



Estimation of maximal oxygen uptake using the heart rate ratio method in male recreational football players

Carlo Castagna^{1,2,3} · Peter Krstrup^{3,4,5} · Susana Póvoas^{3,6}

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Abstract

Maximal oxygen uptake (VO_{2max}) is associated with cardiovascular and metabolic health in the general population. The heart rate (HR) ratio method (HR_{ratio}) is a valid, easy and accessible method for estimating VO_{2max} in well-trained subjects. This study examined the validity of using the HR_{ratio} to estimate VO_{2max} in recreational football players in the untrained and trained states. Sixty-six participants (age 39.3 ± 5.8 years) were tested pre-training and 28 after 12 weeks, for VO_{2max} assessment, running on a treadmill alternating speed (1 km h^{-1}) and inclination (1%) increments every 30 s until exhaustion. Maximal HR (HR_{max}) was assessed directly with a multiple approach and estimated with selected equations. Resting HR (HR_{rest}) was measured in supine position, after 15 min of rest. The HR_{ratio} method considers the product of HR_{max}/HR_{rest} ratio by a theoretical proportionality factor ($15 \text{ ml kg}^{-1} \text{ min}^{-1}$, TPF) to estimate VO_{2max} . This population-specific proportionality factor (SPF) was $14.6 \pm 2.6 \text{ ml kg}^{-1} \text{ min}^{-1}$. In the untrained state ($n=66$), participants' actual VO_{2max} ($41.3 \pm 6.2 \text{ ml kg}^{-1} \text{ min}^{-1}$) was moderately lower ($\sim 2 \text{ ml kg}^{-1} \text{ min}^{-1}$) than the estimated VO_{2max} using the TPF. A nonsignificant difference ($0.7 \text{ ml kg}^{-1} \text{ min}^{-1}$) was found when the VO_{2max} was estimated using the SPF. When using HR_{max} equations and the TPF, a small nonsignificant difference ($\sim 1.5 \text{ ml kg}^{-1} \text{ min}^{-1}$) was reported between actual and estimated VO_{2max} . In the trained state ($n=28$), the estimated VO_{2max} values were not significantly different from the actual VO_{2max} ($44.2 \pm 5.2 \text{ ml kg}^{-1} \text{ min}^{-1}$), with large effect sizes when considering TPF and estimated HR_{max} . The results of this study provide evidence of the applicability of HR_{ratio} in estimating VO_{2max} in male adult/middle-aged recreational football players.

Keywords Soccer · Testing · Team sport · Training · Aerobic fitness

Introduction

Maximal oxygen uptake (VO_{2max}) is the best measure of cardiorespiratory fitness and is associated with cardiovascular and metabolic health in the general population (Liff et al. 2020; Diaz-Canestro and Montero 2019). Higher levels of VO_{2max} are related to a lower risk of cardiovascular events and all-cause mortality (Nes et al. 2014; Zeiher et al. 2019). Interestingly, in the COVID-19 outbreak VO_{2max} was indicated as a variable for estimating patients' global physiological reserves (Ahmed 2020). In fact, individual levels of VO_{2max} were suggested for identifying patients' ability to tolerate intensive care admission and post-admission rehabilitation programmes and as a clinically relevant triage parameter during the COVID-19 emergency (Ahmed 2020). Given the supposed relevance of individual VO_{2max} for guiding treatments in critical health conditions in the general population, easily accessible assessment strategies might have a great impact on public healthcare (Ahmed 2020; Liff et al. 2020).

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✉ Carlo Castagna
castagnac@libero.it

- ¹ University of Rome Tor Vergata, Rome, Italy
- ² Fitness Training and Biomechanics Laboratory, Technical Department, Italian Football Federation (FIGC), Coverciano, Florence, Italy
- ³ Department of Sports Science and Clinical Biomechanics, SDU Sport and Health Sciences Cluster (SHSC), University of Southern Denmark, Odense, Denmark
- ⁴ Department of Physical Education and Sports Training, Shanghai University of Sport, Shanghai, China
- ⁵ Sport and Health Sciences, College of Life and Environmental Sciences, University of Exeter, Exeter, UK
- ⁶ Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, University of Maia, ISMAI, Maia, Portugal

Cardiopulmonary exercise testing (CPET) is currently the reference for assessing patients' VO_{2max} (Liff et al. 2020; Nes et al. 2014; Diaz-Canestro and Montero 2019; Zeiher et al. 2019). Unfortunately, the need for skilled personnel, specific expensive devices and individual testing in certified laboratories limits the accessibility of CPET for the general population (Castagna et al. 2020).

The impact of VO_{2max} on fitness and health promoted the interest in valid, reliable and sustainable alternative methods to CPET to estimate VO_{2max} . Field testing, namely the Yo–Yo intermittent tests, were recently proposed as valid, reliable and practically sustainable tools for estimating individual VO_{2max} in recreational football players (Castagna et al. 2020; Póvoas et al. 2019a). However, CPET and field tests both require participants' maximal effort to obtain valid and satisfactory VO_{2max} estimates. Exhaustive efforts may represent a concern when patients enroll in a training intervention if they have a previous inactive or untrained status and in the presence of chronic morbidity(ies). Alternatively, submaximal field testing may represent a valid and reliable surrogate for exhaustive testing (Póvoas et al. 2019a). However, patients may experience difficulties in adapting to submaximal testing given their reduced familiarisation with testing and their current fitness and health status. Furthermore, inter-individual fitness variability may reduce the validity of the submaximal design of the proposed protocol (Póvoas et al. 2018, 2019a).

