International Journal of Cardiovascular Sciences. 2018;31(4)323-332

ORIGINAL ARTICLE

Cardiorespiratory Optimal Point in Professional Soccer Players: A Novel Submaximal Variable During Exercise

Christina Grüne de Souza e Silva,[1,2] Claudia Lucia Barros de Castro,[3] João Felipe Franca,[3] Altamiro Bottino,[4] Jonathan Myers,[2] Claudio Gil Soares de Araújo[3]

Instituto do Coração Edson Saad, Universidade Federal do Rio de Janeiro,[1] Rio de Janeiro, RJ - Brazil
Veterans Affairs Palo Alto Health Care System/Stanford University,[2] Palo Alto, California - USA
Clínica de Medicina do Exercício, CLINIMEX,[3] Rio de Janeiro, RJ - Brazil
São Paulo Futebol Clube,[4] São Paulo, SP - Brazil

Abstract

Background: Maximal oxygen consumption (VO_2max) and ventilatory threshold (VT) obtained during a cardiopulmonary exercise test (CPX) are used in the evaluation of athletes. However, the identification of these variables may sometimes be unreliable, which limits their use. In contrast, the cardiorespiratory optimal point (COP) is a submaximal variable derived from CPX with objective measurement and prognostic significance. However, its behavior in athletes is unknown.

Objective: To describe the behavior of COP in professional soccer players and its association with VO_2max and VT.

Methods: VO_2max, VT and COP were obtained retrospectively from 198 soccer players undergoing maximal treadmill CPX using ramp protocol. COP was defined as the lowest value of the ventilation/oxygen consumption ratio in a given minute of the CPX. The soccer players were stratified according to their field position: goalkeeper, center-defender, left/right-back, midfielder and forwarder. Continuous variables were compared using unpaired Student t test or ANOVA, or Mann-Whitney test or Kruskal-Wallis test depending on their distribution, and categorical variables were compared using chi-square test. Pearson correlation was used to test the association between COP and other ventilatory variables. A level of 5% was used for statistical significance.

Results: COP (mean ± SD) was 18.2 ± 2.1 and was achieved at a speed 4.3 ± 1.4 $km.h^{-1}$ lower than that achieved at the VT. While VO_2max (62.1 ± 6.2 $mL.kg^{-1}.min^{-1}$) tended to be lower in goalkeepers ($p < 0.05$), the COP did not vary according to field position ($p = 0.41$). No significant association was observed between COP and VO_2max ($r = 0.032$, $p = 0.65$) or between COP and VT ($r = -0.003$, $p = 0.96$).

Conclusion: COP can be easily determined during submaximal exercise performed with incremental speed in soccer players and does not vary according to the athlete's field position. The absence of association with VO_2max and VT indicates that COP provides distinct and complementary information to these variables. Future studies are needed to determine the practical implications of COP in assessing athletes. (Int J Cardiovasc Sci. 2018;31(4)323-332)

Keywords: Exercise; Football / trends; Spirometry / methods; Bronchospirometry / methods; Athletic Performance.

Introduction

The cardiopulmonary exercise test (CPX) is a functional and noninvasive procedure used to assess the integration of the cardiovascular, respiratory and musculoskeletal systems based on the analysis of submaximal and maximal responses to exercise.[1] The information obtained from CPX is important to the prognostic assessment of healthy and unhealthy individuals,[2,3] and the measures of maximal aerobic power, represented by maximal oxygen consumption (VO_2max), and of ventilatory threshold (VT) are often used to assess and monitor athletes'

Mailing Address: Christina Grüne de Souza e Silva
Rua Professor Rodolpho Paulo Rocco, 255 - 8º andar - Cidade Universitária, Campus do Fundão. Postal Code: 21941-913, Rio de Janeiro, RJ - Brazil.
E-mail: christina.g.dss@gmail.com

DOI: 10.5935/2359-4802.20180030

Manuscript received January 26, 2018; revised manuscript April 09, 2018; accepted April 22, 2018.

training.[4-6] For example, soccer players with higher VO_2max are known to cover longer distances during a match,[7] and their mean exercise intensity during the match is approximately 75% of their VO_2max, similarly to the VT level of those players.[7,8]

However, limitations such as low reproducibility, different techniques and criteria for identification of both VO_2max and VT[9-13] hinder their routine use. In addition, mistakes in such measurements can jeopardize the planning of individualized trainings, impairing the athlete's performance improvement.[14]

In 2012, Ramos et al.[15] showed the minimum value of the ventilatory equivalent for oxygen (minimum VE/VO_2) during a CPX – the cardiorespiratory optimal point (COP) – and described its behavior, which, theoretically, represents the point of the best association or integration between the respiratory and cardiovascular systems. Based on the assessment of more than 600 healthy and non-athletes individuals aged aged between 23 and 73 years, those authors showed that COP tends to be higher in women and increases with age. In addition, studies conducted by that same group have shown that COP measurement is easy, objective and stable in CPX performed in adults,[16] supporting its potential use in physiological research and in clinical practice. Similarly to VO_2max and VT, COP proved to be an excellent predictor of all-cause mortality in healthy and unhealthy individuals aged between 40 and 85 years.[17]

So far, the behavior of COP in athletes is unknown. Thus, our objectives are: a) to describe the behavior of COP in professional soccer players; and b) to assess its association with VO_2max and VT.

