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Aerobic evaluation in soccer

Avaliação aeróbia no futebol

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Abstract – Physical assessments are fundamental for the control and improvement of the performance of soccer players. In this respect, field and laboratory tests are commonly used to evaluate physical fitness in this sports modality. However, it is important to choose the appropriate protocol according to the objectives of the assessment. Thus, the aim of the present study was to perform a critical-narrative review of the aerobic assessment of soccer players, including physiological indices and field and laboratory tests. With respect to the aerobic indices identified in this review, maximal oxygen uptake, anaerobic threshold, and running economy were found to contribute to the development of training programs and help monitor their effects in soccer players. However, the anaerobic threshold is the index most sensitive to the effects of training and also better discriminates performance among athletes of different competitive levels. Regarding field tests, the Carminatti test (TCar) and Yo-Yo intermittent recovery level 1 (YYIR1) test are the most suitable tests for the aerobic assessment of soccer players considering their specificity, validity and reproducibility. However, the TCar permits the direct transfer of indicators of aerobic power and capacity to the training sessions, whereas the YYIR1 mainly explores the distance covered, which partly limits this transfer.
Key words: Assessment techniques; Oxygen uptake; Soccer.

Resumo – *A realização de avaliações físicas é fundamental para o controle e melhoria da performance de atletas de futebol. Desta forma, a utilização de testes de campo e laboratório tem sido uma prática constante para avaliar a aptidão aeróbia nesta modalidade. Contudo, é essencial a escolha do protocolo adequado de acordo com os objetivos estipulados. Assim, o objetivo do presente estudo foi realizar uma revisão crítico-narrativa sobre a avaliação aeróbia em jogadores de futebol, englobando índices fisiológicos, testes de laboratório e de campo. Em relação aos índices aeróbios apresentados na presente revisão, foi possível observar que os índices (consumo máximo de oxigênio:* VO_2max*, segundo limiar de transição fisiológica:* LTF_2*, economia de corrida: EC) podem contribuir como subsidio para a elaboração dos programas de treinamento e para acompanhar os seus efeitos em jogadores de futebol. Entretanto, o* LTF_2 *é o índice que apresenta maior sensibilidade aos efeitos de treinamento e que melhor discrimina a performance em atletas de diferentes níveis competitivos. Sobre os testes de campo, é possível afirmar que o TCar (teste de Carminatti) e o Yo-Yo recovery nível 1(YYIR1) são os mais adequados para avaliação aeróbia de atletas de futebol, considerando especificidade, validade e reprodutibilidade. Contudo, o TCar apresenta a possibilidade de transferência dos indicadores de potência (PV) e capacidade (PDFC) aeróbia diretamente para as sessões de treinamento, enquanto que o YYIR1 explora principalmente a distância percorrida, que limita em parte tal transferência.*
Palavras-chave: *Consumo de Oxigênio; Futebol; Técnicas de avaliação.*

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INTRODUCTION

Soccer is characterized by a series of acyclic actions that develop during a match in the form of high--intensity running, jumping, heading, and kicking. These actions are mainly anaerobic activities; however, energy derived from the aerobic metabolism is used for 90% of the movements of soccer players and is a prerequisite for this modality[1,2]. This aerobic predominance is related to the duration of a soccer match (approximately 90 min) and the large distance run by the athletes during the games.

There are numerous protocols for physiological assessment in soccer. The parameters used for the evaluation of aerobic fitness in soccer players include maximal oxygen uptake (VO_2max), which corresponds to the maximum capacity of a subject to take up, transport and utilize oxygen at the cellular level per unit time[3]; peak velocity (PV) which, according to Rampinini et al.[4], is associated with the distance run at high intensity (>19.8 $km.h^{-1}$) and, more recently, the anaerobic threshold and running economy (RE), which can also be used to discriminate performance among athletes of different competitive levels[5]. Although various reports have investigated aerobic parameters in soccer players, there is a lack of studies that evaluate in detail the characteristics related to the assessment of these parameters, particularly factors interfering with the tests (field and laboratory) and standardization of the methods.

Therefore, the aim of the present study was to perform a critical-narrative review of the aerobic assessment of soccer players, including physiological parameters and field and laboratory tests, in order to provide a critical analysis of the information available in the literature. These data are especially helpful for researchers, technicians, physiologists, and trainers working with soccer, as well as for students who wish to acquire knowledge about this modality. In the following sections we will describe physiological parameters evaluated in laboratory and field tests that can be used for the assessment of different aerobic components in soccer players.

