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The Hoff circuit test is more specific than an incremental treadmill test to assess endurance with the ball in youth soccer players

AUTHORS: Zagatto AM[1,3], Papoti M[2], Da Silva ASR[2], Barbieri RA[3], Campos EZ[3], Ferreira EC[4], Loures JP[3], Chamari K[5]

[1] UNESP - Univ Estadual Paulista, Physical Education Department, Bauru-SP, Brazil
[2] School of Physical Education and Sports of Ribeirão Preto, São Paulo University, Ribeirão Preto-SP, Brazil
[3] Post-Graduation Program in Movement Science, UNESP - Univ Estadual Paulista - Rio Claro-SP, Brazil
[4] Laboratory of Exercise Physiology (LAFE) – UNESP - Univ Estadual Paulista – Presidente Prudente-SP, Brazil
[5] Athlete Health and Performance Research Centre, Aspetar, Doha, Qatar

Corresponding author:
Alessandro Moura Zagatto
Department of Physical Education, UNESP - Univ Estadual Paulista, Av. Eng. Luiz Edmundo Carrijo Coube, 14-01, Vargem Limpa, CEP 17033-360 Bauru-SP, Brazil.
Phone/Fax: +55 14 31036082
E-mail: azagatto@yahoo.com.br

ABSTRACT: The assessment of aerobic endurance is important for training prescription in soccer, and is usually measured by straight running without the ball on a track or treadmill. Due to the ball control and technical demands during a specific soccer test, the running speeds are likely to be lower compared to a continuous incremental test. The aim of the present study was to compare the heart rate (HR), rating of perceived exertion (RPE) and speeds corresponding to 2.0 mmol·L^{-1}, 3.5 mmol·L^{-1}, lactate threshold (Dmax method) and peak lactate determined in the laboratory and in the Hoff circuit soccer-specific test. Sixteen soccer players (16±1 years) underwent two incremental tests (laboratory and Hoff circuit tests). The speeds were significantly higher in the treadmill test than on the Hoff circuit (2.0 mmol·L^{-1}: 9.5±1.2 and 8.1±1.0 km·h^{-1}; 3.5 mmol·L^{-1}: 12.0±1.2 and 10.2±1.1 km·h^{-1}; Dmax: 11.4±1.4 and 9.3±0.4 km·h^{-1}; peak lactate: 14.9±1.6 and 10.9±0.8 km·h^{-1}). The HR corresponding to 3.5 mmol·L-1 was significantly higher on the Hoff circuit compared to the laboratory test (187.5±18.0 and 178.2±17.6 bpm, respectively; $P < 0.001$), while the RPE at the last incremental stage was lower on the Hoff circuit ($P < 0.01$). The speeds during the Hoff specific soccer test and the HR corresponding to 2.0 mmol·L^{-1}, 3.5 mmol·L^{-1} and Dmax/threshold were different compared with the laboratory test. The present study shows that it is possible to assess submaximal endurance related variables specifically in soccer players.

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INTRODUCTION

A soccer match is characterized by intermittent high intensity efforts with short recovery periods [1], and therefore the players' running performance is highly dependent on their aerobic ability [2]. In addition, players with higher aerobic endurance are able to perform a higher number of sprints and to cover greater distances during the game [3]. They are also able to improve the technical performance and their involvement with the ball during the match [3,4].

Among the parameters of endurance assessment, the VO_{2max} test variables are often used to determine the aerobic conditioning of soccer players [3-6]. Aerobic endurance (submaximal variables) is considered a useful tool for assessment of physical fitness and to detect changes in aerobic fitness resulting from systematic training [4]. These indicators are more sensitive to training than other aerobic indicators (e.g., maximum oxygen uptake) [7] and have been shown to be associated with soccer match performance [8].

However, the main criticism of the assessment of the aerobic endurance of soccer players is that the tests used do not mimic the activities performed in soccer (i.e. continuous running, track running or treadmill running).