With the aim of limiting the constraints associated with exercise testing involving either maximal or submaximal effort, alternative procedures for estimating VO_{2max} were developed. Uth et al. (2004) and Uth (2005) suggested a heart rate (HR)-based procedure for estimating VO_{2max} in well-trained male and female subjects. The proposed method provided practically acceptable estimates of individual VO_{2max} values resulting from the product of a theoretical factor (i.e. $15 \text{ ml kg}^{-1} \text{ min}^{-1}$) and subjects' maximal HR (HR_{max}) and resting HR (HR_{rest}) ratio (Uth et al. 2004). Popular predictive equations for estimating individual HR_{max} values were examined with the aim of promoting use of this HR-based (HR_{ratio}) procedure (Uth 2005; Uth et al. 2004). However, the reported data were obtained with descriptive studies examining well-trained subjects. The above premises and the procedural simplicity of the proposed HR_{ratio} method warrant extending the research to studies with populations of untrained subjects submitted to exercise interventions (Ahmed 2020).

Recreational football has been reported as providing clinically relevant ($3.5 \text{ ml kg}^{-1} \text{ min}^{-1}$) VO_{2max} improvements in untrained participants (Milanovic et al. 2018). This is across ages, gender and health conditions with limited weekly participation (i.e. ~2 training sessions per week) and short-term exposure (10–16 weeks) (Milanovic et al. 2015, 2018). Periodical evaluation of aerobic fitness was suggested

to control and regulate the effectiveness of recreational football interventions (Castagna et al. 2020). In this regard, the $HR_{ratio} VO_{2max}$ estimating method may be of great practical interest for guiding recreational football interventions. Furthermore, the reported training-induced variations in HR_{rest} and HR_{max} usually associated with VO_{2max} improvements promote assessment of the predictive validity of the HR_{ratio} method during training interventions (Póvoas et al. 2019a, 2019b; Uth et al. 2004).

The aim of this study was; therefore, to examine the applicability of an HR_{ratio} method for estimating VO_{2max} in male subjects participating in a recreational football intervention in the trained and untrained states. Method validity and measurements agreement were assumed as applicability construct.

Methods

Participants

In this study, 66 untrained male adults (age 39.3 ± 5.8 years, body mass 81.9 ± 10.8 kg, stature 173.2 ± 6.4 cm) involved in a recreational football training intervention volunteered to participate. The untrained state was defined as the participants having less than 20 min of exercise on 3 or more days a week (Church et al. 2010). Medical clearance for participation was obtained before the commencement of any of this study procedures. All the participants were familiarised with the procedures used in this investigation during the two weeks before the start of the study, performing submaximal versions of the treadmill test for VO_{2max} assessment and the Yo–Yo intermittent tests. The participants gave their written informed consent to participate in the study, which was conducted in accordance with the Declaration of Helsinki and ethical approval was provided by the local Institutional Review Board before commencement of the study data collection. All participants were informed of the risks and benefits of participation and made aware that they could withdraw from the study at any time without penalty.

Design

The HR_{ratio} method assumes a linear association between body mass specific VO_{2max} (i.e. $\text{ml kg}^{-1} \text{ min}^{-1}$) and HR_{max} and HR_{rest} (Uth et al. 2004). Estimation of VO_{2max} results from the multiplication of the HR_{max} and HR_{rest} ratio by a theoretical proportionality factor (TPF), assumed as $15 \text{ ml kg}^{-1} \text{ min}^{-1}$. Descriptive studies carried out with well-trained (7–9 h of weekly exercise) male ($60.9 \pm 5.5 \text{ ml kg}^{-1} \text{ min}^{-1}$) and female ($50.4 \pm 6.9 \text{ ml kg}^{-1} \text{ min}^{-1}$) participants found a PF of 14.5 ± 1.2 and $15.3 \pm 0.7 \text{ ml kg}^{-1} \text{ min}^{-1}$, respectively (Uth et al. 2004; Uth 2005). In this study, PF, HR_{rest} and

HR_{\max} were evaluated, in male untrained participants who volunteered to participate in a 12-week recreational football intervention, at baseline ($n=66$) and post-intervention ($n=28$), i.e. in the untrained and trained states. It was only possible to evaluate all the procedures considered in this study to assess the individual HR_{\max} at the end of the recreational football intervention, i.e. in the trained state, in 28 out of the initial 66 participants (Póvoas et al. 2019b). The resulting $VO_{2\max}$ values were compared considering either the population-specific proportionality factor (SPF; $14.6 \pm 2.6 \text{ ml kg}^{-1} \text{ min}^{-1}$) or the TPF (i.e. $15 \text{ ml kg}^{-1} \text{ min}^{-1}$). Agreement between measures was assessed by comparing estimated and actual $VO_{2\max}$ values across the intervention using either actual HR_{\max} or estimated HR_{\max} . Participants' HR_{\max} was assessed using a multiple approach to ensure assessment accuracy (Póvoas et al. 2019b). Population-specific equations were used to obtain estimated HR_{\max} (Póvoas et al. 2020). With the aim to test the population validity of the HR_{ratio} method, the participants' actual $VO_{2\max}$ was estimated dividing the HR_{\max} assessed either with the multiple approach or estimated with population valid equations by HR_{rest} . The obtained HR_{ratio} was then multiplied by the TPF ($15 \text{ ml kg}^{-1} \text{ min}^{-1}$) or the SPF for comparisons.

The recreational football intervention, consisted of 2–3 60-min weekly training sessions in the form of 45-min small-sided games played on an artificial pitch (7v7; $43 \times 27 \text{ m}$ pitch, 83 m^2 per player).

