Title: Estimation of oxygen uptake from heart rate and RPE in young soccer players

Running title: Estimate VO2 from HR and RPE

Authors: Del P. Wong¹, Christopher Carling², Anis Chaouachi³, Alexandre Dellal^{3,4}, Carlo Castagna⁵, Karim Chamari³, and David G. Behm⁶

Affiliations

¹ Department of Health and Physical Education, The Hong Kong Institute of Education, Hong Kong.

² LOSC Lille Metropole Football Club, EMSP, Domain de Luchin, France.

³ Tunisian Research Laboratory "Sport Performance Optimisation", National Center of Medicine and Science in Sports, Tunis, Tunisia.

⁴Psychophysiology of the motor behaviour and sports laboratory, University of sports science and exercise, Strasbourg, France

⁵ School of Sport and Exercise Sciences, Faculty of Medicine and Surgery, University of Rome Tor Vergata, Rome, Italy.

⁶ School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's Newfoundland, Canada.

Corresponding Author

Del P. Wong

Address: Department of Health and Physical Education, The Hong Kong Institute of

Education, Tai Po, Hong Kong.

Phone: (852) 2948 6421

Email: delwong@alumni.cuhk.net

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Abstract

The objective of this study was to estimate the oxygen uptake (VO₂) in elite youth soccer players using measures of HR and ratings of perceived exertion (RPE). Forty-six regional-level male youth soccer players (~13 years) participated in two VO₂max tests. Data for HR, RPE and VO₂ were simultaneously recorded during the VO₂max tests with incremental running speed. Regression equations were derived from the first VO₂max test. Two weeks later, all players performed the same VO₂max test to validate the developed regression equations. There were no significant differences between the estimated values in the first test and actual values in the second test. During the continuous endurance exercise, the combination of percentage of maximal heart rate (%HRmax) and RPE measures gave similar estimation of %VO₂max ($R^2 = 83\%$) in comparison to %HRmax alone ($R^2 = 81\%$). However, the estimation of VO₂ using combined %HRmax and RPE was not satisfactory (R^2 = 45 - 46%). Therefore, the use of %HRmax (without RPE) to estimate %VO₂max could be a useful tool in young soccer players during field-based continuous endurance testing and training. Specifically, coaches can use the %HRmax to quantify internal loads (%VO₂max) and subsequently implement continuous endurance training at appropriate intensities. Furthermore, it seems that RPE is more useful as a measure of internal load during non-continuous (e.g. intermittent and sprint) exercises but not to estimate %VO₂max during continuous aerobic exercise ($R^2 = 59\%$).

Keywords: football, energy expenditure, youth, equation, fitness training.

INTRODUCTION

Improvements in athletic performance can be achieved by appropriate periodization of training and recovery (22). The monitoring of training load is important in providing objective information on how athletes respond to training programs. In addition, if training load is not monitored and recovery is insufficient, then athletes may be at risk of over-reaching or over-training along with a concomitant decrease in performance (24). In soccer, it is of practical interest for coaches to measure and control the intensity of training programs in order to quantify improvements in fitness and especially in aerobic capacity. Strong aerobic capacity is important for soccer performance because ~90% of the energy contribution during a soccer match-play is provided by the aerobic metabolism (2). Analyses of match-play have shown that the average work intensity in games is around 80% to 90% of maximal heart rate (HRmax) (2, 25), and 47% to 75% of maximal oxygen uptake (VO₂max) (38). Improvements in aerobic capacity in soccer players can enhance match performance in areas such as the total distance covered, number of sprint efforts and ball actions, and maintain a similar technical performance despite exercising at a significantly higher intensity (25) as well as reducing the fatigue-induced decline in short-passing ability (30).

An accurate and direct measurement of exercise intensity in aerobic training sessions is to analyze oxygen uptake using portable breath-by-breath metabolic gas systems (6, 8). However, metabolic gas systems are often expensive and not available to every soccer club. In addition, it is practically impossible to measure the oxygen uptake of all players from the squad simultaneously by using the metabolic gas system. Moreover, the use of such devices will modify the natural style and activity of players when training by limiting player to player contact especially in certain game situations such as tackling and heading actions. Therefore, direct measurements of the internal intensity in soccer match-play or training are difficult to obtain, despite the fact that external intensity indicated by measures of distance coverage and running speed has been heavily investigated using computerized video motion-analyses (13, 14).

