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Can Heart Rate Values Obtained From Laboratory and Field Lactate Tests Be Used Interchangeably to Prescribe Exercise Intensity for Soccer Players?

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ABSTRACT

This study was undertaken to investigate the relationship between blood lactate concentration ([La]) and heart rate (HR) values obtained during treadmill and field tests at fixed velocities with respect to interchangeability of results to be used in exercise prescription. A total of 22 male soccer players participated in the study. Each player performed exercise tests on a motorized treadmill and in the field with 3-min runs and 30 s allowed for blood sampling. During both tests, velocities at the first, second, and third stages were 8, 10, and 12 km·hr^{-1}, respectively. Velocity was then increased by 1 km·hr^{-1} every 3 min until exhaustion. During the field test, players ran on artificial turf on a 120-m hexagonal track marked with cones placed 20 m apart. Running velocity was controlled by means of audio signals. Blood samples were analyzed immediately with an automated lactate analyzer. HR was monitored continuously at 5-s intervals. Data were analyzed with Student's paired *t* tests to look for differences between treadmill and field data. Coefficients of variation and Bland-Altman plots assessed agreement of HR and blood [La] values between the 2 tests. Although running velocities corresponding to a fixed blood [La] of 4 mmol L^{-1} showed significant differences between treadmill and field tests (15.9±0.9 vs 14.1±0.7 km·h^{-1}, respectively) (P<.01), no significant difference between HR values was noted (190±7 vs 187±7, field vs laboratory, respectively). Overall, the mean intermeasurement coefficient of variation was 4.8% (±0.9%) for HR. Although the lowest

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coefficient of variation (2.4%) was found, fairly wide differences between individual field and laboratory HR values at velocities corresponding to fixed blood [La] of 4 mmol·L^{-1} cast doubt on the interchangeability of tests.

Keywords: soccer; lactate; heart rate; treadmill; field test

INTRODUCTION

Soccer is one of the world's major sports, and players must have technical, tactical, and physical skills to succeed. A soccer player should be capable of maintaining a high energy level throughout the game. Therefore, a portion of the training program should be targeted at improving endurance capacity.[1-3] Several measurements obtained from various types of tests may provide a general picture of endurance capacity as a specific aspect of the physical performance of soccer players.[1-4]

Endurance performance is associated with an attenuated blood lactate concentration ([La]) response during incremental exercise. For many years, blood [La] accumulation during exercise tests has been used to set aerobic training intensity and to elucidate the effects of aerobic training on endurance capacity.[5] Exercise intensities during training and competition have been associated with an anaerobic threshold, as determined in the laboratory, in relation to certain metabolic markers such as serum [La].[6] It may be possible to set up individualized training programs that are based on heart rate (HR) at this reference point. Through monitoring of HR during graded exercise tests, training intensities can be preselected according to the discrete aims of training.[7]

Different methods have been proposed to evaluate endurance capacity with the use of laboratory or field tests.[8] Laboratory tests generally involve incremental running on a motorized treadmill (blood [La]); the relationship between HR and blood [La] is the primary outcome of such testing. These measures are commonly used to assess athletes' aerobic fitness and to prescribe training intensities.[5,9] Furthermore, the lactate threshold appears to be sensitive to changes in training for soccer players. The use of field tests to examine this threshold in the longitudinal monitoring of aerobic fitness is becoming increasingly popular among soccer coaches and fitness trainers.[3,10] Soccer coaches also generally concentrate on HRs obtained from field tests in order to regulate training. For this purpose, exercise intensities are prescribed according to a specific HR related to, for example, the anaerobic or lactate threshold, which has been determined on the basis of the blood [La] versus HR relationship, as discerned during field or laboratory testing.[11] The interchangeability of variables measured within these tests—which is necessary to outline a valid training prescription—is open to debate, however. It is not known whether the relationship between blood [La] and HR that is seen during laboratory testing is also apparent during field testing for soccer players.[5]

Although physiologic measures taken during laboratory treadmill tests are commonly used for regulating training in soccer and are considered the "gold standard," their precise connection to those attained through a corresponding field test remains to be validated with the use of appropriate experimental and statistical techniques.

Therefore, this study was conducted to investigate the relationship between blood [La] and HR values in soccer players, as assessed by field and laboratory tests.