For this review, the Capes, PubMed and Scielo databases were searched. In addition, scientific conference proceedings in the area of Physical Education and master's theses were also reviewed. In this respect, articles and abstracts published after 2000 were primarily retrieved. However, classical studies on this topic conducted in the 1970s, 80s and 90s were also included in the present study.

PHYSIOLOGICAL PARAMETERS OF AEROBIC FITNESS IN SOCCER OBTAINED UNDER LABORATORY CONDITIONS

Soccer is characterized by constant changes in intensity, short intervals of recovery, sudden stops and change of direction, i.e., soccer players experience intermittent efforts during training and competitions[6]. Despite these characteristics, the energy used by soccer players is mainly produced by aerobic metabolism, which is related to the capacity of the athlete to maintain effort intensity during a game through recovery between high-intensity stimuli[7].

VO_2max is an indicator of cardiorespiratory fitness, which corresponds to the highest rate at which oxygen can be taken up and utilized by the body during maximum exercise, breathing atmospheric air at sea level[3]. By representing the upper limit of energy transformation via aerobic metabolism, VO_2max is considered to be the main physiological indicator of maximal aerobic power[8]. Several studies have analyzed VO_2max in soccer players[5,9,10]. Most of them report values ranging from 55 to 68 $mL.kg.min^{-1}$, which are lower than those traditionally found in endurance runners (70 $mL.kg.min^{-1}$). This difference is related to the training characteristics of endurance runners, which focus on aerobic power and capacity. In contrast, the training of soccer players comprises intermittent activities, repeated sprint ability, force, speed and muscle power, emphasizing aerobic fitness at specific time points such as at the beginning of the season[2].

Some studies have compared VO_2max between soccer players of different positions[2,9-11]. Bangsbo et al.[11] and Al-Hazza et al.[10] investigated professional players and found no significant difference between defenders, midfielders, or forwards. In contrast, Balikian et al.[9] observed a significant difference only when the results of goalkeepers were compared to those obtained for the other positions. Santos[12], identifying possible differences resulting from athlete position, found that the VO_2max of wingbacks (59.3 ± 3.6 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) and midfielders (59.5 ± 6.7 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) differed significantly from that of forwards (54.9 ± 8.2 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$), whereas no difference was observed between defenders (56.8 ± 5.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) and the other positions. In agreement with these results, Bangsbo[2] identified higher VO_2max in wingbacks and midfielders (61.5 ± 10.0 and 62.6 ± 4.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$, respectively) when compared to goalkeepers (51 ± 2.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) and defenders (56 ± 3.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$). Despite divergences in the literature, it can be concluded that midfielders and sideways tend to present higher VO_2max. These contradictory findings might be related to the reduced ability of VO_2max to discriminate aerobic performance in soccer players, mainly because these studies have used laboratory protocols involving treadmill walking. This assessment model is not specific for soccer players and differences in aerobic performance may not be detectable when laboratory protocols are used.

VO_2max does not permit to determine performance in soccer because of the intermittent characteristics of this modality, intercalating exercises of variable intensities that increase the request of anaerobic metabolism, and different recovery periods, in relation to duration and intensity[17]. However, this physiological parameter may be useful to evaluate changes in aerobic fitness when these alterations are significant, for example, during the preseason[13].

The velocity at which VO_2max is reached is another relevant variable of aerobic fitness. This intensity is called vVO_2max and is defined as the minimum velocity at which VO_2max occurs[14]. This parameter better illustrates the association between maximal aerobic power and RE since subjects with similar VO_2max may present distinct vVO_2max values, i.e., different aerobic performance (Figure 1).

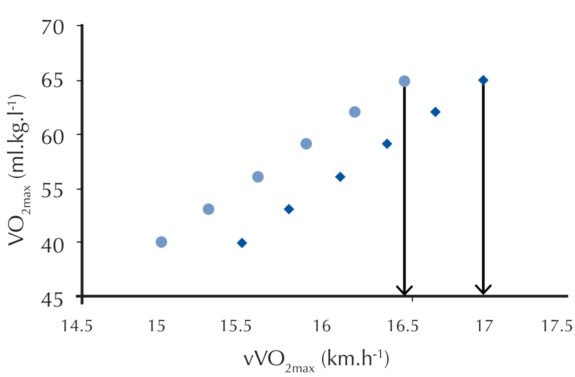

Figure 1. Schematic representation of the relationship between VO_2max and vVO_2max in subjects with different running economies.
● Subject 1- Lower running economy.
◆ Subject 2 - Higher running economy.