Thus, Hoff, Wisloff, Engen, Kemi, and Helgerud [9] proposed a specific circuit with jumps, running backwards and changing directions whilst dribbling the ball (Hoff circuit), which has been shown to be related to match performance [8]. This circuit is also useful to determine maximal oxygen consumption [6,10] and maximal heart rate (HRmax) [10], but the maximum distance covered in the Hoff circuit is not correlated with aerobic endurance determined on the treadmill [11]. In addition, some authors recommend the Hoff circuit as alternative aerobic training, and the related heart rate (HR) as a valid and reliable indicator to monitor soccer players' training [9].

Because of the relationship between aerobic endurance and technical performance as well as ball involvement during a match [3.4.8], and the ecological validity of the Hoff circuit for soccer, Loures et al. [5] have recently demonstrated that the aerobic endurance (i.e., anaerobic threshold) evaluated on the Hoff circuit is valid to predict the maximal lactate steady state and the heart rate (HR) associated with the aerobic endurance in a specific test.

However, the main knowledge gap is whether a specific soccer procedure and non-specific procedures result in similar physiological and perceived intensity responses.

Zouhal et al. [12] reported that the oxygen uptake, the total oxygen consumed (i.e., total area), and blood lactate were higher during the Hoff circuit than during high-intensity intermittent aerobic exercises (15 s/15 s exercise). They found that the HR was similar, but the rating of perceived exertion (RPE) during high-intensity intermittent aerobic exercises was higher. However, Esposito et al. [13] compared the HR vs. oxygen consumption relationship during a laboratory treadmill test and soccer-specific test, and observed that the HR vs. oxygen consumption relation was similar between the two tests. Even though this relationship can be similar, the speed and HR in which the athlete reaches aerobic endurance is likely to be different between the situations. This would mislead the training prescription for soccer players.

Thus, the assessment of aerobic endurance on the Hoff circuit would increase the specificity of aerobic evaluation and optimize the prescription and monitoring of soccer training through specific tools. Since small sided games have been used in soccer training [14], the HR associated with aerobic endurance might be different if analysed with continuous running compared with specific movements. Therefore, a specific HR would be better for controlling the small sided games training load. Thus, the aim of this study was to compare the heart rate (HR), rating of perceived exertion (RPE) and speeds corresponding to 2.0 mmol·L^{-1}, 3.5 mmol·L^{-1} and lactate threshold measured by the Dmax method (AT-Dmax) in the laboratory and on the Hoff circuit. The hypothesis was that, due to the higher energetic cost on the Hoff circuit [12], the speed and HR corresponding to 2.0 mmol·L^{-1}, 3.5 mmol·L^{-1} and aerobic endurance would also be higher.

MATERIALS AND METHODS

Subjects. Sixteen soccer players aged 16 ± 1 years voluntarily participated in the study. They were amateur soccer players with at least four years of practice. Body composition data were estimated by dual-energy X-ray absorptiometry scan (GE Lunar – DPX-NT) and are described in Table 1.

All the procedures and risks of research were explained, and the subjects were included only after their legal guardian had signed the informed consent form approved by the Ethics Committee in Research of the Faculty of Science and Technology of the Sao Paulo State University – Campus Presidente Prudente, SP, Brazil (process no. 54/2010).

TABLE 1. Mean ± standard deviation of total body mass (TBM), lean mass (LM), fat mass (FM) and percentage of body fat (BF) of the participants (n = 16).

