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Research Article

Heart Rate Ratio: A Valid Method for Maximal Oxygen Uptake Assessment in Professional Football Players

Paulo Roberto Santos-Silva[1]*, Júlia Maria Andrea Greve[1], Eneas Martins de Oliveira Lima[1], Júlio Cesar Carvalho Nardelli[1], Adriano Marques Almeida[1], Arnaldo José Hernandez[1], André Pedrinelli[1], Celso Ferreira[2], and Guilherme Veiga Guimarães[3]

[1]*Department of Orthopaedics and Traumatology, FIFA and FIMS Medical Centre of Excellence, São Paulo University Medical School, Hospital das Clinicas, São Paulo, Brazil.*

[2]*Department of Cardiology, Paulista School of Medicine (PSM), Hospital São Paulo, Federal University of São Paulo (UNIFESP), São Paulo, Brazil.*

[3]*Heart Failure Laboratory of the Heart Institute (InCor), São Paulo University Medical School, Hospital das Clinicas, São Paulo, Brazil.*

ABSTRACT

Background: Direct measurement of $\dot{V}O_2max$ (the gold standard) requires expensive equipment and exhaustive exercise testing. In football, the search for non-invasive, practical, and low-cost methods is essential for frequent athlete monitoring. The Heart Rate Ratio (HRratio) method emerges as a viable alternative, based on the linear relationship between oxygen uptake and heart rate.

Objective: The aim of the study was to estimate maximal oxygen uptake ($\dot{V}O_2max$) from the Heart Rate Ratio (HRmax/HRrest) method, providing a practical and non-invasive alternative to maximal testing.

Methods: A proportionality factor (PF) of 15.8 $mL.kg^{-1}.min^{-1}$ was calculated from an experimental group of 24 football players and subsequently validated in a confirmatory group of 70 players. The criterion $\dot{V}O_2max$ was measured using a cardiopulmonary treadmill (Heck protocol) exercise test (gold standard). The estimated $\dot{V}O_2max$ was compared with the measured $\dot{V}O_2max$ and with $\dot{V}O_2max$ predicted using the Tanaka equation for HRmax.

Results: No significant difference was found between the measured $\dot{V}O_2max$ and the $\dot{V}O_2max$ predicted by the validated PF of 15.8 (PF) and HRmax/HRrest (58.3 vs. 59 $mL.kg^{-1}.min^{-1}$; p=0.108; d=0.27, small) or the Tanaka equation (58.3 vs. 58.9 $mL.kg^{-1}.min^{-1}$; p=0.158; d=0.22, small). Significant correlations were observed for both the PF method (r = 0.455, p<0.001) and the Tanaka method (r=0.509, p<0.001). Regression analyses revealed a low Standard Error of Estimation (SEE) for the $\dot{V}O_2max$ measured from HRmax (4%) and HRmax predicted from Tanaka (4.5%). Bland-Altman analysis demonstrated good agreement between the two methods.

Conclusion: The Heart Rate Ratio Method is a valid tool for estimating $\dot{V}O_2max$ in this population. $\dot{V}O_2max$ can be estimated indirectly by the following equation, using a factor specific to football players: $\dot{V}O_2max$ = (PF times HRmax/HRrest), where PF is 15.8 $mL.kg^{-1}.min^{-1}$.

Keywords

Maximal heart rate, Resting heart rate, Maximal oxygen uptake, Athletes, Heart rate index.

Corresponding Author Information

Paulo Roberto Santos-Silva

Department of Orthopaedics and Traumatology, FIFA and FIMS Medical Centre of Excellence, São Paulo University Medical School, Hospital das Clinicas, São Paulo, Brazil, Phone: (+5511) 2661 6041. ORCID: 0000-0003-1223-5862.

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Introduction

The most accurate method for assessing maximal oxygen uptake $\dot{V}O_2$max is through direct analysis of pulmonary gas exchange [1], a gold-standard technique that typically yields a low coefficient of variation (2% to 4%) and high reliability ($r = 0.95$) [2,3]. Despite this rigor, the methodology faces significant practical hurdles: it involves high costs, requires specialized medical infrastructure and qualified personnel, and is time-consuming, limiting testing to one individual at a time [4]. These limitations underscore the importance of precise predictive methods as viable alternatives for large-scale epidemiological and routine field studies [5].