Materials and Methods

Sample

This study analyzed retrospectively the data of 247 soccer players of the major team of a Rio de Janeiro club of the Brazilian Soccer Championship A series, who underwent a maximal CPX at a private Exercise and Sports Medicine clinic between January 2005 and December 2016. Of those, 198 players concomitantly meeting the following inclusion criteria were selected: a) to have undergone a treadmill CPX; b) to have completed a truly maximal CPX, which was not interrupted due to clinical reasons or lack of motivation; c) to have no history of cardiorespiratory diseases. Based on the information provided by the soccer players, they were categorized according to their predominant field positions: goalkeeper, center-defender, left/right-back, midfielder and forwarder.

Assessment protocol

Clinical assessment

Included clinical history and physical examination, as well as anthropometric, spirometric and resting 12-lead electrocardiographic data.

Resting spirometry test

At least three maneuvers were carried out to determine the flow-volume curves using a pneumograph (SP-1 Spirometer, Schiller, Switzerland or KoKo, United States) periodically calibrated according to the protocol recommended by the North American and European guidelines.[18]

Maximal cardiopulmonary exercise test

The CPX were performed on a treadmill (ATL Master, Inbramed, Brazil) in a properly climatized room. All players underwent the same ramp protocol, at an initial velocity of 8.0 $km.h^{-1}$, with progressive increase of 0.1 $km.h^{-1}$ every 7.5 seconds, and without any inclination. All CPX were conducted by specialized physicians with large experience in assessing athletes, following a well-defined routine, mainly regarding the stimulus to achieve truly maximal exertion. CPX was considered maximal based on the physician's subjective assessment and other objective variables, such as: occurrence of VT, U-pattern ventilatory equivalent, and a 10-score in the 0-10 Borg scale.[19] During the CPX, the players were monitored continuously by use of a digital electrocardiograph (ErgoPC Elite versions 3.2.1.5 or 3.3.4.3 or 3.3.6.2, Micromed, Brazil), which measured heart rate (HR) on the electrocardiographic tracing in the CC5 or CM5 leads at the end of every minute.

Analysis of the expired gases

During the CPX, the expired gases were collected by use of a Prevent pneumograph (MedGraphics, United States) coupled to a mouth piece, with concomitant use of a nose clip. The expired gases were measured and analyzed with the VO2000 metabolic analyzer (MedGraphics, United States), which was calibrated with a 2L-serinje and with gases of known concentrations before the first assessment of the day, and this procedure was repeated when necessary. Pulmonary ventilation

(VE) and oxygen and carbon dioxide partial fractions were expressed every 10 seconds, and their mean values for each minute of CPX were then calculated.

Determining maximal oxygen consumption and ventilatory threshold

The VO_2max was considered the highest value at a given minute of CPX. The VT was visually determined as the point at which an interruption in VE's curve linearity and a sustained increment in VE/VO_2 ratio occurred, being described as the percentage of VO_2max at that velocity. In addition, the velocity and the VO_2 at which the VT occurred were recorded.

Determining the cardiorespiratory optimal point

The COP was obtained by identifying the lowest VE/VO_2 ratio at a given minute of CPX, being, thus, a non-dimensional value. In addition, the VO_2 and the running velocity in the ramp protocol at that point were recorded.

Statistical analysis

Data distribution was assessed by use of the Shapiro-Wilk normality test. Continuous variables with parametric distribution were expressed as mean ± standard deviation (SD), being compared by use of the unpaired Student t test or ANOVA and post-hoc Bonferroni test, when appropriate. Continuous variables with non-parametric distribution were expressed as median (interquartile range) and compared by use of Mann-Whitney test or Kruskal-Wallis test, when appropriate. Categorical variables were expressed as percentage of the frequency and compared by use of the chi-square test. The coefficients of variation of the variables COP, VT and VO_2max, obtained by the ratio between standard deviation and mean, were calculated. Pearson correlation was used to test the association between COP and other ventilatory variables. The statistical calculations were performed using the Stata14® software, adopting a significance level of 5%.

Ethical considerations

All soccer players underwent the assessment willingly, having read and signed the specific written informed consent before the CPX, and having authorized the use of their data for scientific research. The retrospective analysis of data was previously approved by the Ethics Committee on Research of the institution.