TBM (kg)	LM (kg)	FM (kg)	BF (%)
63.7 ± 9.4	52.4 ± 6.1	8.4 ± 4.0	13.4 ± 4.6

Experimental design

For the purposes of comparing the parameters of physical fitness evaluated on the Hoff circuit and in the laboratory the participants were submitted to three days of tests (with at least 48 hours in between). Firstly the subjects underwent an assessment of body composition. On subsequent days they performed two progressive tests (laboratory and Hoff circuit in a counter-balanced order) for the determination of speeds, HR and RPE relative to 2.0 mmol·L^{-1}, 3.5 mmol·L^{-1}, lactate threshold (by AT-Dmax method) and peak lactate concentration. Prior to the Hoff circuit test, the players performed a familiarization trial on the Hoff circuit [5,9]; initially, without a ball, the soccer players just ran at different speeds. Afterwards they went through the circuit with the ball, where they dribbled through the circuit at intensities of 7.0, 8.0, 9.0, 10.0 and 11.0 km·h^{-1} for 15 min with speeds controlled by audio signals [5].

Laboratory test

Prior to the incremental test, the athletes warmed up for 7 minutes at 7 km·h^{-1} on a treadmill (ATL Inbrasport, Porto Alegre, Brazil). Subsequently the subjects performed an incremental test with an initial speed of 8.0 km·h^{-1} with increments of 1 km·h^{-1} every three minutes until exhaustion. Exhaustion was declared voluntarily by the participant or by the inability to perform the effort at the predetermined velocity. The treadmill slope was fixed at 1%. At the end of each stage, the participant took a break to collect a blood sample (25 μl) for determination of blood lactate concentration ([La$^-$]). The athletes also reported their rating of perceived exertion (RPE) using the 6-20 point scale proposed by Borg [15] and HR was assessed using a heart rate monitor (Forerunner 410, Garmin, Kansas, USA).

Hoff circuit test

Prior to the test the players warmed up for seven minutes by performing specific soccer movements. The players performed five progressive 580 m efforts (corresponding to two laps of the circuit [16] starting at 7.0 km·h^{-1} and increasing by 1.0 km·h^{-1} by 2-laps effort [5] until the inability to perform the task required in the Hoff circuit. The speed was controlled by audio signals every 58 m. At the end of each 580 m blood samples were immediately collected for determination of [La$^-$], the athletes reported their RPE using a 6-20 point scale [15] and HR was recorded through a heart rate monitor (Forerunner 410, Garmin, Kansas, USA).

The points obtained from the relationship between the speed and the exercises [La$^-$] were then fitted exponentially and the speeds corresponding to 2.0 mmol·L^{-1} ([La$^-$ 2.0]), 3.5 mmol·L^{-1} ([La$^-$ 3.5]), AT-Dmax ([La$^-$ AT-Dmax]) [17] and peak lactate ([La$^-$ peak]) were determined. Through the linear relation between the speeds and

RPE, and the polynomial third order relation between the speeds and HR, the RPE and HR corresponding to [La- 2.0], [La- 3.5], [La- AT-Dmax] and peak-lactate were determined [18] (HR 2.0, HR 3.5, HR AT-Dmax and HR peak; and RPE 2.0, RPE 3.5, RPE AT-Dmax and RPE peak, respectively).

Blood collection and analysis

Twenty-five μL of blood were collected from the earlobe and were deposited directly into polyethylene Eppendorf (1.5 mL) tubes containing 50 μL of sodium fluoride 1% (1% NaF) which were immediately frozen at -20°C. Subsequently 25 μL of the homogenate was added to an electrochemical lactimeter (Yellow Spring, 1500 Sport model; Ohio, USA).

Statistical analysis

Normality and homogeneity of data were verified by the Shapiro-Wilk and Levene tests, respectively. Assumed normality, possible associations of speed, HR and RPE evaluated in the laboratory and on the Hoff circuit were tested using Pearson correlation, and comparisons between values were examined using the Student t test for dependent samples. The Student t test was accompanied by the effect size (ES) analysis, which was classified as negligible (<0.35), small (0.35 to 0.80), moderate (>0.80-1.5) and large (> 1.5). In all cases the level of significance was set at 5%.

RESULTS

The lactate, HR, and RPE measurements obtained during the Hoff circuit test and laboratory test are presented in Figure 1. The response of each variable during both tests was similar.