The core issue with most existing predictive equations, however, is their inconsistent accuracy, often presenting substantial errors that can overestimate $\dot{V}O_2$max by 15% to 20% [6]. In the search for a more precise and accessible field alternative, Uth, Sorensen, Overgaard, & Pedersen [7] proposed a theoretical model derived from the Fick Principle. This principle posits that $\dot{V}O_2$max modification is intrinsically associated with changes in stroke volume, heart rate (HR), and the arteriovenous O_2 difference [8]. Based on this concept, a robust relationship was established between maximal heart rate (HRmax and resting heart rate (HRrest), suggesting that mass-specific $\dot{V}O_2$max mL/kg/min could be estimated by multiplying the HRmax/HRrest ratio by a mathematical proportionality factor of approximately 15.3 [7,8].

While promising, few studies have explored this specific prediction methodology, and none have applied it to professional football players, a population known for unique physiological adaptations. Therefore, using the Uth equation as a methodological model, the present study aimed to address this gap: (a) Examine whether this theoretical proportionality factor could be confirmed by experimental data in elite football players; and (b) Evaluate the Limits of Agreement (LOA) for the prediction of $\dot{V}O_2$max using the experimentally established proportionality factor within a group of well-trained male football players.

Materials and Methods

Participants

Studies on 94 adult male elite professional football players from six teams of the Brazilian first and second division, aged 17 to 35, form the basis for this report (Table 1). To assess total athletic aptitude, the players were selected in the middle of the football season. The exclusion criteria were: (i) aged under 17 years or over 35 years, (ii) playing as a goalkeeper, (iii) and a history of serious injury or operative treatment, which could interfere with normal football training or competing at the time of the study. A general questionnaire was used to collect demographic information as (age, body mass, and height) as well as information concerning sports practice (number of years in high-performance sport, hours of training per week, number of weekly training sessions, and playing position on the field). To define the participants in our study as high-level athletes we follow some minimum criteria proposed by [9] (i) to be training in sports aiming to improve her performance to be formally performance and results, (ii) to be actively participating in sports competitions, (iii) to be formally registered in a local, regional or national sports federation, (iv) to have sports training and competition as major activity (way of living) or focus of personal interest, devoting several hours in all or most of these days to these activities, exceeding the time allocated to other types of professional or leisure activities. The players were experienced with meaningful in organized football training (Table 1). Players attended to our service, at the request of the teams' physicians, our FIFA and FIMS medical center of excellence for a medical-functional evaluation comprising: clinical examination, laboratory blood tests, resting electrocardiogram (ECG) and maximal treadmill cardiopulmonary exercise testing (CPX), under ECG monitoring. All athletes were registered with the Brazilian Football Confederation. All subjects signed written informed consent before volunteering for the study. The research protocol was approved by the Ethics Committee of the Faculty of Medicine, the University of São Paulo [Ref. number # 79975517.7.0000.0065] and by the Federal University of São Paulo (Paulista School of Medicine). [Ref. number # 79975517.7.3001.5505]. The study was conducted based on the principles of the Declaration of Helsinki for studies with human beings [10].

Study design

This study followed a cross-sectional validation design to evaluate the accuracy of the Heart Rate Ratio method in estimating maximal oxygen uptake ($\dot{V}O_2$max) among football athletes. To estimate the maximal oxygen uptake ($\dot{V}O_2$max in high-level male football players, we adapted the Heart Rate Ratio (HRmax/HRrest) technique. Initially, a proportionality factor was determined using a subgroup of players (n=24), yielding a specific value of 16 mL/kg/min. This finding is slightly higher than the 15.3 ± 0.7 mL/kg/min factor reported in endurance runners by Uth et al. [7]. Subsequently, based on an optimized proportionality constant derived from preliminary analyses, the primary study utilized a factor of 15.8 mL/kg/min for the estimation. The $\dot{V}O_2$ (mass-specific) was thus estimated using the following equation:

$$VO_{2max} = 15.8\,\mathrm{mL}\cdot\mathrm{kg}^{-1}\cdot\mathrm{min}^{-1} \times \frac{HR_{max}}{HR_{rest}}$$

A second group of players (70) was then employed to establish the Limits of Agreement (LOA) between these $\dot{V}O_2$max estimates (using both actual and predicted HRmax scenarios) and the direct measurements obtained via the cardiopulmonary exercise test (CPX).