Results

Table 1 describes the major demographic characteristics, and the resting spirometry and CPX results of the soccer players. Age, weight, height and body mass index (BMI) ranged from 16 to 36 years, from 57.5 to 102.0 kg, from 163.3 to 196.3 cm, and from 19.3 to 29.6 $kg.m^{-2}$, respectively. COP, VT and VO_2max showed a parametric distribution ($p > 0.05$), with values ranging from 13.1 to 25.3, from 61.8 to 92.7% of VO_2max, and from 45.0 to 76.2 $mL.kg^{-1}.min^{-1}$, respectively. The coefficients of variation for COP, VT and VO_2max were 16.1%, 10.7% and 10.0%, respectively. On average, COP, VT and VO_2max occurred at the velocities of 10.0 ± 1.0, 14.3 ± 1.1, and 18.7 ± 0.9 $km.h^{-1}$, respectively ($p < 0.01$).

When stratified by their field positions during the match (Table 1), the only characteristics that differed were weight and height, with goalkeepers showing the highest values for both variables ($p < 0.01$). The BMI, however, was similar among the soccer players of different field positions ($p = 0.86$). Regarding CPX, goalkeepers achieved the lowest VO_2max values relative to their body weight ($mL.kg^{-1}.min^{-1}$) ($p = 0.01$) and reached the COP at a higher HR and percentage of VO_2max than the players of other field positions ($p < 0.01$). However, the values of COP ($p = 0.41$) and VT (% of VO_2max) ($p = 0.42$) did not differ according to the soccer players' field positions.

The coefficients of correlation between COP and VO_2max ($mL.kg^{-1}.min^{-1}$) and between COP and VT (% of VO_2max) were 0.032 ($p = 0.65$) and -0.003 ($p = 0.96$), respectively, evidencing the low association between those variables. Figure 1 shows those data.

Discussion

During an exercise training with progressive intensity increase up to the voluntary maximum, the relationship between VE and VO_2 is nonlinear,[20] and the curve that illustrates that relation has a U shape, suggesting higher ventilatory efficiency (lower VE/VO_2) at submaximal exercise levels when compared to rest and to the highest exertion intensities. Based on that, COP was described as the lowest VE/VO_2 value at a given minute during an incremental exercise, representing the time point with the lowest amount of ventilation per liter of oxygen to be consumed, which is the best integration of the relationship between circulation and respiration.[15] Recent studies have shown the clinical applicability of the COP for the diagnostic and prognostic assessment

Table 1 - Major demographic characteristics and results of maximal cardiopulmonary exercise test on treadmill of professional soccer players

Variables*	Total (n = 198)	Goalkeeper (n = 13)	Left/right-back (n = 27)	Center-defender (n = 32)	Midfielder (n = 76)	Forwarder (n = 50)	p value
Characteristics							
Age (years)	23 (21 - 27)	22 (19 - 24)	26 (21 - 28)	22 (21 - 26)	23 (21 - 28)	24 (10 - 27)	0.35
Weight (kg)	76.7 ± 7.6	85.1 ± 4.7	74.3 ± 6.2	80.7 ± 5.4	74.1 ± 7.6[ß]	77.3 ± 7.6[ß]	< 0.01
Height (cm)	179.2 ± 6.4	187.5 ± 4.1	175.5 ± 4.2	184.3 ± 3.8	176.5 ± 6.0[ß]	180.0 ± 5.8	< 0.01
Body mass index ($kg.m^{-2}$)	23.9 ± 1.8	24.2 ± 1.1	24.1 ± 1.7	23.8 ± 1.6	23.8 ± 1.8	23.9 ± 2.1	0.86
HR at rest (bpm)	59 (53 - 66)	62 (57 - 66)	57 (51 - 62)[a]	61 (53 - 65)	61 (54 - 66)	57 (52 - 66)	0.15
SBP at rest (mm Hg)	130 ± 10	130 ± 8	130 ± 14	129 ± 7	129 ± 11	131 ± 10	0.92
DBP at rest (mm Hg)	70 ± 9	72 ± 7	71 ± 11	70 ± 8	70 ± 9	71 ± 9	0.95
Resting spirometry							
FEV1 (L)	4.31 (3.94 - 4.69)	4.74 (4.35 - 5.04)	4.16 (3.96 - 4.41)	4.44 (4.13 - 5.00)[$]	4.24 (3.79 - 4.61)[ß]	4.41 (3.90 - 4.71)[ß,#,€]	< 0.01
% of predicted FEV1	98.5 (90.8 - 105.6)	101.9 (93.9 - 105.3)	96.7 (93.5 - 104.8)	98.5 (88.6 - 105.8)	98.5 (91.6 - 105.0)	100.8 (87.3 - 107.0)	0.99
FVC (L)	5.05 ± 0.68	5.70 ± 0.68	4.83 ± 0.50	5.23 ± 0.66	4.94 ± 0.62[ß]	5.05 ± 0.75[ß,€,#]	< 0.01
% of predicted FVC	96.2 ± 10.5	100.5 ± 10.8	95.7 ± 8.4	94.0 ± 10.3	97.0 ± 10.0	95.6 ± 12.1	0.38
FEV1/FVC ratio (%)	86.0 ± 5.3	83.1 ± 5.6	87.3 ± 4.1[a]	87.6 ± 5.3[a]	85.4 ± 5.1[c]	85.8 ± 5.9	0.05
CPX							
Duration (min)	13.0 (13.0 - 14.0)	13.0 (13.0 - 14.0)	14.0 (13.0 - 14.0)	13.0 (13.0 - 14.0)[b]	14.0 (13.0 - 14.0)	13.0 (13.0 - 14.0)[b]	0.09
Maximal RER	1.10 (1.06 - 1.15)	1.09 (1.06 - 1.13)	1.09 (1.05 - 1.15)	1.13 (1.07 - 1.16)	1.11 (1.06 - 1.15)	1.10 (1.06 - 1.14)	0.59
Maximal HR (bpm)	192 ± 9	194 ± 8	187 ± 7	194 ± 10[$]	192 ± 10[$,€]	192 ± 8[$,€,#]	0.01
Maximal VE ($L.min^{-1}$)	123.2 (113.1 - 133.2)	129.8 (122.6 - 135.2)	123.1 (112.8 - 133.7)	125.4 (113.7 - 136.0)	121.7 (111.6 - 129.9)[a]	122.9 (113.9 - 134.4)	0.30
Maximal velocity ($km.h^{-1}$)	18.8 (18.4 - 19.2)	18.4 (18.0 - 19.2)	19.2 (18.4 - 19.5)	18.5 (17.9 - 19.2)[b]	18.8 (18.4 - 19.2)	18.6 (18.4 - 19.2)[b]	0.13
COP (lowest VE/VO_2)	18.2 ± 2.1	19.1 ± 2.2	18.7 ± 2.1	17.9 ± 2.5	18.1 ± 2.2	18.2 ± 1.9[ß]	0.41
Time to reach COP (min)	2.0 (2.0 - 3.0)	3.0 (2.0 - 4.0)	2.0 (2.0 - 3.0)	2.0 (2.0 - 3.0)	2.0 (2.0 - 2.5)[a]	2.0 (2.0 - 2.0)[a.c]	0.07
Velocity at the COP ($km.h^{-1}$)	9.6 (9.6 - 10.4)	10.4 (9.6 - 11.2)	9.6 (9.6 - 10.4)	9.6 (9.6 - 10.4)	9.6 (9.6 - 10.0)[a]	9.6 (9.6 - 9.6)[a.c]	0.07
HR at the COP (bpm)	132 (122 - 142)	142 (134 - 148)	131 (122 - 138)	139 (128 - 152)[$]	131 (121 - 140)[$]	128 (121-137)[ß,#]	< 0.01