Significant differences were found in the speed corresponding to [La--2.0] (ES = 1.18; moderate), [La- 3.5] (ES = 1.58; large), [La- AT-Dmax] (ES = 2.06; large), and [La- peak] (ES = 3.55; large) (Figure 2). Heart rate was higher on the Hoff circuit than in laboratory at [La- 3.5] (ES = 0.52; small), as well as HR related to AT-Dmax (ES = 1.20; moderate) (Figure 2B). No significant difference was observed in RPE 2.0 (ES = 0.35; small), RPE 3.5 (ES = 0.64; small), or RPE AT-Dmax (ES = 0.54; small) (Figure 2C). The [La- AT-Dmax] was similar between the Hoff and laboratory test (2.61 ± 0.82 mmol·L^{-1} and 2.61 ± 0.77 mmol·L^{-1}, respectively; ES = 0.00; negligible).

A significant positive correlation was found between HR and speeds corresponding to 3.5 mmol·L^{-1} determined in the laboratory and on the Hoff circuit (Table 2). No significant association was found between [La- AT-Dmax] in the Hoff circuit and laboratory tests.

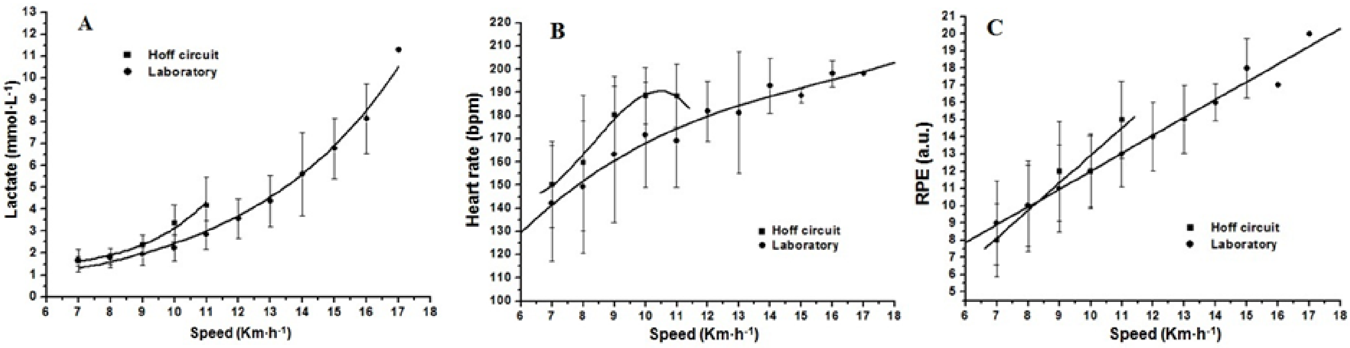

FIG. 1. Mean ± standard deviation of the behaviour of lactate concentration ([La-] - A), heart rate (HR - B) and rating of perceived exertion (RPE - C) during the incremental test in the laboratory and on the Hoff circuit.