METHODS

Subjects

A total of 22 male soccer players who were competing in the Turkish Youth League participated in this study during the 2002 to 2003 soccer season. Players represented all playing positions except goalkeeper. A description of the physical characteristics of the players is provided in Table 1. The local ethics committee at Ankara University School of Medicine approved the study. Subjects were informed about the test protocols and signed an informed consent form.

Table 1. Physical Characteristics of Study Participants*

Age, y	17.91±0.81
Height, m	1.77±0.05
Body mass, kg	71.68±3.73

*n=22; mean±SD.

Laboratory and field tests were performed in the morning at the same time each day and were preceded by a day of rest. Ambient temperature and humidity were similar. All subjects were taken from the same team, so the nutrition of players was also similar. Field tests were performed on dry artificial turf. A randomized study design was established, and each of the athletes performed exercise tests on the treadmill and on the field, with 1-wk intervals separating the timing of tests. All players were informed about the test protocols and were familiarized with treadmill and outdoor running. Incremental "steps" with 3-min runs and 30 s for blood sampling were performed to determine the velocity of running at a fixed blood [La] of 4 $mmol \cdot L^{-1}$ from the lactate performance curve by assessing the relationship between blood [La], HR, and running velocity.

Laboratory Testing

All soccer players were tested in the laboratory with a range in room temperature of 19°C to 22°C and a relative humidity of 40% to 50%. Subjects were familiar with test procedures and treadmill running technique. The treadmill test consisted of an incremental step protocol involving 3-min steps, during which blood [La] and HRs were measured. Each test was performed at zero grade, and velocities of the first, second, and third stages were 8, 10, and 12 $km \cdot hr^{-1}$, respectively. Then, velocity was increased by 1 $km \cdot hr^{-1}$ every 3 min until exhaustion.

Field Testing

The test field was surrounded by high walls; therefore, wind velocity had no effect on the athletes. Subjects ran on artificial turf on a 120-m hexagonal track marked with cones placed 20 m apart. Acoustic signals were produced by a Conconi-Shuttle Run Timer (Prosport TMR ESC 1100, Tumer Engineering, Ankara, Turkey), which was used to control running velocity. The player had to be "on" a specific cone when he heard the respective audio signal. Velocities at the first, second, and third stages were 8, 10, and 12 $km \cdot hr^{-1}$, respectively. Velocity was then increased by 1 $km \cdot hr^{-1}$ every 3 min until the subject was no longer capable of following the set velocity. Temperature and relative humidity ranges were 18ºC to 21ºC and 40% to 55%, respectively, during field testing.

Blood [La] and HR Measurements

During both exercise tests, blood samples were taken from the ear lobe between running stages for determination of blood [La]. A 30-s pause allowed the collection of 25 to 40 mL of capillarized blood. This whole blood, in a heparinized pipette, was analyzed immediately with an automated lactate analyzer (Sport Lactate Analyzer YSI Model 1500, Yellow Springs Instrument Co., Yellow Springs, Ohio). The lactate analyzer was calibrated with a 5 $mmol \cdot L^{-1}$ lactate standard before each test was given. HR was monitored continuously at 5-s intervals by short range radio telemetry (Polar 610 S, Polar Electro, Oy, Finland). Mean HR was calculated for each minute during running. The average HR during the last minute of each stage was taken as the representative HR for that stage.

Data Analysis

The Statistical Package for the Social Sciences (SPSS) for Windows, version 13.0 (SPSS Inc., Chicago, Ill), was used for all statistical analyses. Descriptive statistics are presented as means±standard deviation (SD). Statistical significance was accepted at $P<.05$. Comparisons of HR and blood [La] values between laboratory and field tests were made with the use of paired *t* tests. Blood [La] values for laboratory and field tests were individually interpolated against velocity and HR values to allow comparisons of blood [La] for a given HR or running velocity, and to obtain running velocities and HRs at a fixed blood [La] of 4 $mmol \cdot L^{-1}$. To assess how well laboratory and field measurements agreed, intermeasurement coefficients of variation were calculated. Differences between the 2 methods were plotted against the average of the 2 measurements, and 95% limits of agreement were calculated through the Bland-Altman approach.[12]

RESULTS

A significant difference was observed in HR and blood [La] responses between treadmill and field running at 12 to 18 $km \cdot h^{-1}$ (Tables 2 and 3; Figs 1 and 2). Although running velocities corresponding to a fixed blood [La] of 4 $mmol \cdot L^{-1}$ showed significant differences between treadmill and field tests (15.9±0.9 vs 14.1±0.7 $km \cdot h^{-1}$, respectively) ($P<.01$), no significant difference was reported between HR values that

corresponded to a fixed blood [La] of 4 mmol·L^{-1} (190±7 vs 187±7, field vs laboratory, respectively).