Studies investigating vVO_2max in soccer are scarce. In addition, the different protocols used for the determination of this parameter impair the comparison of the results obtained. The measurement of vVO_2max is associated with its use for the prescription of aerobic power training[14]. In soccer, this training model has been recommended for specific time points, such as the beginning of the season or after various subsequent games when aerobic fitness, especially that of alternate athletes, seems to decline[15]. The measurement of this variable in laboratory tests shows the same limitations as VO_2max, including a lack of specificity, high cost, and difficulty in evaluating several athletes within a short period of time.

For a long time, VO_2max has been the main physiological indicator for the evaluation of aerobic fitness. However, some studies have shown that VO_2max is not the best discriminator of performance in predominantly aerobic events[19]. As a consequence, increasing attention has been paid to parameters derived from the blood lactate response, which are more sensitive to the effects of training than VO_2max, even in groups of highly trained athletes with similar VO_2max[8].

The blood lactate response has shown a higher predictive power of aerobic performance in homogenous groups due to the fact that it is associated with peripheral adaptations of aerobic training, including an increase in capillary density and in the ability to transport lactate and H^+ ions[16]. According to Bourdon[17], it is possible to assume the existence of physiological domains separated by two thresholds or two losses of continuity in the blood lactate response, identified as the first (LT_1) and the second (LT_2) blood lactate transition threshold. LT_1 is associated with the first intensity at which a sustained increase in [La] above resting levels occurs. In contrast, LT_2 corresponds to the intensity that provokes a rapid increase in [La], indicating the upper limit of the steady state between lactate production and removal. LT_1 is the minimum lower limit of training intensity that causes improvement of aerobic capacity and is also used in regenerative training[18]. On the other hand, LT_2 corresponds to the transition from the heavy to severe domain and is associated with maximal lactate steady state (MLSS). According to Beneke et al.[16], MLSS is defined as the highest workload that can be maintained over time without continued blood lactate accumulation.

McMillan et al.[1] showed that LT_1 and LT_2 are sensitive to the effects of training during a soccer season. In addition, running velocity at the two thresholds increased markedly during the first weeks of training and was constant during the remaining season. The authors attributed this finding to the fact that the athletes had returned from a summer break during which they were not involved in any type of training. Recently, Ziogas et al.[5] demonstrated differences in LT_2 between soccer players of different competitive levels (1st, 2nd and 3rd Greek division). The highest values were observed in athletes of the 1st division, suggesting that this parameter can be used as a discriminator of aerobic performance in soccer since in that study LT_2 was the only aerobic parameter able to distinguish between the three divisions.

Therefore, measurement of LT_2 should be implemented as a tool during the soccer season for the investigation of aerobic fitness, mainly because LT_2 is associated with peripheral aerobic responses such as an increase in capillary density and in the ability to transport lactate and H^+ ions[16], whereas VO_2max is basically limited to central factors (cardiac output)[3]. In support of these results, Silva et al.[15] demonstrated a significant correlation between the anaerobic threshold and repeated sprint ability, whereas VO_2max was not associated with the latter.

With respect to the protocols used to measure the intensity corresponding to LT_2, some of them employ fixed blood lactate concentrations, some use variable concentrations in individual protocols, and some are based on respiratory equivalents. Studies have a reported a mean velocity of 13.0 to 15.0 $km.h^{-1}$ at which LT_2 occurs in soccer players (Table 1).