Assessment procedure

Cardiopulmonary Exercise Testing (CPX)

All tests were always performed at the same time of the day between 8 a.m. and 12 a.m. All measurements took place under laboratory conditions (room temperature varying from 18°C to 23°C, at a relative humidity ranging between 35% to 70% and barometric pressure ranging between 692 mmHg to 697 mmHg). Each athlete underwent physician-supervised standard incremental CPX testing conducted on a motor-driven treadmill (h/p/cosmos™, pulsar, Nussdorf-Traunstein, South of Germany). The treadmill grade was constant at 1.15° (2% slope) to replicate outdoor over-ground running on grass, as according to Santos-Silva [11] running on grass corresponds to an inclination of approximately 2%. Besides, strong verbal encouragement to promote maximum effort was provided. Tests were terminated upon volitional exhaustion of the participant or the participant's inability to maintain the target treadmill speed. In this protocol, the players remained at rest for two minutes, and then warmed up for three minutes at treadmill speeds of 4.8, 6 and 7.2 $km \cdot h^{-1}$(one minute each). The test began at 8.4 $km \cdot h^{-1}$and the treadmill speed increased by 1.2 $km \cdot h^{-1}$ every two minutes. The incremental protocol performed by athletes was chosen to obtain time to exhaustion around 8-17 minutes [12]. During each graded exercise testing, breath-by-breath pulmonary ventilation, oxygen consumption, carbon dioxide production, and respiratory exchange ratio (RER) data were determined via a metabolic cart system (CPX/Ultima, MedGraphics™, St. Paul, Minnesota, USA). Before testing, subjects were fitted with a mouthpiece, nose clip, and headgear, which were used with the measurements. Prior to testing, the pneumotachometer was calibrated with ten samples from a 3-L calibration syringe. The gas analyzers were also calibrated before each test to room air and medically-certified calibration gases (12% and 21 % O_2 and 5.14% CO_2, respectively). Before each testing session, the gas analyzers were calibrated according to the manufacturer's recommendations. Heart rate (HR) was recorded during exercise by electrocardiography (6.4, HeartWare™, BH, Minas Gerais, Brazil). The ECG at resting and in the effort was performed by a cardiologist, while data collection was carried out by an experienced exercise physiologist. The day before the tests the athletes abstained from any intense exercise training for that period and all served fed 2-hours before the tests.

$\dot{V}O_2$ max Testing Assessment

Maximal oxygen uptake was assessed by the fulfillment of the following criteria: (1) a plateau ($\dot{V}O_2 \leq 2.1$ $mL \cdot kg^{-1} \cdot min^{-1}$ between the penultimate and the last stage of the test) in $\dot{V}O_2$ with increases in external work [13], (2) maximal respiratory exchange ratio (RER) ≥ 1.1 [14], (3) maximal HR within 5 $beats \cdot min^{-1}$ of the age-predicted maximum [208 - (0.7 ^{x} age)] [15], and (4) volitional fatigue and more than 18 on subjective Borg's scale (6-20) [16]. All subjects met the first three criteria. Additionally, data from the $\dot{V}O_2$max tests breath-by-breath data were time-averaged using 30-second intervals.

Resting Heart Rate Protocol

Resting heart rate (HRrest) was measured following the European Society of Hypertension guidelines [17]. To ensure accuracy, training intensity was reduced 24 hours prior to testing, and data collection was performed in the morning. The protocol consisted of a 10-minute stabilization period: 5 minutes in a supine position to ensure parasympathetic stabilization and minimize pre-test stress, followed by 5 minutes in a seated position to standardize the baroreflex response and sympathetic tone. This duration exceeds the 7-minute rest period recommended for obtaining reliable HRrest [18]. Following this, a 12-lead supine ECG was performed [19]. Maximum heart rate (HRmax) was recorded during the maximal exercise test, while predicted HR_{max} was calculated using the Tanaka equation [208 - (0.7 ^{x} age)] [15].