Testing procedures

The participants' HR_{\max} was assessed using the procedures suggested by Póvoas et al. (2019b). This procedure considered HR_{\max} as the highest value across a treadmill test until exhaustion (TT), field tests (i.e. Yo–Yo intermittent tests) and football matches played by the participants during the recreational football intervention. The field tests were performed at the same time of day, on the same artificial pitch, wearing the same footwear and under neutral environmental conditions. Before the field tests, the participants performed a standardised warm-up consisting of 10 min of running at different intensities including changes of direction. The field and TT tests were performed in a random order with at least a 4-day recovery period in between. No vigorous physical activity was performed on the day before the test procedures took place. Resting HR was measured in a quiet room at a constant temperature, with the participant in a supine position, after 15 min of rest. According to the evidence provided in recreational football interventions, estimations of individual HR_{\max} were performed using the $211 - 0.64 \times \text{age}$ and $226 - \text{age}$ equations (Póvoas et al. 2020; Warburton et al. 2006; Nes et al. 2013).

The TT (HP Cosmos Quasar, Nussdorf, Germany) consisted of 3 min of walking at 5 km h^{-1} and 2 min of

running at 8 km h^{-1} , with 0% inclination and then alternating between increases in speed (1 km h^{-1}) and inclination (1%) every 30 s until voluntary exhaustion. Expired respiratory gas fractions were measured using an open-circuit breath-by-breath automated gas analysis system (Quark CPET, Cosmed, Rome, Italy). Attainment of $VO_{2\max}$ was assumed when participants achieved a plateau in VO_2 despite an increase in exercise intensity and at least one of the following criteria: a respiratory exchange ratio (RER) greater than 1.10 and RPE equal to or higher than 7 (Midgley et al. 2006, 2007). The highest 15-s VO_2 during the final stages of the test was considered as the individual $VO_{2\max}$ (Midgley et al. 2006, 2007). Data analysis was performed with manual inspection of each TT data file using an Excel file (Microsoft, Redmont, USA). The average TT duration was within the range suggested for $VO_{2\max}$ assessment ($10.7 \pm 1.5 \text{ min}$; 95% CI 9.8–10.7) (Midgley et al. 2006, 2007). Post-test verification was performed for metabolic computations to correct gas analyser drift bias (Garcia-Tabar et al. 2015).

All exercise HRs were recorded in 1-s intervals using Polar Team System 2 HR monitors (Polar Electro Oy, Kempele, Finland). The participants were acquainted with the use of HR monitors in advance. The participants were allowed to drink water ad libitum to ensure proper hydration during all the exercise conditions considered in this study.

Statistical analyses

Results are expressed as means \pm standard deviations, 95% confidence intervals (95% CI) and ranges when appropriate. Normality assumption was verified using the Shapiro–Wilk W test. An one-way repeated-measurements analysis of variance (ANOVA) with post hoc Least Significant Difference test was used to compare $VO_{2\max}$ values across the considered estimation methods. Practical differences were assessed as partial eta squared (η^2_p) and magnitudes rated as follows: $\eta^2_p \geq 0.14$ large effect, $0.14 > \eta^2_p \geq 0.06$ medium effect, $0.06 > \eta^2_p \geq 0.01$ small effect and $\eta^2_p < 0.01$ trivial effect (Bakeman 2005). Pearson correlation (r) was used to assess the associations between variables. The magnitude of the reported effects was described using the Hopkins et al. (2009) criteria and the Cook's distance analysis was considered to detect possible influential outliers. The Cohen's d was used to evaluate the effect size, with values above 0.8, between 0.8 and 0.5, between 0.5 and 0.2 and lower than 0.2 considered as large, moderate, small and trivial, respectively (Cohen 1988). Measurement agreement was assessed using the Bland and Altman approach (Bland and Altman 1986). Significance was set at 5% ($p < 0.05$).

Results

Pre-intervention

Pre-intervention HR_{max} and HR_{rest} values were 189 ± 8 beats min^{-1} (187–191) and 68 ± 12 beats min^{-1} (65–71), respectively. The average baseline SPF value was 14.6 ± 2.6 ml $kg^{-1} min^{-1}$ (13.9–15.2). The participants' actual VO_{2max} was significantly different from the VO_{2max} ($+0.6$ ml $kg^{-1} min^{-1}$, $\sim 2\%$, $p=0.01$) estimated using the theoretical TPF (i.e. $VO_{2max} Est_{TPF}$, $TPF=15$) and VO_{2max} (-1.9 ml $kg^{-1} min^{-1}$, $\sim 5\%$, $p=0.01$) assessed considering the theoretical HR_{max} equation (i.e. $211 - 0.64 \times age$, $VO_{2max} Est_{Nes}$) with a medium effect (Table 1). Nonsignificant small differences were reported between $VO_{2max} Est_{War}$ (i.e. HR_{max} using the $226 - age$ equation), $VO_{2max} Nes_{TPF}$ (using the $211 - 0.64 \times age$ equation and 15 as PF), $VO_{2max} War_{TPF}$ (using the $226 - age$ equation and 15 as PF) and actual VO_{2max} values. A trivial nonsignificant difference between $VO_{2max} Est$ (using the SPF) and actual VO_{2max} was found.

A moderate and significant ($p=0.008$) association was found between pre-intervention VO_{2max} and HR_{rest} ($r=-0.33$, from -0.52 to -0.09). Pre-intervention HR_{max} and VO_{2max} were not significantly correlated ($r=0.16$, -0.08 to 0.39 , $p=0.20$). A moderate significant association was detected between pre-intervention VO_{2max} and TPF ($r=0.46$, $0.24-0.63$, $p=0.0001$). Resting HR was significantly associated with TPF ($r=0.66$, $0.49-0.77$, $p<0.0001$, large). A small nonsignificant association ($r=0.16$, -0.08 to 0.39 , $p=0.20$) was found between HR_{max} and PF.

The measurement agreement between pre-intervention VO_{2max} and VO_{2max} estimating variables reported significant

bias when considering $VO_{2max} Est_{Nes}$ and $VO_{2max} Est_{TPF}$ (Table 2, Figs. 1 and 2).

