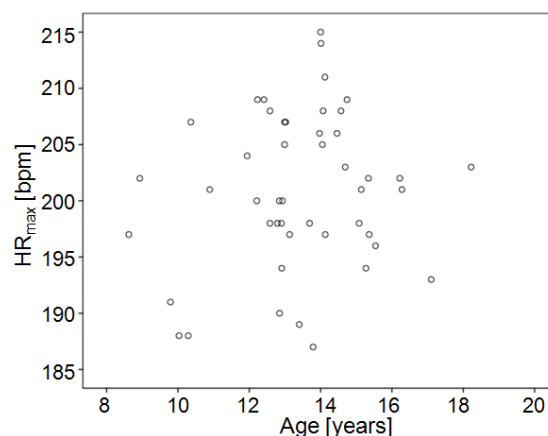
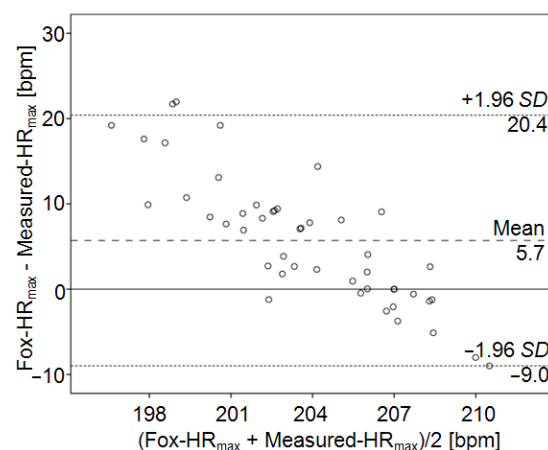
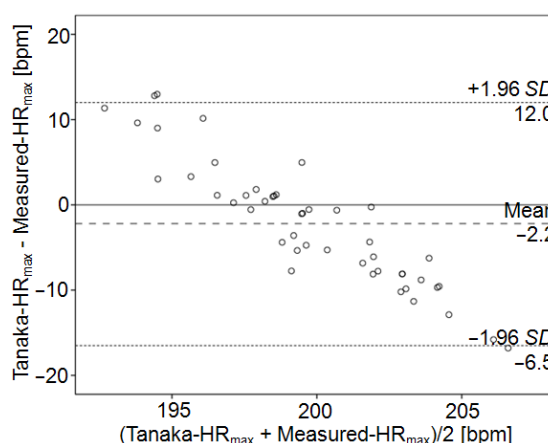
Figures 2 and 3 show Bland-Altman plots of the difference between predicted-HR<sub>max</sub> and measured-HR<sub>max</sub> for Fox-HR<sub>max</sub> and Tanaka-HR<sub>max</sub>, respectively. In general, we observed that there was overestimation at low values of HR<sub>max</sub> and underestimation at high values of HR<sub>max</sub>.

## Discussion

The main finding of the present study was that the widely used ‘220–age’ formula to predict HR<sub>max</sub> overestimates actual HR<sub>max</sub> by ~6 bpm (~3%), whereas the Tanaka equation provides more valid results. Our findings confirmed other results finding that Fox-HR<sub>max</sub> overestimates HR<sub>max</sub> in adolescents [14]. Practically, this finding implies that adopting this widely used prediction equation in young female volleyball players leads them to work at higher intensities than what it is desired, increasing the risk of overtraining during the intense phases of training.

The participants in the present study had analogous anthropometric characteristics and body composition with other samples of Greek volleyball players [21, 22]. Compared with 15.2-year-old volleyball players [22], the participants weighed less and were shorter, and had lower BMI and BF. However, compared with 12.5-year-old volleyball players [21], they weighed less and were taller, and also had lower BMI and BF. The mean time in the shuttle run test (4 min 51 s) corresponded to a maximal running speed 10.5 km · h<sup>–1</sup>. This score is higher than the mean of age- and sex-matched populations, for instance, 10.2 km · h<sup>–1</sup> according to worldwide norms (18) and 9.9 km · h<sup>–1</sup> to English norms [23]. The level of aerobic capacity was in agreement with recent findings that showed a better level in adult female volleyball players than in general population. Compared with boys of a similar age (10–16 years) [14] who performed a GXT on treadmill, the participants in the present study achieved similar HR<sub>max</sub>. In addition, we also found similar HR<sub>max</sub> compared with another study on individuals aged 7–17 years [9].