Another variable that has been recently suggested as a predictor of aerobic fitness in soccer players is RE[5,19,20], which is defined as oxygen cost at a submaximal exercise intensity[21]. On the basis of this definition, a more economic athlete consumes less oxygen and is theoretically able to run faster or to save energy for final stages of the run[8], resulting in better performance. Hoff et al.[19] demonstrated that aerobic performance can be achieved by an increase in RE during endurance training without significant alterations in VO_2max or LT_2. In addition, Helgerud et al.[20] found that high-intensity interval training (4 x 4 min at 90 to 95% maximal heart rate, twice a week) for 8 weeks increases RE by 6.7%, supporting that this variable is sensitive to aerobic training in soccer players. Studying soccer players of different competitive levels (2nd and 3rd Greek division), Ziogas et al.[5] observed no difference in VO_2max, whereas there was a difference in RE, suggesting that this variable better distinguishes competitive level than VO_2max. Di Prampero et al.[22] demonstrated that an increase of 5% in RE results in a 3.8% increase of performance in middle-distance running. This finding may have important implications for the planning of soccer training, especially for the combination of aerobic and endurance training which has been shown to be the best alternative to increase RE.

In this respect, it can be clearly seen that all aerobic parameters reported in this review (VO_2max, LT_2, RE) contribute to the development

Table 1. Mean (± SD) VO_2max in soccer players.

Reference	Country	n	Level	VO_2max ($mL\cdot kg^{-1}\cdot min^{-1}$)
Aziz et al.[36]	Singapore	23	P	58.2 ± 3.7
Casajus[37]	Spain	15	P	66.4 ± 7.6
Fernandes da Silva et al.[15]	Brazil	29	J	63.2 ± 4.9
Helgerud et al.[20]	Norway	19	J	58.1 ± 4.5
Balikian et al. [9]	Brazil	25	P	59.0 ± 5.6
Wisloff et al.[38]	Norway	29	P	63.7 ±5.0
Ziogas et al.[5]	Greece	53	P	58.8 ± 3.3

VO_2max: maximal oxygen uptake.

Table 2. Mean (± SD) of velocity and heart rate at the second blood lactate transition threshold in soccer players.

Reference	Country	n	Level	VLT_2 (km/h)	HR LT_2 (bpm)	Method used
Casajus[37]	Spain	15	P	12.4 ± 1.5	164.0 ± 6.0	Respiratory equivalent
McMillan et al.[1]	England	9	J	14.6 ± 0.2	-	4.0 mmol
Santos[12]	Portugal	44	P	14.2 ± 1.4	-	Respiratory equivalent
Silva et al.[15]	Brazil	29	J	13.5 ± 1.2	174.0 ± 7.0	3.5 mmol
Balikian et al.[9]	Brazil	25	P	13.5±0.9	-	4.0 mmol
Ziogas et al. [5]	Greece	53	P	13.2±0.7	170.0 ± 10.0	Dmax

VLT_2: velocity at the second blood lactate transition threshold; HR LT_2: heart rate at the second blood lactate transition threshold.

of training programs and to monitor their effects on athlete performance. However, LT_2 is the parameter most sensitive to the effects of training and also better discriminates performance among athletes of different competitive levels. This is due to the constant occurrence of supramaximal stimuli (>VO_2max) in soccer, which mainly cause peripheral aerobic adaptations, such as an increase in capillary density and in the ability to transport lactate and H^+ ions, with these adaptations being directly related to LT_2[15,23].

PHYSIOLOGICAL PARAMETERS OF AEROBIC FITNESS IN SOCCER OBTAINED IN THE FIELD

In this section we will present field tests used for aerobic assessment of soccer players. However, continuous tests performed in the laboratory are not included since they are basically designed to estimate VO_2max and LT_2 and are of low value for the prescription of training.

In view of the short time clubs have for assessments, the high cost of laboratory tests[24] and the principle of specificity[13], there is a growing number of field tests that reproduce as closely as possible the movements used during training and competition[25-27]. Among the tests reported in the literature, the 20-m shuttle run test (SHT20) proposed by Legér and Lambert[25] and subsequently validated by Ramsbottom et al.[28] is an interesting alternative for the determination of maximal aerobic power (PV and VO_2max), since it permits to evaluate several subjects at the same time and only requires a CD recorder, a compact disk, a 20-m measuring tape, and four cones. However, this test does not include rest intervals, thus reducing its specificity for intermittent modalities[13]. In addition, the use of PV determined in SHT20 seems to be inadequate for the prescription of aerobic power training[24].