Post-intervention

Post-intervention HR_{rest} and HR_{max} were 61 ± 10 and 181 ± 10 beats min^{-1} , respectively. Significant ($p<0.0001$) differences were reported between pre-to-post HR_{rest} (6.7 ± 7.5 beats min^{-1} , $3.9-9.7$) and HR_{max} (4.8 ± 4.1 beats min^{-1} , $3.2-6.4$). Nonsignificant associations were detected between VO_{2max} post and HR_{rest} ($r=-0.10$, -0.45 to 0.29 , $p=0.63$) and HR_{max} ($r=0.23$, -0.15 to 0.56 , $p=0.23$). The post-intervention SPF was moderately ($r=0.46$, $0.09-0.70$, $p=0.02$) associated with post-intervention VO_{2max} . Very large and small associations were detected between post-intervention HR_{rest} ($r=0.80$, $0.62-0.91$, $p<0.0001$) and HR_{max} ($r=-0.21$, -0.54 to 0.17 , $p=0.28$) with post-intervention SPF, respectively. The VO_{2max} estimation values were not significantly different (from trivial to medium effect) from post-intervention VO_{2max} (Table 3).

Training intervention

The participants' ($n=28$) VO_{2max} significantly ($p<0.0001$, $d=0.93$) improved at post-intervention, by 3.2 ± 3.4 ml $kg^{-1} min^{-1}$ (1.9–4.5), with mean values changing from 41.0 ± 5.3 to 44.2 ± 5.2 ml $kg^{-1} min^{-1}$. Significant decreases in HR_{rest} (from 68 ± 13 to 61 ± 10 beats min^{-1} , $4-10$, $p<0.0001$, $d=1.0$) and HR_{max} (from 186 ± 9 to 181 ± 10 beats min^{-1} , $3-6$, $p<0.0001$, $d=1.3$) were observed at post-intervention.

Table 1 Comparisons between pre-intervention actual VO_{2max} and VO_{2max} estimated values ($n=66$)

Variable	VO_{2max}	Actual VO_{2max}		Estimated VO_{2max}			
		$VO_{2max} Est_{SPF}$	$VO_{2max} Est_{TPF}$	$VO_{2max} Nes_{SPF}$	$VO_{2max} Warb_{SPF}$	$VO_{2max} Nes_{TPF}$	$VO_{2max} Warb_{TPF}$
Mean	41.3	42.0	43.2	40.7	40.9	42.6	42.8
SD	6.2	6.9	7.1	6.4	6.4	7.3	7.4
95% CI	39.8–42.8	40.3–43.7	41.5–44.9	39.1–42.2	39.3–42.5	40.8–44.4	41.0–44.6
%CV	15.1	16.5	16.5	2.0	3.1	17.2	17.3
p Level		0.45	0.04	0.01	0.09	0.16	0.11
η^2_p		0.009	0.065	0.098	0.045	0.030	0.040
95%CI diff		-2.4 to 1.1	-3.7 to -0.1	0.2–1.1	-0.1 to 1.0	-3.1 to 0.5	-3.3 to 0.4

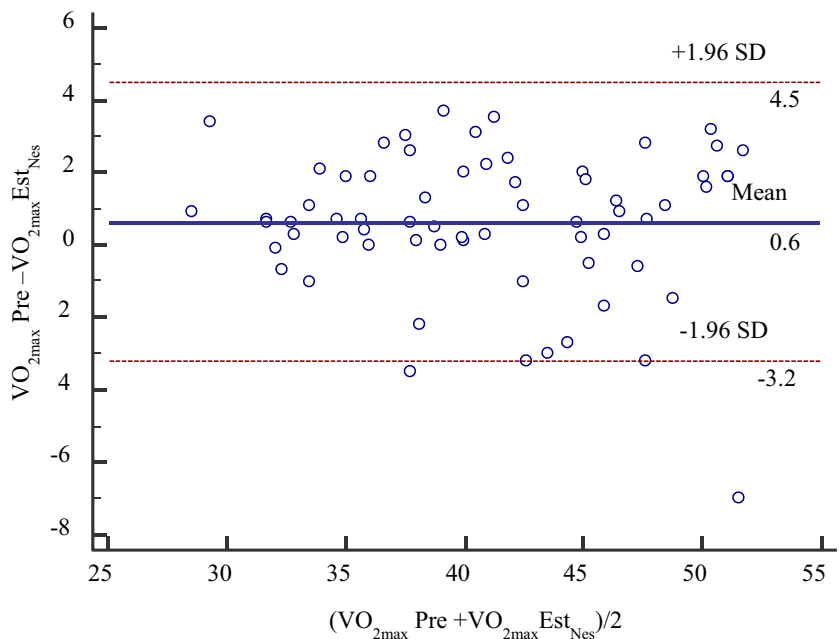
VO_{2max} baseline maximal oxygen uptake, $VO_{2max} Est_{SPF}$ baseline maximal oxygen uptake estimated with this study population-specific proportional factor (SPF) and actual HR_{max} , $VO_{2max} Est_{TPF}$ baseline maximal oxygen uptake estimated using theoretical proportional factor (TPF, i.e. 15) and actual HR_{max} , $VO_{2max} Nes_{SPF}$ baseline maximal oxygen uptake estimated using Nes et al. (2013) equation for HR_{max} with this study population-specific proportional factor (SPF), $VO_{2max} Warb_{SPF}$ baseline maximal oxygen uptake estimated using Warburton et al. (2006) equation for HR_{max} with this study population-specific proportional factor (SPF), $VO_{2max} Nes_{TPF}$ baseline maximal oxygen uptake estimated using Nes et al. (2013) equation for HR_{max} and theoretical proportional factor (TPF, i.e. 15), $VO_{2max} Warb_{TPF}$ baseline maximal oxygen uptake estimated using Warburton et al. (2006) equation for HR_{max} and theoretical proportional factor (TPF, i.e. 15)