Statistical Analysis

Data were presented as mean ± standard deviation (SD) and median. The Gaussian distribution (normality) and the homogeneity of the data variances were verified by the Kolmogorov-Smirnov test (Z value <1.0) and Levine's tests. For the variables that presented these two qualifications, we used parametric tests (t-test), otherwise, non-parametric tests (Mann-Whitney U test). The number of samples required of individuals to compare two groups (control vs. confirmatory) of a finite population less than 5,000 and considering the common standard deviation to verify whether the two averages were similar, and considering the 95% probability to avoid the Type I error with a power of 80%, 77 players were needed. Linear regression was also used to verify the standard error of estimation (SEE) between the values measured (real) and estimated (predict), and if we're an association between the methods. The Bland-Altman technique was used to evaluate the agreement between the two proposed methods to measure the same item, presenting agreement limits that may or may not be clinically acceptable. When the limit of the agreement is too large, this represents little agreement between the methods. Therefore, the Bland-Altman analysis for the concordance limit analysis was used to test the applicability of an indirect test when it was validated in terms of the direct method [20]. We also use Cohen´s "*d* "scale to measure the size of the treatment effect between $\dot{V}O_2$max quantified by measured and estimated values [21]. The guidelines were originally set specifically for a scale as follows: 0.00–0.19: trivial; 0.20–0.59: small; 0.60–1.19: moderate; 1.20–1.99: large, and >2.00: very large [22]. The statistical analysis was performed using Sigma Stat software (version 3.5, Systat Software, Inc., Point Richmond, CA, USA). The confidence level for each was set at 95%.

Results

After medical screening, no health problems were found in football players, therefore, all were eligible for competitions and exercise training. Table 1 gives a comparative summary of the anthropometrics and physiological variables of the two groups used to study the proposed problem, and it was verified that both groups were homogeneous.

The data represent mean and standard deviation (SD), and in parentheses a (median). BMI, body mass index; $\dot{V}O_2$max, maximal oxygen uptake relative and absolute by CPX test; max HR, heart rate at max exercise test; resting HR, resting heart rate after 10 min; HR index, max heart rate ÷ resting heart rate; RER, respiratory exchange rate.

The age, body mass, height, and body mass index (BMI) were not different (Table 1). The players had the same experience time in football. There was no difference in HR max found in the CPX test and in resting HR in both groups used to test the study hypothesis (Table 1).

Table 1: Descriptive characteristics of the study sample.

Variables	Control subgroup (n=24/25%)	Confirmatory Group (n=70/75%)	Difference (%)	*p* value
Age (years)	21.3±4.6 (20)	20.8±3.7 (19)	2.34	<0.816
Body mass (kg)	72.0±5.3 (72.5)	72.1±5.0 (73)	-0.13	<0.962
Height (cm)	175.7±4.5 (175)	176±4.5 (175.5)	-0.17	<0.915
BMI ($kg{\cdot}m^{-2}$)	23.2±1.3 (23.2)	23.2±1.3 (23.5)	0	<0.747
Football practice (years)	7±3.5 (7.1)	6±3 (6.2)	14	<0.340
Football activity ($h{\cdot}wk^{-1}$)	10.6±0.7 (10.4)	10.7±0.2 (10.8)	0.9	<0.756
$\dot{V}O_2$max ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	58.8±2.6 (58.9)	58.3±2.6 (57.9)	0.85	<0.286
$\dot{V}O_2$max ($mL{\cdot}min^{-1}$)	4240±359 (4245)	4203±329 (4161.5)	0.9	<0.643
Max HR (bpm)	194±5.5 (194)	194±2.7 (193)	0	<0.824
Resting HR (bpm)	53±3 (53.5)	53±2.4 (53.5)	0	<0.352
HR index	3.65±0.1 (3.62)	3.68±0.1 (3.70)	-0.82	<0.402
Proportionality factor	16.1±0.72 (16)	15.8±0.72 (16)	1.8	<0.075
RER (VCO_2/VO_2)	1.11±0.05 (1.12)	1.12±0.07 (1.13)	-0.9	<0.521

The subgroup (n = 24) showed that the proportionality factor between HRmax/HRrest) and mass-specific $\dot{V}O_2$max was 15.8 (0.72) $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ (Table 1) $\dot{V}O_2$max in the remaining 70 football players could be estimated with a SEE of 2.386 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ (4.0%). When substituting measured HRmax with an age-predicted one (Tanaka equation, i.e., 208- 0.7 ^{x} age), SEE was 2.306 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ (4.5%), which is still equivalent to other indirect tests (Figure 2, 2A e 2C). This same thinking from the Uth group was practiced in the present study.