Indirect measures such as heart rate (HR) (17, 31) and rate of perceived exertion (RPE) (10, 29) are alternative means for estimating internal intensity and exercise load in soccer players. Previous studies have reported strong correlations between measures of HR and VO₂ ranging from 0.84 to 0.99 among adult soccer players (17, 26). Additionally, it has been reported that the HR-VO₂ relationship in adult soccer players when tested on the treadmill is not different to that obtained in on-field testing (17). This experimental evidence suggests that it is logical and more practical to use HR measures to estimate players' VO₂ during on-field situations (17). However, previous studies in this area were performed using adult soccer players (17, 26, 33) and to the best of our knowledge, the HR-VO₂ relationship in young soccer players has not been investigated. The HR-VO₂ relationship in young soccer players should therefore be determined in order to interpret metabolic information by using the HR

measures obtained in the field.

While a strong association exists between VO₂ and HR, there are psychological factors that may not be taken into account by simple HR measures (43) in addition to some characteristics of physical activity profiles in soccer that are not well reflected by HR, e.g. sprinting and explosive actions (35). Subjective RPE is used as a measurement of integrated afferent information during exercise (43) and is well associated to physiological measurements such as HR, ventilation, respiratory rate, and VO₂ (40). Recently, RPE has also been used as a global indicator to monitor intensity in exercise training session among athletes (20, 21) and adolescent soccer players (10, 29). However, no information on the association between RPE and VO₂ in younger soccer players is available in the literature.

We hypothesized that more accurate estimation of VO_2 in young soccer players can be achieved by employing HR and RPE simultaneously as compared to each of these measures alone. Moreover, it is practical for coaching staff to measure objective HR and subjective RPE during field training to estimate exercise intensity (VO₂). However, no previous study has provided an equation to accurately estimate VO₂ from HR and RPE among young soccer players. Therefore, the main purpose of this study was to assess the accuracy of estimation of VO₂ in elite youth soccer players by using measures of HR and RPE.

METHODS

Experimental Approach to the Problem

There is no information on the association between RPE and VO₂ in younger soccer players available in the literature, and the HR-VO₂ relationship in young soccer players should be determined in order to interpret metabolic information by using the HR measures obtained in the field. In the present study, all players participated in the first VO₂max test in a sport science laboratory in which VO₂, HR and RPE were simultaneously recorded. The present exercise protocol has previously been used to determine VO₂max in young soccer players (8, 9). To estimate VO₂ from HR and RPE, regression equations were determined from the above parameters. Two weeks after the first test, all players performed the same VO₂max test to validate the regression equations. The differences between the estimated values in the first test and the actual values in the second test were compared.

Subjects

A total of 46 young male soccer players from a Chinese regional Under-14 team competing at the highest level of competition for their age category participated in this study. All tests were performed during the competitive season. All players participated in training twice a week with each session lasting for ~2 hours, in addition to the regular weekly competitive game. Their respective age, soccer experience, body mass, height, and body mass index were: 13.5 ± 0.7 years-old, 4.2 ± 1.5 years, 50.9 ± 8.8 kg, 1.65 ± 0.1 m, and 18.5 ± 2.0 $kg \cdot m^{-2}$. Only outfield players participated in the present study. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Clinical Research Ethics Committee before the commencement of the assessments. Prior to participation, written informed consent was received from all players and parents after detailed explanation about the aims, benefits, and risks involved with this investigation. All players were instructed not to perform vigorous exercise 48 hrs prior to the day of testing. All players were familiar with the VO₂max test protocol as they performed the same test every 2 months throughout the season.

VO2max Testing

On two occasions separated by 2 weeks, players ran on a 5.5% slope motorized treadmill (cos10198, h/p/cosmos, Germany) for 4mins at 7 km·h⁻¹, followed by a 1 km·h⁻¹ increment every minute until exhaustion. In the first VO₂max test, breath-by-breath VO₂ and the corresponding HR were measured. The VO₂ values obtained at the completion of each treadmill velocity increment were later divided by the VO₂max measurement to obtain a %VO₂max for each submaximal stage (velocity increment). The regression formula to estimate % VO₂max and VO₂ were based on these submaximal or incremental VO₂ values. The second VO₂max performed 2 weeks later used the same procedure and measures. Players performed both VO₂max tests at the same time on each testing day to minimize circadian

variation in HR (15). The regression equation derived from the first test was used to estimate the $%VO_2max$ and VO_2 of the second test and was compared to the true measured value of the second VO_2max test.