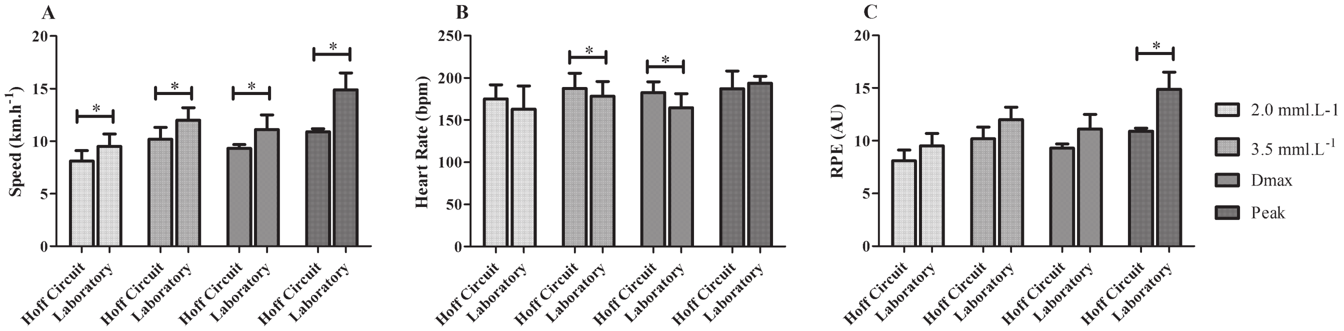

FIG. 2. Mean ± standard deviation of speed (A), heart rate (B) and rating of perceived exertion (C), corresponding to 2.0, 3.5 mmol·L^{-1}, AT-Dmax and peak of [La-] in the laboratory and on the Hoff circuit.
Note: *Significantly different compared to other test at the same intensity.

TABLE 2. Correlation coefficient (95% CI) for speed, rating of perceived exertion (RPE) and heart rate (HR) determined in the laboratory and on the Hoff circuit corresponding to the blood lactate concentration 2.0 mmol·L^{-1} and 3.5 mmol·L^{-1}, AT-Dmax and peak value.

Intensities at	RPE (AU)	HR (bpm)	Speed (km·h^{-1})
2 mmol·L^{-1}	-0.10 (-0.58 to 0.43)	-0.44(-0.15 to 0.80)	0.05 (-0.48 to 0.55)
3.5 mmol·L^{-1}	0.34 (-0.21 to 0.73)	0.73* (0.33 to 0.91)	0.79* (0.30 to 0.84)
AT Dmax	-0.18 (-0.65 to 0.39)	-0.08 (-0.61 to 0.49)	0.43 (-0.13 to 0.78)
Peak of lactate	0.50 (-0.02 to 0.80)	0.05 (-0.49 to 0.57)	0.01 (-0.52 to 0.50)

* Significant correlation ($P<0.05$)

DISCUSSION

The aim of the present study was to compare the HR, RPE, and speed corresponding to [La$^-$ 2.0], [La$^-$ 3.5], [La$^-$ AT-Dmax] and [La$^-$ peak] evaluated in an incremental laboratory test and on the Hoff soccer-specific circuit. The main finding of the study was that the speed corresponding to each lactate concentration was significantly lower on the Hoff circuit than during the laboratory test, as well as the AT-Dmax (i.e. anaerobic threshold). The HR 3.5 was higher on the Hoff circuit and the RPE-peak was higher in the laboratory. The HR and speed corresponding to 3.5 mmol·L^{-1} determined in the laboratory and on the Hoff circuit were significantly correlated. These results partly confirm our hypothesis; however, no differences were found in HR 2.0 and RPE 2.0 and RPE 3.5.

It is important to highlight that the time course of lactate, heart rate and rating of perceived effort were similar when analysed in the laboratory and on the Hoff circuit (Figure 1). Kemi et al. [10] observed that it is possible to determine maximal oxygen consumption on the Hoff circuit, and recently, Loures et al. [5] observed that the anaerobic threshold evaluated on the Hoff circuit is capable of predicting the maximal lactate steady state. Together with the present findings, these results indicate that, even on a specific circuit, the lactate concentration, heart rate and rating of perceived exhaustion present the same time course as when analysed in the laboratory. Thus, it is possible to evaluate the aerobic endurance such as anaerobic threshold using an incremental test on the Hoff circuit. This is an important finding, as this specific method is probably much more appreciated by soccer players and practitioners.