As seen in Figure 2, the regression lines obtained from these significant statistical correlations of direct $\dot{V}O_2$max by CPX test and indirect HR method at max exercise were significant ($r = 0.455$, $p < 0.001$ and $r = 0.81$, $p < 0.001$) (2A and 2B) and was also significant to indirect method of by Tanaka equation of prediction of HR by age ($r = 0.509$, $p < 0.001$, $r = 0.814$, $p < 0.001$) (2C and 2D) for prediction of $\dot{V}O_2$max. The SEE of $\dot{V}O_2$max in both predictive comparative conditions from HR method and application of proportionality factor 15.8 from exercise CPX test were 4% in $mL{\cdot}kg^{-1}{\cdot}min^{-1}$and 4.6% in $mL{\cdot}min^{-1}$, respectively), while by Tanaka equation were 4.5% at $mL{\cdot}kg^{-1}{\cdot}min^{-1}$and 4.5% at $mL{\cdot}min^{-1}$, respectively).

As illustrated in Figure 1, the direct $\dot{V}O_2$max measured via the CPX test was not statistically different from the estimated $\dot{V}O_2$max values across both calculation scenarios. Furthermore, the effect size verified by Cohen's d was consistently small when comparing the direct measurement to the estimated methods (Table 2).

As illustrated in Figure 3, a Bland-Altman means bias and LoA results for the $\dot{V}O_2$max measured and estimated for both methods. Mean bias results that are close to mean with narrow LoA indicate that there is little difference between the relative and absolute values. Bland-Altman plot of measured and predicted $\dot{V}O_2$max showed no significant trend among the mean and the difference between the two methods. Therefore, the results show that 95% of the differences between mean are between d+1.96 SD and d-1.96 SD. Therefore, the mean values found between the measured and estimated $\dot{V}O_2$max and the heart rate ratio method were within the established limits of agreement of 95% (± 1.96 SD). The Bland-Altman analysis comparing the directly measured $\dot{V}O_2$max and the $\dot{V}O_2$max estimated by the HRmax/HRrest ^{x} 15.8 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ method revealed a mean bias of 0.32 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. The 95% Limits of Agreement (LOA) ranged from -3.08 to +3.65 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ (Figure 3).

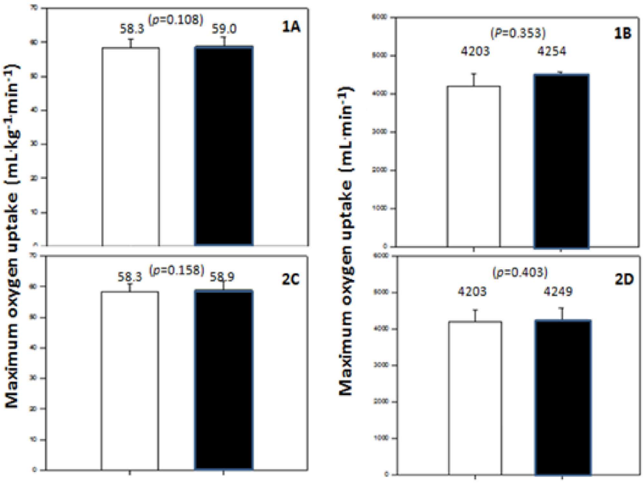

Figure 1: Comparative values of relative and absolute VO_2max by direct measurement (panel 1A and 1B) by the HRmax*HR rest ration in the CPX test and by predicted HRmax by age*HR rest (panel 2C and 2D) using the Tanaka equation.

Table 2: Compares the direct measurement (CPX test) to the two estimation methods for relative $\dot{V}O_2$max. Cohen´s *d* effect size (*ES*) between methods direct vs indirect.