Table 2 Measurements agreement values between pre-intervention actual VO_{2max} and VO_{2max} estimated values ($n=66$)

Variable	Actual VO_{2max}		Estimated VO_{2max}			
	$VO_{2max}Est_{SPF}$	$VO_{2max}Est_{TPF}$	$VO_{2max}Est_{NES_{SPF}}$	$VO_{2max}Est_{Warb_{SPF}}$	$VO_{2max}Nes_{TPF}$	$VO_{2max}Warb_{TPF}$
Difference	- 0.7	- 1.9	0.6	0.4	- 1.3	- 1.5
SD	7.1	7.2	2.0	2.1	7.5	7.5
95% CI	- 2.4 to 1.1	- 3.7; - 0.1	0.2–1.1	0.1–1.0	- 3.1 to 0.5	- 3.3 to 0.4
<i>p</i> value	0.45	0.04	0.01	0.09	0.2X	0.11
Upper limit	13.3	12.3	4.9	4.5	13.4	13.2
95% CI	10.3–16.3	9.2–15.3	3.7–5.3	3.6–5.3	10.2–16.5	10.0–16.3
Lower limit	- 14.6	- 16.1	- 3.2	- 3.59	- 16.0	- 16.1
95% CI	- 17.6; - 11.6	- 4.0; - 2.4	- 4.46; - 2.72	- 19.1; - 13.0	- 19.1; - 12.8	- 19.3; - 13.0

$VO_{2max}Est_{SPF}$ baseline maximal oxygen uptake estimated with this study population-specific proportional factor (SPF) and actual HR_{max} , $VO_{2max}Est_{TPF}$ baseline maximal oxygen uptake estimated using theoretical proportional factor (TPF, i.e. 15) and actual HR_{max} , $VO_{2max}NES_{SPF}$ baseline maximal oxygen uptake estimated using Nes et al. (2013) equation for HR_{max} with this study population-specific proportional factor (SPF), $VO_{2max}Warb_{SPF}$ baseline maximal oxygen uptake estimated using Warburton et al. (2006) equation for HR_{max} with this study population-specific proportional factor (SPF), $VO_{2max}Nes_{TPF}$ baseline maximal oxygen uptake estimated using Nes et al. (2013) equation for HR_{max} and theoretical proportional factor (TPF, i.e. 15), $VO_{2max}Warb_{TPF}$ baseline maximal oxygen uptake estimated using Warburton et al. (2006) equation for HR_{max} and theoretical proportional factor (TPF, i.e. 15)

Fig. 1 Bland and Altman plot of pre-intervention VO_{2max} against VO_{2max} estimated using the Nes et al. (2013) equation for maximal heart rate. For estimating the VO_{2max} was used the theoretical factor (i.e. $15\text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)



Discussion

The purpose of this study was to examine the applicability of the HR_{ratio} method for estimating VO_{2max} in recreational football players in the untrained and trained states. This with the aim of avoiding all the logistical and procedural costs and constraints usually associated with field and laboratory assessments. This study’s results have shown that in the untrained state the participants’ actual VO_{2max} was moderately lower than the estimated VO_{2max} using TPF. A

trivial nonsignificant difference was found when VO_{2max} was estimated using SPF. When using estimated HR_{max} and TPF, a small nonsignificant difference was reported between actual and estimated VO_{2max} . In the trained state, the estimated VO_{2max} values were not significantly different from the post-intervention actual VO_{2max} . Large effect sizes were found when considering TPF for estimating VO_{2max} using actual HR_{max} (i.e. $VO_{2max}Est_{TPF}$) and using the Nes et al. (2013) formula (i.e. $VO_{2max}Nes_{TPF}$). The results of this study provide evidence of the applicability

Fig. 2 Bland and Altman plot of pre-intervention VO_{2max} against VO_{2max} estimated using the theoretical factor (i.e. 15 ml $kg^{-1} min^{-1}$) and actual maximal heart rate

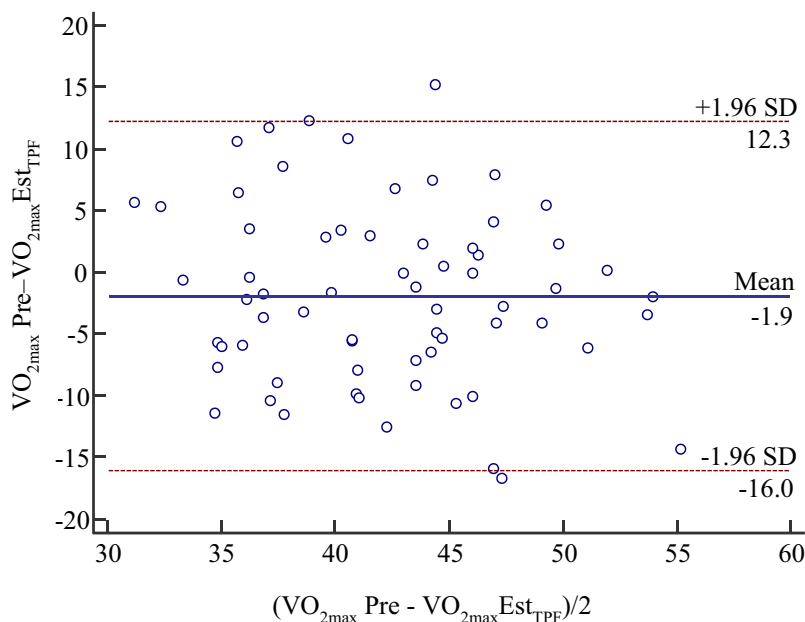


Table 3 Comparisons between post-intervention actual VO_{2max} and VO_{2max} estimated values ($n = 28$)