Cont. Table 1 - Major demographic characteristics and results of maximal cardiopulmonary exercise test on treadmill of professional soccer players

Variables*	Total (n = 198)	Goalkeeper (n = 13)	Left/right-back (n = 27)	Center-defender (n = 32)	Midfielder (n = 76)	Forwarder (n = 50)	p value
VO_2 at the COP ($mL.kg^{-1}.min^{-1}$)	31.8 (29.0 - 34.6)	33.6 (31.0 - 33.7)	32.2 (28.6 - 35.7)	33.1 (30.9 - 35.6)	31.3 (28.2 - 34.4)^c	31.3 (33.8 - 29.7)^c	0.10
%VO_2max at the COP	51.4 (46.4 - 55.8)	57.0 (53.3 - 59.3)	48.4 (45.1 - 54.7)	55.9 (51.2 - 59.2)$^{\$}$	51.0 (44.2 - 54.3)^{ß}	50.7 (45.9 - 54.0)$^{ß,\#}$	< 0.01
Time to reach the VT (min)	7.9 ± 1.4	8.1 ± 0.9	8.1 ± 1.3	7.3 ± 1.3^b	8.0 ± 1.6^c	7.8 ± 1.3	0.06
Velocity at the VT ($km.h^{-1}$)	14.3 ± 1.1	14.5 ± 0.7	14.5 ± 1.0	13.8 ± 1.1^b	14.4 ± 1.2^c	14.3 ± 1.0	0.06
HR at the VT (bpm)	169 (160 - 178)	178 (168 - 181)	165 (162-169)^a	172 (160 - 178)^b	167 (160 - 177)^a	166 (160 - 178)^a	0.08
VO_2 at the VT ($mL.kg^{-1}.min^{-1}$)	46.8 ± 5.0	45.3 ± 2.5	47.9 ± 4.7	45.5 ± 4.5	46.7 ± 6.1	47.4 ± 4.0	0.25
%VO_2max at the VT	75.5 ± 5.7	77.3 ± 4.3	74.7 ± 4.8	76.1 ± 6.3	74.7 ± 6.2	76.0 ± 5.4	0.42
VO_2max ($L.min^{-1}$)	4.75 ± 0.52	4.98 ± 0.35	4.74 ± 0.35	4.82 ± 0.43	4.63 ± 0.60^a	4.81 ± 0.53	0.09
VO_2max ($mL.kg^{-1}.min^{-1}$)	62.1 ± 6.2	58.6 ± 3.6	64.2 ± 6.5	59.8 ± 4.8$	62.6 ± 6.8^{ß}	62.5 ± 5.8$^{ß,\#}$	0.01