Comparison	Mean Difference	Cohen's d Effect Size (ES)	Conclusion on Significance
CPX vs. HRmax test	+0.7	0.27 (Small)	The group difference is not practically relevant
CPX vs. HRmax/Tanaka	+0.6	0.22 (Small)	The group difference is not practically relevant

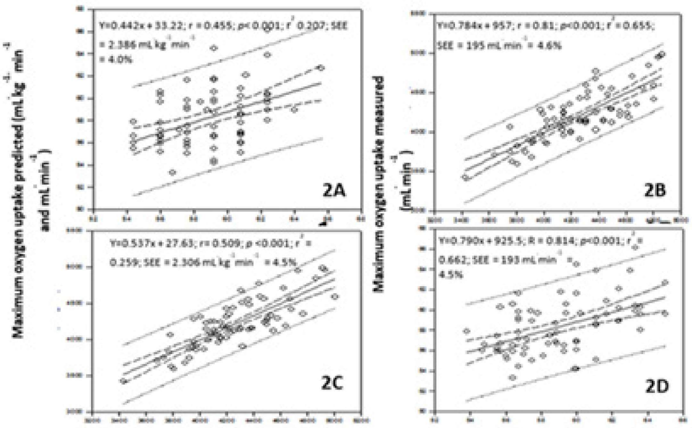

Figure 2: Scatter plot between estimated and measured VO_2max by the HRmax * HR rest ratio (panel 1A and 1B) in the CPX test and by predicted HRmax by age * HR rest (panel 2C and 2D) using Tanaka equation. The solid lines depicted are the least-squares derived best-fitting lines.

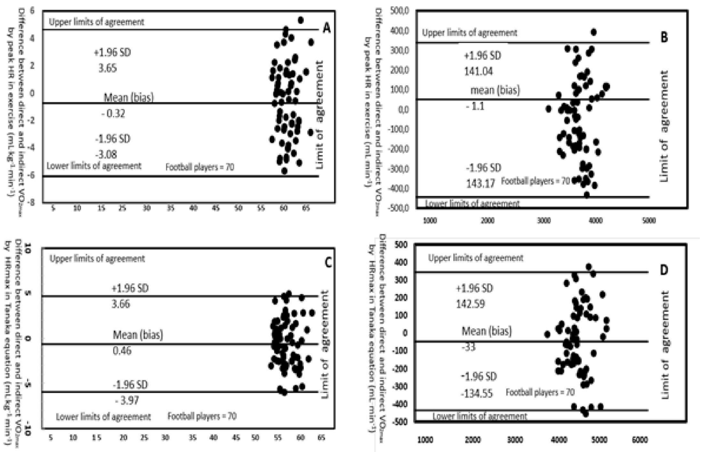

Figure 3: Bland-Altman plots with estimated mean bias and 95% limits of agreement for the difference in VO_2max corresponding to estimated and measured values of VO_2max CPX test (A and B) and Tanaka equation (C and D) by plotted against the mean in professional football players.

Discussion

This research represents a pioneering effort as the first study to validate the Heart Rate Ratio method specifically within a population of professional elite soccer players. The primary benefit of the present study was to develop and validate an estimated $\dot{V}O_2$max max equation (the HR factor 15.8) specifically for high-performance football players, addressing a gap in the current literature. Following the established concept of the Fick principle, we created this simple HR index and validated it against the gold standard criterion: $\dot{V}O_2$max obtained during a maximal CPX test.

In line with our hypothesis, the predicted $\dot{V}O_2$max was not significantly different from the direct measures and demonstrated a high level of accuracy. The model, developed in a large sample of elite players and tested across two scenarios (effort and no-effort), yielded a Standard Error of Estimate (SEE) of only 4% and 4.6% (or 2.386 and 2.306 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively). In the context of sports physiology, this margin of error is very low. This low error is a highly promising result, especially when compared to the 10% to 15% error often associated with traditional field tests. Traditional field tests, such as the Yo-Yo Intermittent Recovery Test or the 2.4-km run, although widely used, often carry SEE values between 10% and 15% [23]. Furthermore, our results compare favorably to the well-known Uth et al. Study [7,8], which reported a SEE of 4.5% and 7.8% in runners male and female, respectively. Other established protocols often exhibit considerably higher SEE values (e.g., 7% to 15% for Astrand-Rhyming and 8% for Andersen). This low error is a highly promising result, especially when compared to the 10 to 15% error frequently associated with traditional field tests (e.g., Astrand-Rhyming and Andersen). Our results also compare favorably to the well-known Uth et al. [7] study, which reported an SEE of 4.5% in runners, confirming the robustness of the method for estimating the cohort mean.