Ahmaidi et al.[24] studied PV and VO_2max using three different protocols (two field and one laboratory protocol). No significant differences in VO_2max were observed between the SHT20, Montreal University Track Test and a treadmill protocol. However, PV was on average 3.0 $km.h^{-1}$ lower in the SHT20 when compared to the other two protocols. This finding can be explained by the characteristics of the test, which consists of constant accelerations and decelerations with changes of direction every 20 m, contributing to a significant loss of RE. Furthermore, Edwards et al.[29] observed that VO_2max determined in the SHT20 did not differ between university and recreational soccer players. Odetoyinbo and Ramsbottom[30] did not find differences in performance in the SHT20 after application of an 8-week high-intensity training program to soccer players. Taken together, these results show that the SHT20 is not an adequate test for the evaluation of soccer players when the objective is to determine the effects of training, probably because of the continuous characteristics of the test, whereas soccer is an intermittent activity.

Another method frequently reported in the literature for the evaluation of soccer players is the Yo-Yo test proposed by Bangsbo[2]. This test is performed at the training site of the athlete (field, court, track) at a fixed distance of 20 m. There are three different versions of the test.

The Yo-Yo endurance test (YYE) is used for the evaluation of the ability to run continuously over a long period of time. This test possesses characteristics similar to the SHT20, but is divided into two levels according to athlete conditioning. The initial velocity is 8 $km.h^{-1}$ at level 1 (YYE1) and 11.5 $km.h^{-1}$ at level 2 (YYE2). At the two levels the velocity is increased regularly every minute (0.5 $km.h^{-1}$). The subject who reaches stage 17 in the YYE1 should perform the YYE2 in the next evaluation. The test provides two indicators, estimated VO_2max and distance covered.

The Yo-Yo intermittent endurance test (YYIE) is recommended for the evaluation of the subject's ability to perform intermitted activities for prolonged periods of time. The test is also performed at a fixed distance of 20 m and is divided into two levels with initial velocities of 8 $km.h^{-1}$ (level 1) and 11.5 $km.h^{-1}$ (level 2). However, the difference to the YYE is the adoption of rest intervals of 5 s at every 40 m (2 x 20) run. The physiological indicator provided by the test is the distance covered.

However, the most frequently investigated and most widely used version is the Yo-Yo intermittent recovery test (YYIR). The main characteristic of this test is the adoption of rest intervals of 10 s every 40 m (2 x 20). The initial velocity at level 1 (10 $km.h^{-1}$), as well as the increments of the first velocities, are higher than those of the other two versions. At level 2 (YYIR2), the initial velocity is 13 $km.h^{-1}$. Another characteristic of the YYIR are the irregular durations of the stages. The physiological indicator provided by this version is the distance covered. With respect to physiological responses, the two levels of the YYIR place maximum demand on the aerobic system, but the anaerobic requirements are higher at level 2 (YYIR2). The blood and muscle lactate concentrations observed at the end of the YYIR2 are higher than those seen in the YYIR1, whereas creatine phosphate and muscle pH are lower[31,32].

Castagna et al.[33] compared the physiological responses between the YYIR1 and YYE2 in order to determine which physiological variables related to anaerobic power (counter movement jump) aerobic power (VO_2max) and aerobic capacity (ventilatory threshold) are determinants of performance in the two models. The authors observed that the YYE2 was significantly correlated with VO_2max ($r=0.75$, $p \leq 0.01$), relative velocity at the ventilatory threshold (LT_2) ($r=0.83$, $p \leq 0.01$), and PV obtained in an incremental treadmill test ($r=0.87$, $p \leq 0.01$). On the other hand, the YYIR1 was correlated with the relative velocity at the ventilatory threshold ($r=0.69$, $p \leq 0.01$) and PV ($r=0.71$, $p \leq 0.01$), whereas the correlation with VO_2max was lower ($r=0.46$, $p \leq 0.05$). PV obtained in the YYE2 was also significantly lower than that determined in the treadmill protocol and in the YYIR1. In contrast, no significant difference in PV was observed between the treadmill test and YYIR1. Taken together, these results show that performance in the two tests is determined by different mechanisms, i.e., the YYIR1 is mainly influenced by peripheral factors related to muscle strength, whereas the YYE2 basically depends on submaximal aerobic variables (ventilatory threshold). These findings confirm the initial proposal of the authors of the test that the YYE2 is an excellent method for aerobic assessment in field situations, whereas the YYIR1 provides an evaluation of aerobic-anaerobic fitness in soccer players using only one specific test.