** Data expressed as median (interquartile range) or mean ± standard deviation according to the distribution of the variables. The results were compared by use of the unpaired Student t test, ANOVA, Mann-Whitney test, Kruskal-Wallis test or chi-square test, according to the characteristics of the variables. $^{\$}$No statistically significant difference as compared to the goalkeeper group ($p > 0.05$). $^{\#}$No statistically significant difference as compared to the midfielder group ($p > 0.05$). ^{ß}No statistically significant difference as compared to the left/right-back group. $^{€}$No statistically significant difference as compared to the center-defender group. ^{a}There was a statistically significant difference as compared to the goalkeeper group ($p < 0.05$). ^{b}There was a statistically significant difference as compared to the left/right-back group ($p < 0.05$); ^{c}There was a statistically significant difference as compared to the center-defender group ($p < 0.05$). FVC: forced vital capacity; HR: heart rate; VT: ventilatory threshold; SBP: systolic blood pressure; DBP: diastolic blood pressure; COP: cardiorespiratory optimal point; RER: respiratory exchange rate; CPX: cardiopulmonary exercise test; VE: ventilation; FEV1: forced expiratory volume in the first second; VO_2max: maximal oxygen consumption.*

of the cardiorespiratory interaction of both healthy individuals and those with chronic diseases; in addition, by being a submaximal variable of CPX, the use of COP is particularly interesting for patients unable to achieve a maximal CPX because of functional limitations (eg, peripheral obstructive arterial disease, orthopedic disorders) or because of their fear of achieving peak exertion (eg, patients with panic syndrome),[17,21] as well as for athletes during the competition season.[22] For example, the COP bears an inverse relationship with all-cause mortality in healthy and ill individuals aged from 40 to 85 years, having, thus, prognostic value and being a new possibility for mortality risk assessment.[17] Based on those observations, it is worth trying to expand the applicability of COP to other scenarios. In theory, one might assume that for athletes of modalities with high aerobic demands, such as soccer, low COP values can represent a physiological advantage, especially when occurring at relatively high velocities. Because the aerobic demands vary according to the field position during the match, the opportunity to compare a large number of elite soccer players tested in standard conditions can contribute to better understand the meaning and the potential applicability of COP in sports. The present study is an original contribution because it is the first to describe the COP behavior in athletes, in particular, high-level adult soccer players submitted to a CPX on a treadmill following the ramp protocol.

The COP has advantages related to its determination and measurement when compared to VO_2max and VT, the two major variables of CPX used to assess the performance of athletes. Obtaining a true VO_2max