There were significant differences in running speed at all time points. These results are contrary to the study of Di Michele, Di Renzo, Ammazzalorso and Merni [19] which submitted soccer players to progressive tests on three surfaces (natural grass, synthetic grass, and mat). They did not find any differences in speeds corresponding to 2.0, 3.0, or 4.0 mmol·L^{-1} for any condition. Therefore, the surface used to evaluate the players does not influence the speed, but shifts the lactate vs. speed relation to an upright position without interference with speed. However, the present study addressed not only the surface (treadmill vs. natural grass) but also the motion (continuous running vs. specific soccer movements). Thus, ball control seems to increase the energy cost at a set running speed [20,21], thereby increasing lactate concentration. Moreover, when prescribing aerobic soccer training on the Hoff circuit it is necessary to evaluate the aerobic endurance on the circuit, since the higher energy cost due to the grass and mainly technical demand leads to a slower speed compared to that of a conventional treadmill test. Thereby, the time motion analysis of specific soccer training and game might take into account a specific evaluation to determine the time spent above anaerobic threshold zones. This is especially true since a difference was found in anaerobic threshold speed (i.e. AT-Dmax) observed on the Hoff circuit and in the laboratory with high ES (i.e. 2.06; large).

The HR 3.5 was higher on the Hoff circuit than in the laboratory, while no difference was found at HR 2.0 or peak value (Figure 2). Contrary to the present findings, Esposito et al. [13] did not find differences in HR behaviour or values observed during a treadmill test and field soccer-specific test, suggesting that HR in the field reflects the aerobic demand during a conventional incremental test. However, the latter authors used three intensities during the field test and no incremental protocol in the laboratory, hampering the comparison with the present study. Moreover, Esposito et al. [13] compared the HR vs. oxygen consumption relation between the two environments, enabling them to compare the speed in each situation (e.g. laboratory and specific soccer protocol). Likely, the speed during the specific soccer protocol is lower than during the incremental test, since the technical and higher energy cost might limit the speed during the specific protocol.

The HR associated with 3.5 mmol·L^{-1} might correspond to the aerobic endurance HR, but the difference between them found in the present investigation highlights the necessity of a specific evaluation for aerobic endurance. Because of the growth in small sided game training use in soccer [14], an evaluation with specific motion and technical demand would be necessary to avoid underestimation of training load by using the HR associated with the aerobic endurance assessed in the laboratory [8]. The difference in the HR related to the aerobic endurance on the Hoff circuit compared to the laboratory evidences that during specific soccer training (i.e. small sided games) a higher HR might be evoked to produce aerobic adaptations. This can also explain the relation observed between percentage of increase on aerobic endurance (laboratory), and time spent in HR zones above the aerobic endurance (laboratory) [8]. The player that maintains higher HR during small sided games may reach his specific HR related to aerobic endurance (e.g. HR related to aerobic endurance on the Hoff circuit), inducing aerobic changes. Together with this finding, the HR related to AT-Dmax was significantly higher in the Hoff circuit than the laboratory test, and presented a high ES value (1.20; moderate). Thus, the boundary to aerobic adaptation during specific soccer training must consider the differences between the HR observed during continuous running and specific activity (with the ball, and changes of direction).

Other studies have investigated the differences between anaerobic threshold [16], lactate, and HR time course during incremental exercise on a treadmill and during a field test (natural grass and synthetic turf) [19]. Williams, Abt and Kilding [22] verified the reliability of a specific endurance soccer test (i.e. Ekblom test). However, (i) the authors did not present an incremental exercise as the present study did, preventing a robust training prescription on the circuit, and (ii) the proposed test was too long to be included in a soccer training routine. The difference between HR corresponding to 3.5 mmol·L^{-1} and AT-Dmax is also due to the increased oxygen demand when dribbling the ball [20], since the field test proposed in our study has an added technical demand (dribbling the ball whilst changing direction/motion), a crucial characteristic in soccer performance [23], while in all other studies this demand was not taken into account [19,22].

Since the Hoff circuit requires high technical skills, the peak speed was limited by the inability of subjects to cover the circuit dribbling the ball. One player out of the sixteen participants did not achieve 11 km·h^{-1}. This is the reason why it was decided to use the peak value in the Hoff circuit instead of the maximal value. The difference in speed at peak was expected by the need of technique to cover the Hoff circuit; however, it is interesting to note that despite the absence of difference in HR at peak values, the RPE was significantly lower in the Hoff circuit.