Cardiorespiratory variables were determined using a calibrated breath by breath system (MetaMax 3B, Cortex, Germany). The following criteria were met by all players when VO_2max was tested: a) a plateau in VO_2 despite an increase in treadmill speed; b) a respiratory gas exchange ratio > 1.1; and c) blood lactate > 6 mmol·L⁻¹. VO_2max was determined as the average of last 30 s of the test, and HRmax was the highest value attained at exhaustion (7). Previous studies have shown that the coefficient of variance of this incremental treadmill VO_2max test was < 5% (39). VO_2max values were represented relative to body mass (ml·min·kg⁻¹) and scaled to body mass (ml·min·kg^{-0.75}) (3).

RPE with 10-point scale (29) was obtained at the last 5 s of each running speed. All players were familiar with the use of RPE. The RPE was previously implemented during soccer training for 8 weeks which was equivalent to 16 training sessions. The players were asked to provide their respective RPE during and after each of these soccer training sessions.

Heart rate was determined from a portable monitor and recorded every 5 s (Polar, Finland). Blood lactate was collected 3.5 min after the VO₂max test, with 25 µl samples of capillary blood withdrawn from fingertip. Blood lactate concentration was subsequently measured using an enzymatic method (YSI 1500, Yellow Springs Instruments, USA).

Statistical Analyses

Data are expressed as mean \pm SEM. The normality distribution of the data was checked with the Kolmogorov-Smirnov test. Pearson product moment correlation coefficient was used to examine the relationship between parameters in the first VO₂max test, and the test-retest reliability of the VO₂max tests. The magnitude of the correlations was determined using the modified scale by Hopkins (28): trivial: r < 0.1; low: 0.1-0.3; moderate: 0.3-0.5; high: 0.5-0.7; very high: 0.7-0.9; nearly perfect > 0.9; and perfect: 1. Stepwise multiple regression was used to estimate VO₂ values by HR and RPE. A paired-sample t-test was used to compare the estimated values in the first test and the actual values in the second test. Significant level was defined as *p* < 0.05.

RESULTS

In the first VO₂max test, values for HRmax, relative and scaled VO₂max of the players were 199 \pm 1 beat·min⁻¹, 54.9 \pm 0.9 ml·min·kg⁻¹, and 146.7 \pm 2.5 ml·min·kg^{-0.75}, respectively. The %HRmax was highly correlated with VO₂ (r = 0.67, *p* < 0.001) and very highly correlated with %VO₂max (r = 0.90, *p* < 0.001) (Table 1). Similarly, RPE was highly correlated with VO₂ (r = 0.53 – 0.55, *p* < 0.001) and very highly correlated with %VO₂max (r = 0.77, *p* < 0.001) (Table 1). Compare to RPE, the %HRmax had higher shared variance with VO₂ (45% vs. 28-30%) and %VO₂max (81% vs. 59%). Furthermore, the combined use of %HRmax and RPE to estimate %VO₂max ($R^2 = 83\%$, p < 0.001, Table 2) was similar to the use of %HRmax ($R^2 = 81\%$) alone. Higher explained variances were observed when %HRmax and RPE were used to estimate %VO₂max ($R^2 = 83\%$, Equation 1 & 2, Table 2) but lower values were observed when estimating VO₂ ($R^2 = 45\%$ and 46%, Equation 3 & 4, Table 2). To validate the four equations presented in Table 2, the values estimated by the equations were compared with the actual values obtained in the second VO₂max test. Small and non-significant (p > 0.05) mean differences were observed for the VO₂max tests (r = 0.90 - 0.91, Table 3).