The correlation between HR<sub>max</sub> and age was positive, small, and non-significant, which was not in agreement with the existing literature that indicates a significant, moderate to very large, negative correlation [4, 10, 11, 14]. The variation in the span of examined age groups may

Figure 1. Relationship between age and maximal heart rate (HR<sub>max</sub>)Figure 2. Bland-Altman plots of the difference between Fox-HR<sub>max</sub> and measured-HR<sub>max</sub>Figure 3. Bland-Altman plots of the difference between Tanaka-HR<sub>max</sub> and measured-HR<sub>max</sub> means

explain the discrepancy between this study and previous research with regard to the magnitude of the correlation. In a previous study covering a relatively short span of ages (10 to 16 years), the correlation between HR<sub>max</sub> and age was –0.10 [14], while in studies with a larger span large to very large correlations were observed (e.g. 19 to

89 years at  $r = -0.60$  [11], 16 to 65 years at  $r = -0.60$  [10], 18 to 81 years at  $r = -0.79$  [4]). Therefore, the lack of a significant and large correlation was not surprising when considering the sample of participants, independently from its size, covers only a few years.

Although volleyball is a team sport with an intermittent nature, where the actions that determine the score last for only a few seconds (e.g. spiking and blocking), volleyball players need to possess adequate cardiorespiratory power in order to cope with fatigue during match-play and training. This is supported by relevant research which has revealed high levels of cardiorespiratory power in adolescent and adult volleyball players [21, 22, 24] and by the findings of the present study. Therefore, achieving or maintaining an adequate level of cardiorespiratory power should be a concern of those involved in the training process.

In this context, measuring or predicting HR<sub>max</sub> contributes to monitoring exercise intensity. An issue with important practical implications is to recognize the risks that coaches and fitness trainers undertake if they choose to use a prediction equation. Using the Fox equation, which tends to overestimate HR<sub>max</sub>, might result in prescribing an excessively high exercise intensity. Therefore, based on our findings, it is recommended to apply a lower intensity when the Fox equation is used or, instead, adopt the Tanaka equation as it appears to provide more accurate results than the Fox equation.

A limitation of the present study was that a field GXT was used to assess HR<sub>max</sub> instead of one performed on a treadmill in a laboratory setting. The contention that a field GXT lacks the validity of laboratory testing is certainly valid since it is difficult to evaluate whether end physiological values are truly maximal (based on a plateau in oxygen uptake, post-exercise blood lactate, respiratory exchange ratio). On the other hand, a field GXT better imitates natural running movements than a test on treadmill, where speed is dictated by the equipment, possibly explaining why it is possible to observe higher HR<sub>max</sub> in the former than in the latter [16].

The present study focused on the assessment methods of exercise intensity, however, we acknowledge that a complex team sport such as volleyball possesses many other parameters that influence performance, including tactics [25, 26] and physical [27, 28], psychological, and cognitive characteristics [29, 30]). Another aspect that requires attention when interpreting the findings of the present study was the heterogeneity of the sample, which included volleyball players from late childhood till early adulthood. Thus, the chronic adaptations of the parasympathetic nervous system to exercise training might have varied.

## Conclusions

The results of the present study failed to validate the widely used '220-age' formula in volleyball players.

Coaches and fitness trainers should take into account that the overestimation of HR<sub>max</sub> by the Fox equation might lead to prescribing exercise at a higher intensity than what is targeted. Therefore, the Tanaka equation appears to offer a more accurate prediction of HR<sub>max</sub> in young female volleyball players. These findings are useful for athletes and coaches when monitoring exercise intensity and for sports scientists involved in concomitant experimental studies.

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