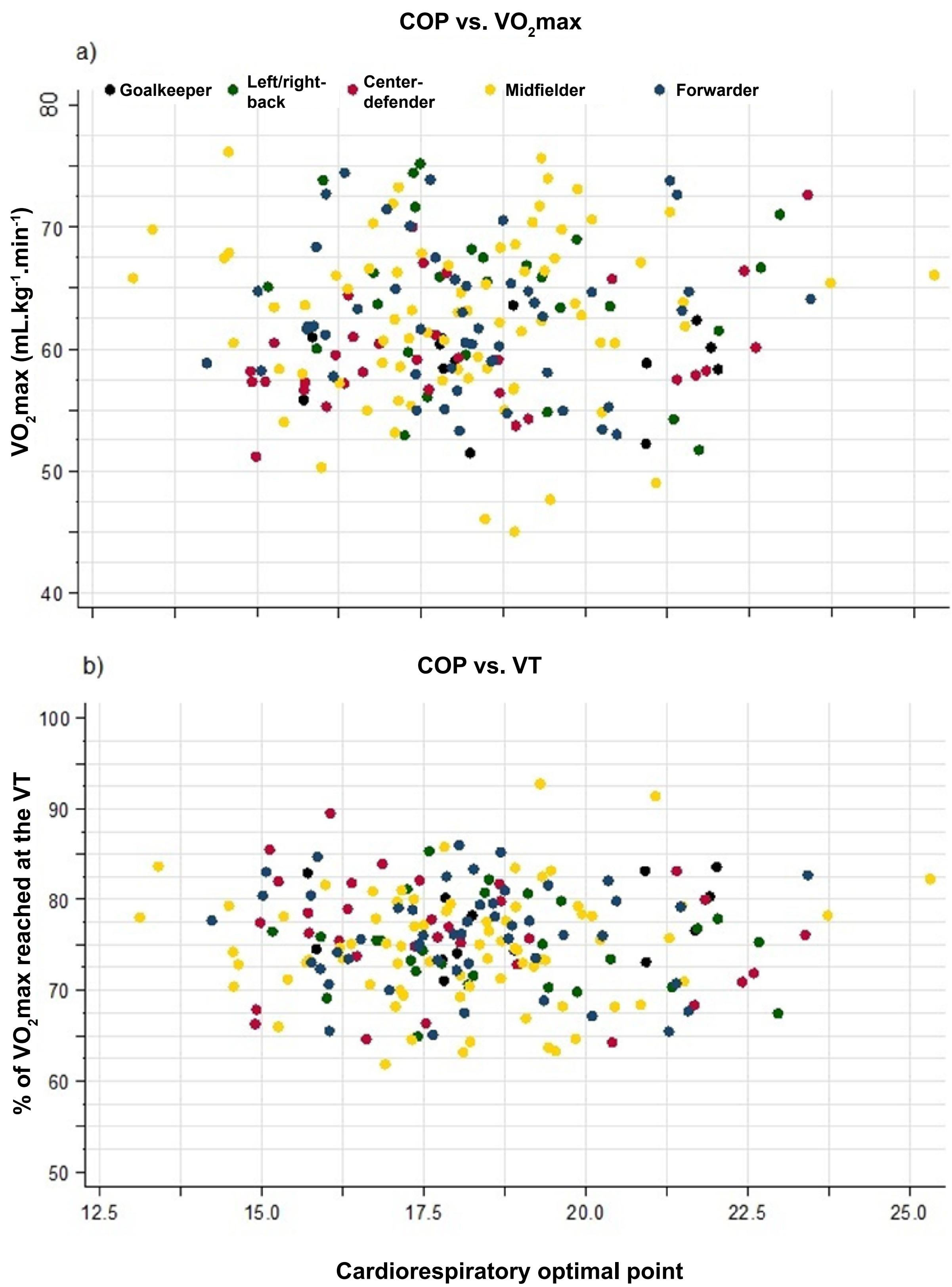

Figure 1 - Diagram of dispersion between variables: a) cardiorespiratory optimal point (COP) and maximal oxygen consumption (VO_2max); and b) COP and percentage of VO_2max reached at the ventilatory threshold (VT).

suggests the existence of a plateau in the VO_2 curve, which is not always possible, and it can vary according to the CPX protocol used and the gas sampling or collection interval.[10,11] In addition, VO_2max depends on performing a truly maximal exercise test, whose determination criteria vary in the literature, being subjective to a certain extent. On the other hand, although the VT does not require a maximal test, it requires a more intense exercise than COP does, and VT measurement is hindered by the existence of several distinct criteria for its identification and/or characterization, which, in a significant percentage of cases, cannot be obtained, limiting its use in clinical practice and sports.[13] In addition, although both VO_2max and VT can be detected automatically with commercial software, the methods available for that have been developed from varied definitions and algorithms, implying the need for its review by at least one experienced observer, making those measures subjective and widening the potential of high inter- and intraobserver variability.[23,24] In contrast, COP is easily determined from the identification of the lowest value of the VE/VO_2 ratio for each minute of CPX, not depending, thus, on the interpretation and experience of the observer, and relying on a relatively small effort, because it occurs at relatively low exercise intensities, before the VT.

Regarding the COP of the soccer players assessed, some findings are worth noting: 1- as expected, COP was obtained at lower percentage of VO_2max and velocity than those at the VT; 2- similarly to VT, but opposite to VO_2max, COP did not differ according to the different field positions of the soccer players; 3- no significant association was observed between COP and the variables VO_2max and VT; and 4- the coefficient of variation of oxygen consumption at the time of the COP was greater than that observed at the VT and VO_2max. It is interesting to point out that, on average, the COP values found for the soccer players were below the 50th percentile of the values found for healthy male non-athletes of the same age group in a previous study,[15] and that only eight (4%) soccer players had COP over 22, considered the cutoff point for optimal clinical prognosis,[17] suggesting that those soccer players have a privileged circulation-respiration interaction, probably more economic at the submaximal exercise. However, it is worth noting that the COP values described for non-athletes were obtained from a CPX performed on a lower limb cycle ergometer, with an individualized ramp protocol. Thus, the description of COP in different exercise modalities and protocols should be approached in future studies, because there is evidence that the behavior of some variables obtained in CPX differ depending on the ergometer and protocol used.

The running velocity on the treadmill and the exercise intensity represented by the percentage of VO_2max at which the soccer players assessed in this study reached the COP (10.0 ± 1.0 km.h^{-1} and $51.3 \pm 8.7\%$, respectively) were lower than the values obtained at the VT by soccer players assessed in other studies, even when compared to those of players of lower athletic performance, who are expected to reach an earlier VT. For example, according to Ziogas et al.,[25] soccer players of the first, second and third Greek division submitted to a CPX in the pre-season period reached the VT at a mean velocity of 13.2, 12.6 and 12.3 km.h^{-1}, respectively. Boone et al.,[26] however, assessing 289 soccer players of the first Belgian division, have reported mean running velocities on the treadmill at the VT ranging from 12.7 ± 1.4 in goalkeepers to 14.4 ± 0.7 km.h^{-1} in center-defenders. Regarding the exercise intensity, Impellizzeri et al.[27] and Helgerud et al.[28] have reported that junior soccer players reached the VT at a mean percentage of VO_2max greater than 80%. Considering that the running velocity and the exercise intensity at which the VT is reached reflect the training status of the soccer players, future studies should assess whether COP is also useful to differentiate the physical performance of athletes.