****Table 1, 2, & 3 here****

DISCUSSION

The first purpose of this study was to examine the relationship between VO₂ and HR and RPE respectively in a group of regional level youth soccer players. The present study showed that during continuous endurance exercise, the %HRmax was highly correlated with VO₂ and very highly correlated with %VO₂max. The applicability of the HR-VO₂ equation obtained in laboratory setting to on-field soccer exercise has been examined by Esposito et al. (17). The

authors reported that data on the HR-VO₂ relationship obtained in the laboratory setting were not statistically different to those observed when performing a field-based soccer training circuit involving jumping, change of direction, walking, jogging, running with and without the ball, forward, backward and lateral movements (17). Esposito et al. (17) reported that the correlation coefficients of the HR-VO2 relationships obtained in the laboratory and on the field were 0.98 and 0.99 respectively. In addition, Hoff et al. (27) found that the correlation coefficient of the HR-VO₂ obtained during treadmill running was 0.84. Findings from these studies (17, 27) suggest that HR is a valid indicator of aerobic demand during soccer activities. In contrast, Ogushi et al. (38) found that HR was 25% higher during match-play compared to figures obtained in a laboratory protocol at the same level of VO₂. This disparity may be caused in part by the additional requirements involved with emotional stress and complex mental processes during match-play. With the above mentioned reasons, it is suggested that HR is a valid indicator of aerobic demand in continuous endurance soccer training session (17, 27). However, the limitation of using HR as measure of internal training load is that it is a relatively poor method in match-play (38) and high intensity and short duration exercises such as sprinting and plyometric training (12, 29).

The present study showed that RPE was highly correlated with VO₂ and very highly correlated with %VO₂max. The validity of self-regulation of exercise intensity guided by the RPE has been confirmed in treadmill running (16, 18, 23), cycling (5, 19), arm and leg

ergometry (32), and rowing ergometry (36). The RPE based training load is recently reported as being an accurate indicator of exercise intensity during soccer training (29, 35). However, in the present study, RPE was shown to be a poor predictor of oxygen uptake as only 28% of VO₂ and 59% of %VO₂max can be explained by RPE (Table 1). This result suggests that in youth soccer players, RPE measures alone can not be accurately employed to estimate oxygen uptake. Therefore, RPE should not be used to estimate VO₂ nor %VO₂max during continuous endurance training session in youth soccer players. In contrast, RPE can be used as measure of internal training load during non-continuous training sessions such as small-sided games and interval training drills (12). However, psychosocial factors can influence up to 30% of the variability in an RPE score (44) and a future study comparing match-play and laboratory measures of HR and RPE measures in young soccer players is warranted.

The second purpose of this study was to estimate VO₂ and %VO₂max by using HR and RPE together. We found that the combine use of both %HRmax and RPE to estimate %VO₂max ($R^2 = 83\%$) was similar to %HRmax alone ($R^2 = 81\%$) but better than using RPE alone ($R^2 = 59\%$). Furthermore, higher explained variances were observed when %HRmax and RPE were used to estimate %VO₂max ($R^2 = 83\%$) but lower values were observed when estimating VO₂ ($R^2 = 45\%$ and 46\%). The present study showed that %HRmax had higher shared variance with VO₂ (45% vs. 28-30%) and %VO₂max (81% vs. 59%) as compared to RPE. It appears that %HRmax (instead of RPE) is better indicator of internal training load and

can accurately estimate %VO₂max during continuous endurance training. This is in agreement with the findings of Desgorces et al. (12) which showed that HR is a more sensitive indicator of internal training load compared to blood lactate and RPE during on-field endurance training session.

In the present study, a very high correlation (r = 0.76) was observed between RPE and %HR_{max}. This association was stronger than that previously reported in soccer-specific small-sided games (r = 0.60) in amateur adult soccer players (10). The lower explained variance observed in the previous study might be partly attributed to differences in age and fitness level (4). This discrepancy may also be due to the nature of the exercise undertaken. For example, small-sided game training sessions with an intermittent running nature at different speeds (1) and which greatly vary in intensity (31). As the anaerobic contribution in small-sided games is considerably larger than that in continuous running endurance training, this may affect the RPE-HR relationship (12). In this regard, Alexiou and Coutts (1) found that higher correlations between RPE and HR were found with less intermittent, aerobic-based training session in women soccer players. In the present study, a continuous incremental protocol was employed with much less anaerobic contribution than that observed during small-sided games which may have contributed to the difference in findings. In future studies, research could be conducted to test the validity of alternative effort perception scales such as the OMNI scale (41, 42) in regressing against data on HR or oxygen uptake in young soccer players.