Variable	VO_{2max}	$VO_{2max} Est_{SPF}$	$VO_{2max} Est_{SPF}$	$VO_{2max} Est_{TPF}$	$VO_{2max} Est_{NES_{SPF}}$	$VO_{2max} Est_{2 Warb_{SPF}}$	$VO_{2max} Nes_{TPF}$	$VO_{2max} Warb_{TPF}$
Mean	44.2	44.3	45.4	45.6	46.4	46.6	46.7	46.8
SD	5.2	7.9	8.1	8.1	7.7	8.0	7.8	8.0
95% CI	42.1–46.2	41.3–47.4	42.2–48.5	42.5–48.8	43.5–49.4	43.48–49.65	43.7–49.7	43.7–49.9
%CV	11.8	17.8	17.8	17.8	16.6	17.1	16.6	9.4
p Level		0.920	0.481	0.389	0.176	0.150	0.133	0.114
η^2_p		0.000	0.019	0.280	0.067	0.075	0.820	0.090
95%CI diff		- 3.5 to 3.2	- 4.6 to 2.2	- 4.9 to 2.0	- 5.5 to 1.1	- 5.7 to 0.9	- 5.8 to 0.8	- 6.0 to 0.7

VO_{2max} baseline maximal oxygen uptake, $VO_{2max} Est_{SPF}$ baseline maximal oxygen uptake estimated with this study population-specific proportional factor (SPF) and actual HR_{max} , $VO_{2max} Est_{TPF}$ baseline maximal oxygen uptake estimated using theoretical proportional factor (TPF, i.e. 15) and actual HR_{max} , $VO_{2max} NES_{SPF}$ baseline maximal oxygen uptake estimated using Nes et al. (2013) equation for HR_{max} with this study population-specific proportional factor (SPF), $VO_{2max} Warb_{SPF}$ baseline maximal oxygen uptake estimated using Warburton et al. (2006) equation for HR_{max} with this study population-specific proportional factor (SPF), $VO_{2max} Nes_{TPF}$ baseline maximal oxygen uptake estimated using Nes et al. (2013) equation for HR_{max} and theoretical proportional factor (TPF, i.e. 15), $VO_{2max} War_{TPF}$ baseline maximal oxygen uptake estimated using Warburton et al. (2006) equation for HR_{max} and theoretical proportional factor (TPF, i.e. 15)

of HR_{ratio} in estimating VO_{2max} in male adult/middle-aged recreational football players.

In clinical settings, VO_{2max} is used to classify the patient’s physiological reserve and to discipline admission and guide rehabilitation programmes (Ahmed 2020). Uth (2005) and Uth et al. (2004) tested the validity and measurement accuracy of a VO_{2max} estimation method requiring resting and maximal HR values. To facilitate the procedures in the use of their proposed VO_{2max} estimating method, the cited authors proposed the use of age-dependent equations. The satisfactory results reported with trained individuals suggested the use of this HR_{ratio} method with untrained participants.

Recreational football has been reported as an effective exercise mode for enhancing participants’ VO_{2max} with

low training exposure (i.e. 2 weekly training sessions for 10–12 weeks) (Milanovic et al. 2018). Furthermore, the reported average changes (i.e. 3.5 ml $kg^{-1} min^{-1}$) are deemed to be clinically sound and to potentially reduce cardiovascular disease and all-cause death (Aspenes et al. 2011; Nes et al. 2013). The interest in recreational football for cardiovascular fitness promoted its popularity as a training intervention in the general population and the use of objective low-costs tests to estimate VO_{2max} to control and regulate recreational football implementation (Castagna et al. 2020; Póvoas et al. 2019a).

This study’s results clearly indicated that the HR_{ratio} method may represent a useful tool for evaluating cardiorespiratory fitness in healthy adult/middle-aged men enrolled

in recreational football interventions. The reported differences were practically acceptable by reference to the usual measurement error for $VO_{2\max}$ assessment and the supposed clinical importance of variations in cardiorespiratory fitness (Aspenes et al. 2011; Nes et al. 2014). Indeed, this study's calculations to estimate $VO_{2\max}$ produced average differences in the range of $\pm 2\%$, corresponding to approximately $2 \text{ ml kg}^{-1} \text{ min}^{-1}$. Although lower than the supposed clinical relevance, the use of TBF (i.e. 15) reported overestimations in actual $VO_{2\max}$ values that may exceed 1 MET when considering the reported 95% confidence interval limits (Table 1). This suggests that SPF is of interest when dealing with recreational football participants with health and baseline fitness levels like those seen in this study.

The assessment of $VO_{2\max}$ under laboratory controlled procedures has been reported to be affected by biological and systematic error that is supposed to result in a $\sim 6\%$ measurement error (Katch et al. 1982), with biologically derived variations accounting for 90% of the global variation (Beltz et al. 2016; Balady et al. 2010). In their review, Balady et al. (2010) quantified the biological error in $VO_{2\max}$ assessment as 3–4%. Given that the beneficial effects of variations on patients' cardiorespiratory fitness have been reported in absolute values, the quantification of raw differences assumes clinical relevance (Aspenes et al. 2011; Nes et al. 2014). The absolute test–retest error in $VO_{2\max}$ has been reported to be quantified as $2.58 \text{ ml kg}^{-1} \text{ min}^{-1}$ (Beltz et al. 2016), a value that is greater than the differences reported across the various estimation approaches used in this study (i.e. $0.7\text{--}1.5 \text{ ml kg}^{-1} \text{ min}^{-1}$).

This recreational football training resulted in a $\sim 8\%$ improvement in $VO_{2\max}$, corresponding to $3.2 \text{ ml kg}^{-1} \text{ min}^{-1}$. Large and significant decrements were reported in HR_{rest} ($\sim 10\%$) and HR_{\max} ($\sim 3\%$) post-intervention. Cardiorespiratory fitness improvement was unrelated to the reported variations in HR ratio variables. These changes are in line with previously reported training studies, supporting the contention of football as an effective intervention for improving cardiorespiratory fitness in previously untrained men (Milanovic et al. 2015). In the acquired higher cardiorespiratory fitness condition, i.e. trained state, the variables estimating $VO_{2\max}$ used in this study maintained their predictive strength, suggesting the use of the HR ratio method in recreational football interventions to control and regulate the training process. Interestingly, the reported variations at post-training rest and maximal HR did not affect the predictive strength of the proposed metrics.