When comparing the soccer players according to their field positions, goalkeepers, midfielders, left/right-backs, center-defenders and forwarders did not differ regarding the COP. Manari et al.,[29] comparing the VT and the VO_2max of 450 European elite soccer players of different field positions, have found no differences regarding the VT, similarly to our study's findings regarding VT and COP. However, similarly to our study's findings, VO_2max was lower in goalkeepers. Tonessem et al.,[30] assessing 1,545 male soccer athletes, have found small to moderate differences in VO_2max according to the athlete's field position, with greater values in the midfielders, followed, in decreasing order, by the defense athletes, forwarders and goalkeepers. Similarly, Balikian et al.,[31] assessing 25 professional soccer players, have found lower mean VO_2max values of goalkeepers (52.68 mL.kg^{-1}.min^{-1}) as compared to the mean values of soccer players of other field positions. However, in contrast to our study's findings, the mean velocity at which the players reached the VT differed according to their field position, being lower for goalkeepers (12.66 km.h^{-1}) and higher for left/right-backs (14.33 $km.h^{-1}$) and midfielders (14.11 $km.h^{-1}$). Nevertheless, it is worth noting that the heterogeneity of the methods used to measure VT hinders the comparison of the results between the studies.

Finally, the COP failed to show a linear association with the variables VT and VO_2max. Ramos et al.[15] have not only described a moderate association with VO_2max (-0.47) and VT (-0.42), but have also observed that the combination of COP and VO_2max adds more prognostic information to all-cause mortality than each variable in isolation.[17] Such findings suggest a possible independence and complementarity of COP regarding VO_2max and VT, which could contribute with additional information to the interpretation of the relationship between the cardiovascular and respiratory systems during a CPX. Thus, one can speculate that the submaximal variables – COP and VT – might better reflect the energetic demands of a soccer match in the current context, in which the differences in distance and in percentage of time spent in intense efforts are less evident in soccer players of different field positions.

The present study has some limitations in addition to those already mentioned. The CPX analyzed were limited to those performed in the pre-season period, not allowing us to assess the COP behavior in different training periods of the soccer players. In addition, this study only assessed male adult elite soccer players, which limits the extrapolation of the results to female soccer players, other age groups, different technical levels and other sport modalities.

Conclusion

The present study described the COP behavior and its absence of association with VO_2max and VT of male adult elite soccer players. Thus, future studies are required to assess whether COP can provide additional and relevant information to other sport contexts.

Author contributions

Conception and design of the research: de Souza e Silva CG, Castro CLB, Franca JF, Bottino A, Myers J, Araújo CGS; Acquisition of data: Castro CLB, Franca JF, Araújo CGS; Analysis and interpretation of the data, Statistical analysis and Writing of the manuscript: de Souza e Silva CG, Araújo CGS; Critical revision of the manuscript for intellectual content: Castro CLB, Franca JF, Bottino A, Myers J, Araújo CGS.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Sources of Funding

There were no external funding sources for this study.

Study Association

This study is not associated with any thesis or dissertation work.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Suprema - Faculdade de Ciências Médicas e da Saúde de Juiz de Fora under the protocol number 0218/11. All the procedures in this study were in accordance with the 1975 Helsinki Declaration, updated in 2013. Informed consent was obtained from all participants included in the study.

References

1. Albouaini K, Egred M, Alahmar A, Wright DJ. Cardiopulmonary exercise testing and its application. Postgrad Med J. 2007;83(985):675-82.
2. Ross R, Blair SN, Arena R, Church TS, Després JP, Franklin BA, et al; American Heart Association Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Cardiovascular and Stroke Nursing; Council on Functional Genomics and Translational Biology; Stroke Council. Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. Circulation. 2016;134(24):e653-e99.
3. Gitt AK, Wasserman K, Kilkowski C, Kleemann T, Kilkowski A, Bangert M, et al. Exercise anaerobic threshold and ventilatory efficiency identify heart failure patients for high risk of early death. Circulation. 2002;106(24):3079-84.
4. Edwards AM, Clark N, Macfadyen AM. Lactate and ventilatory thresholds reflect the training status of professional soccer players where maximum aerobic power is unchanged. J Sports Sci Med. 2003;2(1):23-9.
5. Hoff J. Training and testing physical capacities for elite soccer players. J Sports Sci. 2005;23(6):573-82.
6. Midgley AW, McNaughton LR, Jones AM. Training to enhance the physiological determinants of long-distance running performance: can valid recommendations be given to runners and coaches based on current scientific knowledge? Sports Med. 2007;37(10):857-80. Erratum in: Sports Med. 2007;37(11):1000.