Therefore, the YYIR1 has been shown to be a valid alternative for the evaluation of soccer players as demonstrated by the findings cited above and mainly by the results reported by Krustrup et al.[31], who observed a significant correlation ($r=0.71$, $p<0.05$) between the YYIR1 and high-intensity performance (velocity > 15 $km.h^{-1}$) in professional soccer players during a game. Despite the specificity and validity of the Yo-Yo test for soccer, it should be remembered that the main information provided by this test is the distance covered and that the test offers no data that could be precisely applied to the training of aerobic power and capacity.

In an attempt to provide more detailed data for the prescription of training, Carminatti et al.[26] proposed an incremental intermittent running test (TCar), which consists of accelerations, decelerations, changes of direction, and intermediate rest periods and is therefore considered to be specific for soccer. The initial velocity of the TCar is 9 $km.h^{-1}$ (initial distance of 15 m), with increments of 0.6 $km.h^{-1}$ per stage (90 s) until voluntary exhaustion through successive increases of 1 m from the initial distance. The main parameters of the test are PV and heart rate deflection point (HRDP), which are associated with aerobic power and capacity, respectively.

The first study on the TCar[26] investigated the construct validity of the test by determining PV in juvenile (16 ± 0.8 $km.h^{-1}$) and junior athletes (16.7 ± 0.8 $km.h^{-1}$). The difference observed between categories demonstrates the construct validity of the test considering that the groups were in the same period of training. Thus, the test was able to distinguish physiological differences due to maturation factors. Another study[6] analyzed the concurrent validity of the TCar compared to the SHT20, which provided evidence of its validity and a high coefficient of reproducibility. In that study, a significant correlation between the two tests was observed in terms of maximal heart rate ($r=0.90$, $p \leq 0.01$) and PV ($r=0,93$, $p \leq 0.01$). In addition, there was a mean difference in PV of more than 2.4 $km.h^{-1}$, a finding that can be attributed to the intermediate rest periods and the variable distance (15 to 32 m) in the TCar, providing the athlete with greater space for acceleration at the beginning of each run and/or during the recovery of speed after each change of direction, especially at the highest velocities of the protocol (>15 $km.h^{-1}$).

Carminatti et al.[34] investigated the sensitivity of PV determined in the TCar after a period of soccer training (9 weeks) and found a high degree of sensitivity to the effects of training in young athletes. Similar results have been reported by Floriano et al.[34] who demonstrated that PV in the TCar is sensitive to adaptations that occurred during the competitive season in junior soccer players. This test can therefore be used to monitor and control physiological adaptations in soccer players, as well as to examine changes in physical skills during the season. In a subsequent study, Carminatti[36] evaluated 8 players of an indoor soccer team and confirmed that the intensity corresponding to 80% of PV and the velocity at the HRDP found in the TCar (obtained by a visual or mathematical method) are highly correlated with MLSS velocity in the test. No significant differences ($p>0.05$) were observed between the two models used for the determination of aerobic capacity. These results support the validity of the TCar to predict LT_2, offering trainers a more accessible method for the evaluation of the aerobic component in soccer.

Recently, Silva et al.[15] showed that PV obtained in the TCar is associated with aerobic (vVO_2max, VO_2max, and anaerobic threshold) and anaerobic (average time and best time) parameters. In addition, PV and heart rate presented high reproducibility (ICC=094, p<0.01, and ICC=0,97, p<0.01, respectively), with a low coefficient of variation (1.4%).

Taken together, the studies cited above demonstrate that the TCar and YYIR1 are the most adequate tests for aerobic assessment of soccer players considering their specificity, validity, and reproducibility. However, the TCar permits the direct application of parameters of aerobic power (PV) and capacity (HRDP) to training sessions, whereas the YYIR1 mainly explores the distance covered, which limits in part this application.

FINAL CONSIDERATIONS

Among the aerobic parameters measured in laboratory protocols and used for the evaluation and monitoring of soccer players, LT_2 is the parameter most sensitive to the effects of training. In addition, this parameter more precisely discriminates performance among athletes of different competitive levels.

With respect to field tests, the TCar and YYIR1 are the most adequate protocols for the evaluation of aerobic fitness in soccer players. However, the TCar permits the application of the indicators measured (HRDP and PV) to the prescription of training intensity.

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