This study's findings provide strong supporting evidence for interest in the HR_{ratio} method, previously successfully proposed for estimating $VO_{2\max}$ in trained individuals (Uth 2005; Uth et al. 2004), for untrained participants. With this study, the practical interest of the HR_{ratio} method was confirmed and proved successful for estimating

cardiorespiratory fitness in the untrained state. Thus, extending the applicability of this HR-based method to the general population. The precision of the HR_{ratio} may be satisfactory even when using the available equations to estimate individual HR_{\max} , which remains the most challenging variable in the calculation involved in this ideally cardiopulmonary test-independent approach (Uth 2005; Uth et al. 2004). However, this study's findings suggest that the precision of the estimation may be promoted if population-specific equations are considered (Póvoas et al. 2020) and specifically the use of the Nes et al. (2013) equation in the untrained state when considering the theoretical BF.

Perspectives

The robustness of the HR_{ratio} approach logically lies in the accuracy of the variables considered. The internal validity of this study was promoted using a validated population-specific (i.e. recreational football) multiple approach for determining participants' HR_{\max} (Póvoas et al. 2019b). Individual HR_{\max} was determined using maximal laboratory and field tests to confirm the achievement of maximal values (Póvoas et al. 2019b). However, no form of re-test was performed to confirm participants' $VO_{2\max}$ achievement (Poole and Jones 2017). This may be regarded as this study's main limitation in light of the arguments reported on maximal aerobic scopus of humans and the methods that should be used to achieve it (Poole and Jones 2017; Green and Askew 2018). Even if consideration for a confirmation $VO_{2\max}$ test is methodologically sound, the practical effectiveness of this consistency measurement procedure has been challenged when dealing with untrained populations (Azevedo et al. 2018). Although an impeccable procedure, the $VO_{2\max}$ confirmation test (i.e. cardiorespiratory re-testing) was reported to not provide the expected measurement accuracy, calling into question the cost/benefit of this practice in untrained individuals (Azevedo et al. 2018).

The interest of the HR_{ratio} method due to its a priori potential for categorising the cardiorespiratory fitness of recreational football players warrants further studies with populations of different sex and age from this study's participants. In addition, future cross-validation studies should confirm this study's SPF. The robustness of the HR_{ratio} validity of the training study should be verified with large-scale randomised controlled trials.

Author contributions CC devised the study. SP: collected the data. CC and SP analysed the data and wrote the first draft of the paper. PK supervised data analyses and edited the manuscript until the submitted version. All authors read and approved the final version of the manuscript.

Declarations

Conflict of interest The authors do not have any conflict of interests and state that the results of the present study do not constitute endorsement by EJAP. The authors alone are responsible for the content and writing of the manuscript.