RPE is considered a method of quantifying training load that does not require expensive and sophisticated equipment, compared with other tools [24]. A large number of researchers have found significant correlations between RPE and other methods of quantifying training load (blood lactate and HR) [24-26]. Unlike the observations in previous studies [24-26], RPE did not show any significant difference when determined in the field or in a laboratory under submaximal effort. This suggests that RPE could be a useful tool for monitoring training loads and intensities [27] independent of the environmental assessment of aerobic fitness. However, Foster et al. [26] suggest that the players should go through an adjustment period of an exertion scale that must be performed during progressive tests, providing players' RPE over a wide range of intensities. The difference between RPE at peak [La$^-$] is probably due to the high speeds reached during the laboratory test compared to the Hoff circuit. This supposition is supported by Zouhal et al. [12], who reported that the Hoff circuit is perceived as less intense than high-intensity intermittent exercise, although higher oxygen uptake and blood lactate concentration were observed during this specific test.

Despite the differences between HR and speed corresponding to 3.5 mmol·L^{-1} determined in the laboratory and on the Hoff circuit, there was a significant correlation between these variables. Since this point of 3.5 mmol·L^{-1} might represent the 'lactate threshold', these results suggest that it does not matter where the test is performed, and players with a higher lactate threshold on the treadmill will present higher speeds on the specific Hoff circuit. Some authors have shown significant correlations between Hoff test parameters and aerobic performance variables. Chamari et al. [16] and Nassis et al. [28] found a significant correlation between performance on the Hoff circuit and maximal oxygen consumption. However, the aerobic endurance can change without changes in maximal oxygen consumption, and also a higher aerobic endurance theoretically indicates that they sustain a higher level of activity at high intensity without the accumulation of lactate [3]. Moreover, it is known that the maintenance of technical proficiency is directly related to success in sports performance [23], as the combination of aerobic exercise with demanding technique makes the workload greater.

The AT-Dmax method was used in the current study as an individual method to determine the lactate threshold [17] instead of fixed blood lactate values (such as 3.5 mmol·L^{-1}). On the other hand, no other individual method to determine the lactate threshold could be applied. However, the speed, HR and RPE determined at Dmax during the Hoff circuit and laboratory test were not correlated. Probably this could have occurred due to a difference in blood lactate response during the Hoff test, which involves a specific task with the ball and results in higher blood lactate values [11]. Unfortunately, no other individual method to determine the lactate threshold could be applied for the present study setting.

The absence of comparison between the speed corresponding to 3.5 mmol·L^{-1} with the maximal lactate steady state evaluated on the Hoff circuit and the inherent need of technical quality for training on the Hoff circuit limits the present study. However, we believe that the circuit can be widely used for endurance training, especially for youth soccer training, because it is more attractive and includes a ball.

CONCLUSIONS

It can be concluded that the speeds corresponding to 2, 3.5 mmol·L^{-1}, AT-Dmax and peak [La$^-$], HR corresponding to 3.5 mmol·L^{-1} and RPE corresponding to peak [La$^-$] are different between the incremental Hoff circuit and the incremental laboratory test. This fact evidences the specificity imposed (technical demand and continuous changes of direction) in the incremental Hoff circuit test. The similar time course and high correlation in the speed corresponding to 3.5 mmol·L^{-1} (i.e. in the range corresponding to aerobic endurance) suggest that the proposed test may be used in soccer since it respects the sport specificity and takes into account the technical demands of football. Thus, the use of laboratory evaluations for soccer players should have a diagnostic character, since they do not seem to be accurate for training prescription, considering the changes in HR and speed when using specific drills with a ball on the grass. Furthermore, the time motion analysis (speed analysis) and time spent in the zone above the laboratory-measured 'aerobic endurance' should be adapted since the speed during a field-specific incremental test is lower and the HR related to the aerobic endurance is higher when being tested with the ball.

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