A limitation of the present study identified beforehand was the mode of exercise analyzed as only straight line running was done on a motorized treadmill. The pattern and mechanics of treadmill running are different to those observed on the pitch and may have modulated RPE. Running actions in soccer match-play are more closely represented by the movements observed in shuttle running protocols that require 180 degree turns and abrupt accelerations and decelerations inducing significantly higher HR responses and RPE values (11). Therefore, future studies are recommended to develop and test regression equations using shuttle type exercise protocols in a field setting combined with physiological measures from portable gas analyzers to collect data in situations that are better representative of the demands of the game.

PRACTICAL APPLICATION

The ability to accurately control and monitor training load to analyze variations in fitness in soccer players is an important aspect of effective coaching. There are also concerns about the negative impact of intensive participation in training and match-play on player's health especially at youth levels. In the present study, we found that the use of heart rate (%HRmax) alone to estimate percentage of maximal oxygen uptake (%VO₂max) during continuous endurance training was as accurate as using a combination of heart rate and RPE measures in young soccer players. By measuring the %HRmax, coaches will be able to detect youth players who have differing physiological responses (%VO₂max) to the same continuous endurance training session. These players can subsequently receive individualized training to enhance their aerobic fitness to meet the overall team standard (37). In addition, the high risk of injury in youth soccer players over time suggests the need for frequent evaluation and control of the physical stress placed on players in training (34). Furthermore, it seems that RPE is more useful as a measure of internal load during non-continuous (e.g. intermittent and sprint) exercises but not in estimating %VO₂max during continuous endurance exercise.

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	%VO ₂ max	%VO ₂ max	VO ₂	VO ₂	%HRmax
	(ml·min·kg ^{-0.75})	$(ml \cdot min \cdot kg^{-1})$	ml·min·kg ^{-0.75}) (ml·min·kg ⁻¹))
%VO ₂ max (ml·min·kg ^{-0.75})					
%VO2max (ml·min·kg ⁻¹)	1.0***				
VO ₂ (ml·min·kg ^{-0.75})	0.74***	0.74***			
VO ₂ (ml·min·kg ⁻¹)	0.75***	0.75***	0.97***		
%HRmax	0.90***	0.90***	0.67***	0.67***	
RPE	0.77***	0.77***	0.53***	0.55***	0.76***

Table 1. Correlation coefficient matrix of the parameters.

 $\overline{***} p < 0.001.$

 $VO_2 = oxygen uptake, %VO_2max = percentage of maximal oxygen uptake, %HRmax = percentage of maximal heart rate, and RPE = rate of perceived exertion.$

Table 2. Regression equation derived from the results in the first maximal oxygen uptake test (n = 46).

	Equation		\mathbb{R}^2	SEE
1.	VO_2 max (ml·min·kg ^{-0.75}) = 1.04 (%HRmax) + 1.41 (RPE) - 17.4	0.91	83%***	4.95
2.	$%VO_2max (ml·min·kg^{-1}) = 1.04 (%HRmax) + 1.41$	0.91	83%***	4.95
3.	(RPE) - 17.4 VO ₂ (ml·min·kg ^{-0.75}) = 1.55 (%HRmax) + 0.78	0.67	45%***	15.88
4.	(RPE) - 17.0 VO ₂ (ml·min·kg ⁻¹) = 0.57 (%HRmax) + 0.34 (RPE) - 5.7	0.68	46%***	5.79

*** *p* < 0.001.

 $VO_2 = oxygen uptake, % VO_2max = percentage of maximal oxygen uptake, % HRmax = percentage of maximal heart rate, and RPE = rate of perceived exertion.$

Parameter	Mean difference (Estimated - actual)	Test-retest reliability	t	р
% VO ₂ max (ml·min·kg ^{-0.75})	0.34 ± 0.24	0.91	-1.44	0.15
%VO2max (ml·min·kg ⁻¹)	0.30 ± 0.24	0.91	-1.44	0.15
VO ₂ (ml·min·kg ^{-0.75})	0.30 ± 0.76	0.90	-0.40	0.69
VO ₂ (ml·min·kg ⁻¹)	0.10 ± 0.28	0.90	-0.35	0.73

Table 3. Comparison between estimated and actual VO₂ values (n = 46).

 $VO_2 = oxygen uptake$, and $%VO_2max = percentage of maximal oxygen uptake.$