References

- Ahmed I (2020) COVID-19—does exercise prescription and maximal oxygen uptake (VO_{2max}) have a role in risk-stratifying patients? *Clin Med (lond)*. <https://doi.org/10.7861/clinmed.2020-0111>
- Aspenes ST, Nilsen TI, Skaug EA, Bertheussen GF, Ellingsen Ø, Vatten L, Wisløff U (2011) Peak oxygen uptake and cardiovascular risk factors in 4631 healthy women and men. *Med Sci Sports Exerc* 43(8):1465–1473. <https://doi.org/10.1249/MSS.0b013e31820ca81c>
- Azevedo P, Bhammar DM, Babb TG, Bowen TS, Witte KK, Rossiter HB, Brugniaux JV, Perry BD, de Lucas RD, Turnes T, Sabino-Carvalho JL, Lopes TR, Zacca R, Fernandes RJ, McKie GL, Hazell TJ, Helal L, da Silveira AD, McNulty CR, Roberg RA, Nightingale TE, Alrashidi AA, Mashkovskiy E, Krassioukov A, Clos P, Laroche D, Pageaux B, Poole DC, Jones AM, Schaun GZ, de Souza DS, de Lopes TOB, Vagula M, Zuo L, Zhao T (2018) Commentaries on viewpoint: VO_{2peak} is an acceptable estimate of cardiorespiratory fitness but not VO_{2max} . *J Appl Physiol* (1985) 125(1):233–240. <https://doi.org/10.1152/jappphysiol.00319.2018>
- Bakeman R (2005) Recommended effect size statistics for repeated measures designs. *Behav Res Methods* 37(3):379–384
- Balady GJ, Arena R, Sietsema K, Myers J, Coke L, Fletcher GF, Forman D, Franklin B, Guazzi M, Gulati M, Keteyian SJ, Lavie CJ, Macko R, Mancini D, Milani RV (2010) Clinician's guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. *Circulation* 122(2):191–225. <https://doi.org/10.1161/CIR.0b013e3181e52e69>
- Beltz NM, Gibson AL, Janot JM, Kravitz L, Mermier CM, Dalleck LC (2016) Graded exercise testing protocols for the determination of VO_{2max} : historical perspectives, progress, and future considerations. *J Sports Med* 2016:3968393. <https://doi.org/10.1155/2016/3968393>
- Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1(8476):307–310
- Castagna C, Krstrup P, Povoas S (2020) Yo–Yo intermittent tests are a valid tool for aerobic fitness assessment in recreational football. *Eur J Appl Physiol* 120(1):137–147. <https://doi.org/10.1007/s00421-019-04258-8>
- Church TS, Blair SN, Cocroham S, Johannsen N, Johnson W, Kramer K, Mikus CR, Myers V, Nauta M, Rodarte RQ, Sparks L, Thompson A, Earnest CP (2010) Effects of aerobic and resistance training on hemoglobin A1c levels in patients with type 2 diabetes: a randomized controlled trial. *JAMA* 304(20):2253–2262. <https://doi.org/10.1001/jama.2010.1710>
- Cohen J (1988) *Statistical power analysis for the behavioral sciences*, 2nd edn. Lawrence Erlbaum Associates, Hillsdale
- Diaz-Canestro C, Montero D (2019) Sex dimorphism of VO_{2max} trainability: a systematic review and meta-analysis. *Sports Med* 49(12):1949–1956. <https://doi.org/10.1007/s40279-019-01180-z>
- Garcia-Tabar I, Eclache JP, Aramendi JF, Gorostiaga EM (2015) Gas analyzer's drift leads to systematic error in maximal oxygen uptake and maximal respiratory exchange ratio determination. *Front Physiol* 6:308. <https://doi.org/10.3389/fphys.2015.00308>
- Green S, Askew C (2018) VO_{2peak} is an acceptable estimate of cardiorespiratory fitness but not VO_{2max} . *J Appl Physiol* 125(1):229–232. <https://doi.org/10.1152/jappphysiol.00850.2017>
- Hopkins WG, Marshall SW, Batterham AM, Hanin J (2009) Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41(1):3–13. <https://doi.org/10.1249/MSS.0b013e31818cb278>
- Katch VL, Sady SS, Freedson P (1982) Biological variability in maximum aerobic power. *Med Sci Sports Exerc* 14:21–25
- Liff MH, Hoff M, Fremo T, Wisløff U, Videm V (2020) An estimation model for cardiorespiratory fitness in adults with rheumatoid arthritis. *Med Sci Sports Exerc* 52(6):1248–1255. <https://doi.org/10.1249/mss.0000000000002250>
- Midgley AW, McNaughton LR, Wilkinson M (2006) Criteria and other methodological considerations in the evaluation of time at VO_{2max} . *J Sports Med Phys Fit* 46(2):183–188
- Midgley AW, McNaughton LR, Polman R, Marchant D (2007) Criteria for determination of maximal oxygen uptake: a brief critique and recommendations for future research. *Sports Med* 37(12):1019–1028
- Milanovic Z, Pantelic S, Covic N, Sporis G, Krstrup P (2015) Is recreational soccer effective for improving VO_{2max} a systematic review and meta-analysis. *Sports Med* 45(9):1339–1353. <https://doi.org/10.1007/s40279-015-0361-4>
- Milanovic Z, Pantelic S, Covic N, Sporis G, Mohr M, Krstrup P (2018) Broad-spectrum physical fitness benefits of recreational football: a systematic review and meta-analysis. *Br J Sports Med*. <https://doi.org/10.1136/bjsports-2017-097885>
- Nes BM, Janszky I, Wisloff U, Stoylen A, Karlsen T (2013) Age-predicted maximal heart rate in healthy subjects: the HUNT fitness study. *Scand J Med Sci Sports* 23(6):697–704. <https://doi.org/10.1111/j.1600-0838.2012.01445.x>
- Nes BM, Vatten LJ, Nauman J, Janszky I, Wisloff U (2014) A simple nonexercise model of cardiorespiratory fitness predicts long-term mortality. *Med Sci Sports Exerc* 46(6):1159–1165. <https://doi.org/10.1249/MSS.0000000000000219>
- Poole DC, Jones AM (2017) Measurement of the maximum oxygen uptake VO_{2max} : VO_{2peak} is no longer acceptable. *J Appl Physiol* 122(4):997–1002. <https://doi.org/10.1152/jappphysiol.01063.2016>
- Póvoas SCA, Krstrup P, Castagna C, da Silva PMR, Coelho ESMJ, Pereira RLM, Larsen MN (2018) Reliability of submaximal Yo–Yo tests in 9- to 16-year-old untrained schoolchildren. *Pediatr Exerc Sci* 30(4):537–545. <https://doi.org/10.1123/pes.2017-0139>
- Póvoas SC, Krstrup P, Castagna C (2019a) Submaximal field testing validity for aerobic fitness assessment in recreational football. *Scand J Med Sci Sports*. <https://doi.org/10.1111/sms.13606>
- Póvoas SCA, Krstrup P, Pereira R, Vieira S, Carneiro I, Magalhaes J, Castagna C (2019b) Maximal heart rate assessment in recreational football players. A study involving a multiple testing approach. *Scand J Med Sci Sports*. <https://doi.org/10.1111/sms.13472>
- Póvoas S, Krstrup P, Castagna C (2020) Estimation of maximal heart rate in recreational football: a field study. *Eur J Appl Physiol* 120(4):925–933. <https://doi.org/10.1007/s00421-020-04334-4>
- Uth N (2005) Gender difference in the proportionality factor between the mass specific VO_{2max} and the ratio between HR(max) and HR(rest). *Int J Sports Med* 26(9):763–767. <https://doi.org/10.1055/s-2005-837443>
- Uth N, Sorensen H, Overgaard K, Pedersen PK (2004) Estimation of VO_{2max} from the ratio between HR_{max} and HR_{rest} —the Heart Rate Ratio Method. *Eur J Appl Physiol* 91(1):111–115. <https://doi.org/10.1007/s00421-003-0988-y>
- Warburton D, Nicol C, Bredin SSD (2006) Prescribing exercise as preventative therapy. *CMAJ* 174(7):961–974
- Zeijer J, Ombrellaro KJ, Perumal N, Keil T, Mensink GBM, Finger JD (2019) Correlates and determinants of cardiorespiratory fitness in adults: a systematic review. *Sports Med Open* 5(1):39. <https://doi.org/10.1186/s40798-019-0211-2>

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