7. Stølen T, Chamari K, Castagna C, Wisløff U. Physiology of soccer: an update. Sports Med. 2005;35(6):501-36.

8. Reilly T. Physiological aspects of soccer. Biol Sport. 1994;11:3-20.

9. Taylor HL, Buskirk E, Henschel A. Maximal oxygen intake as an objective measure of cardiorespiratory performance. J Appl Physiol.1955;8(1):73-80.

10. Myers J, Walsh D, Buchanan N, Froelicher VF. Can maximal cardiopulmonary capacity be recognized by a plateau in oxygen uptake? Chest. 1989;96(6):1312-6.

11. Myers J, Walsh D, Sullivan M, Froelicher V. Effect of sampling on variability and plateau in oxygen uptake. J Appl Physiol (1985). 1990;68(1):404-10.

12. Doherty M, Nobbs L, Noakes TD. Low frequency of the "plateau phenomenon" during maximal exercise in elite British athletes. Eur J Appl Physiol. 2003;89(6):619-23.

13. Yeh MP, Gardner RM, Adams TD, Yanowitz FG, Crapo RO. Anaerobic threshold: problems of determination and validation. J Appl Physiol Respir Environ Exerc Physiol. 1983;55(4):1178-86.

14. Zinner C, Sperlich B, Wahl P, Mester J. Classification of selected cardiopulmonary variables of elite athletes of different age, gender, and disciplines during incremental exercise testing. Springerplus. 2015;4:544.

15. Ramos PS, Ricardo DR, Araújo CG. Cardiorespiratory optimal point: a submaximal variable of the cardiopulmonary exercise testing. Arq Bras Cardiol. 2012;99(5):988-96.

16. Ramos PS, Araújo CG. Análise da estabilidade de uma variável submáxima em teste cardiopulmonar de exercício: ponto ótimo cardiorrespiratório. Rev Bras Ativ Fis e Saúde (Pelotas-RS). 2013;18(5):585-93.

17. Ramos PS, Araújo CG. Cardiorespiratory optimal point during exercise testing as a predictor of all-cause mortality. Rev Port Cardiol. 2017;36(4):261-9.

18. Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, et al; ATS/ERS Task Force. Standardisation of spirometry. Eur Respir J. 2005;26(2):319-38.

19. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377-81.

20. Hagan RD, Smith MG. Pulmonary ventilation in relation to oxygen uptake and carbon dioxide production during incremental load work. Int J Sports Med. 1984;5(4):193-7.

21. Ramos PS, Sardinha A, Nardi AE, de Araújo CG. Cardiorespiratory optimal point: a submaximal exercise variable to assess panic disorder patients. PLoS One. 2014;9(8):e104932.

22. Nikolaidis PT. Can maximal aerobic running speed be predicted from submaximal cycle ergometry in soccer players? The effects of age, anthropometry and positional roles. Adv Biomed Res. 2015;4:226.

23. Myers J, Goldsmith RL, Keteyian SJ, Brawner CA, Brazil DA, Aldred H, et al. The ventilatory anaerobic threshold in heart failure: a multicenter evaluation of reliability. J Card Fail. 2010;16(1):76-83.

24. Gaskill SE, Ruby BC, Walker AJ, Sanchez OA, Serfass RC, Leon AS. Validity and reliability of combining three methods to determine ventilatory threshold. Med Sci Sports Exerc. 2001;33(11):1841-8.

25. Ziogas GG, Patras KN, Stergiou N, Georgoulis AD. Velocity at lactate threshold and running economy must also be considered along with maximal oxygen uptake when testing elite soccer players during preseason. J Strength Cond Res. 2011;25(2):414-9.

26. Boone J, Vaeyens R, Steyaert A, Vanden Bossche L, Bourgois J. Physical fitness of elite Belgian soccer players by player position. J Strength Cond Res. 2012;26(8):2051-7.

27. Impellizzeri FM, Marcora SM, Castagna C, Reilly T, Sassi A, Iaia FM, et al. Physiological and performance effects of generic versus specific aerobic training in soccer players. Int J Sports Med. 2006;27(6):483-92.

28. Helgerud J, Engen LC, Wisloff U, Hoff J. Aerobic endurance training improves soccer performance. Med Sci Sports Exerc. 2001;33(11):1925-31.

29. Manari D, Manara M, Zurini A, Tortorella G, Vaccarezza M, Prandelli N, et al. VO_2max and VO_2AT: athletic performance and field role of elite soccer players Sport Sci Health. 2016;12(2):221-6.

30. Tønnessen E, Hem E, Leirstein S, Haugen T, Seiler S. Maximal aerobic power characteristics of male professional soccer players, 1989-2012. Int J Sports Physiol Perform. 2013;8(3):323-9.

31. Balikian P, Lourenção A, Ribeiro LF, Festuccia WTL, Neiva CM. Consumo máximo de oxigênio e limiar anaeróbio de jogadores de futebol: comparação entre as diferentes posições. Rev Bras Med Esporte. 2002;8(2):32-6.