The simplicity of the HR index and $\dot{V}O_2$max estimation, which requires only standardized resting HR and HRmax (measured or predicted by age using the Tanaka equation), presents a huge advantage. Due to the high financial costs and specialized equipment of CPX testing, this simple and reliable method makes aerobic fitness assessment accessible to the vast majority of clubs that lack sophisticated resources.

The robust accuracy is partly attributable to the homogeneous sample of elite male athletes, characterized by a high aerobic capacity ($\dot{V}O_2$max median above 57 $mL \cdot kg^{-1} \cdot min^{-1}$) and expected cardiovascular adaptations, such as rest bradycardia.

However, one limitation of this work was the non-division of the sample by player position/pitch function. We recognize that skill level and positional demands may influence outcomes. This aspect limits the generalizability of the findings across all tactical roles but presents a promising window of opportunity for further, more specialized research. Despite this, the reliability of the methodology, confirmed by the low SEE, provides a solid basis for analyzing the aerobic level of high-performance football players and planning individualized training. This efficiency allows for the seamless integration of physiological monitoring into the daily training routine, enabling the assessment of an entire squad in a single session without disrupting the technical-tactical schedule. Furthermore, the ability to obtain near-instantaneous data facilitates immediate adjustments to individual training loads, ensuring that aerobic conditioning is optimized while minimizing the risk of overreaching. Ultimately, this method democratizes high-level physiological tracking, providing a reliable proxy for cardiovascular fitness in environments where laboratory-grade equipment is inaccessible or impractical.

Study Limitation

The primary methodological limitation of this study, as demonstrated by the Bland-Altman Limits of Agreement (LOA), relates to the individual precision of the Heart Rate Ratio Method

(HRmax/HRrest ^{x} 15.8). While the method exhibits a negligible mean **bias** (-0.32 mL·kg^{-1}·min^{-1}, indicating high group-level accuracy, the 95% LOA span a wide range (-3.08 to +3.65 mL/kg/min. This range signifies a substantial random error when estimating $\dot{V}O_2$max or an individual footballer. Specifically, for a single athlete, the estimated $\dot{V}O_2$max may differ from their true, directly measured value by up to 3.65 mL·kg^{-1}·min^{-1}. This margin of error exceeds the minimum differences considered meaningful in elite sports performance (e.g., 1-2 mL·kg^{-1}·min^{-1}), thereby limiting its utility for high-stakes individual decisions such as precise training load prescription or athlete selection.

What does this study adds?

This study provides a significant contribution to football physiology by bridging the gap between laboratory precision and field practicality. In a sport characterized by a saturated competitive calendar and drastically varying financial resources among clubs, the validation of the 15.8 proportionality factor introduces fundamental advancements. It transforms heart rate a simple and accessible metric into a potent surrogate for global cardiovascular function. This allows $\dot{V}O_2$max to evolve from a data point obtained only once per season into a constant monitoring parameter. By providing a tool that is both non-invasive and highly accurate (with only a 4% error margin), this research democratizes high-performance assessment, enabling technical staffs at all levels to implement evidence-based training prescriptions and precise workload management throughout the competitive cycle.

Conclusion

Based on the robust Bland-Altman analysis comparing the $\dot{V}O_2$max estimation method (HRratio times 15.8) with direct measurement in professional football players, we conclude that the indirect method is a statistically valid and unbiased tool for assessing aerobic fitness. The very low mean bias -0.32 mL·kg^{-1}·min^{-1} confirms the method's high accuracy at the cohort level, making it highly suitable for population-based research and large-scale group monitoring within professional football. This derived proportionality factor is specifically validated for footballer athletes, and caution is required for extrapolation to other populations. Despite the wide 95% Limits of Agreement (LOA), the negligible systematic error and the practical, low-cost nature of the method endorse its use as a reliable field alternative for monitoring mean trends and changes across an entire squad, especially when the gold-standard direct measurement is unavailable. However, the results must be interpreted with caution for the judgment of the aerobic capacity of individual athletes.

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