Table 2. Comparison of Blood [La] at All Stages Between Treadmill and Field Exercise (mmol·L^{-1})

	Field	Treadmill	*P* Value
Rest	0.91±0.19	0.86±0.22	
8 km·hr^{-1} (2.22 m·s^{-1})	1.26±0.27	1.19±0.35	
10 km·hr^{-1}(3.06 m·s^{-1})	1.32±0.29	1.24±0.38	
12 km·hr^{-1}(3.33 m·s^{-1})	1.89±0.49	1.49±0.48	<.001
13 km·hr^{-1}(3.61 m·s^{-1})	2.65±0.73	1.84±0.58	<.001
14 km·hr^{-1}(3.89 m·s^{-1})	4.01±1.26	2.32±0.77	<.001
15 km·hr^{-1}(4.17 m·s^{-1})	5.77±1.70	3.06±0.99	<.001
16 km·hr^{-1}(4.44 m·s^{-1})	7.43±1.37*	4.21±1.42	<.001
17 km·hr^{-1}(4.72 m·s^{-1})		5.38±1.15†	
18 km·hr^{-1}(5 m·s^{-1})		7.01±0.86‡	

*n=14; †n=20; ‡n=10.

Table 3. Comparison of HR Values at All Stages and Between Treadmill and Field Exercises

	Field	Treadmill	*P* Value
Rest	74±4	72±4	
8 km·hr^{-1}	135±8	137±12	
10 km·hr^{-1}	152±7	150±11	
12 km·hr^{-1}	170±8	163±10	<.001
13 km·hr^{-1}	180±6	170±10	<.001
14 km·hr^{-1}	187±6	178±9	<.001
15 km·hr^{-1}	192±5	184±8	<.001
16 km·hr^{-1}	196±4*	190±7	<.001
17 km·hr^{-1}	193±6†		
18 km·hr^{-1}	195±5‡		
V4 mmol·L^{-1}	187±7	189±7	<.001

*n=14; †n=20; ‡n=10.

V4 mmol·L^{-1}: Velocity corresponding to a fixed blood [La] of 4 mmol·L^{-1} (14.1±0.7 and 15.9±0.9 km/h for field and laboratory testing, respectively.)

Fig 1. Comparison of blood [La] at all stages between treadmill and field exercise.

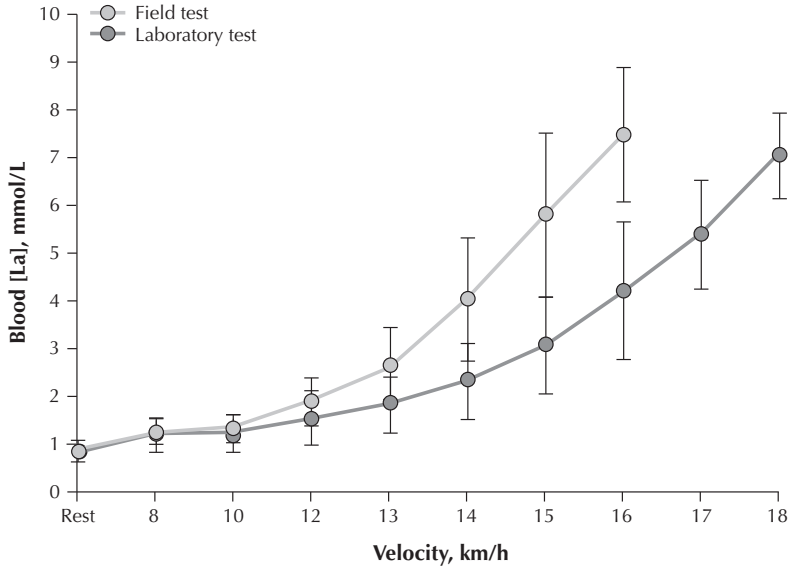
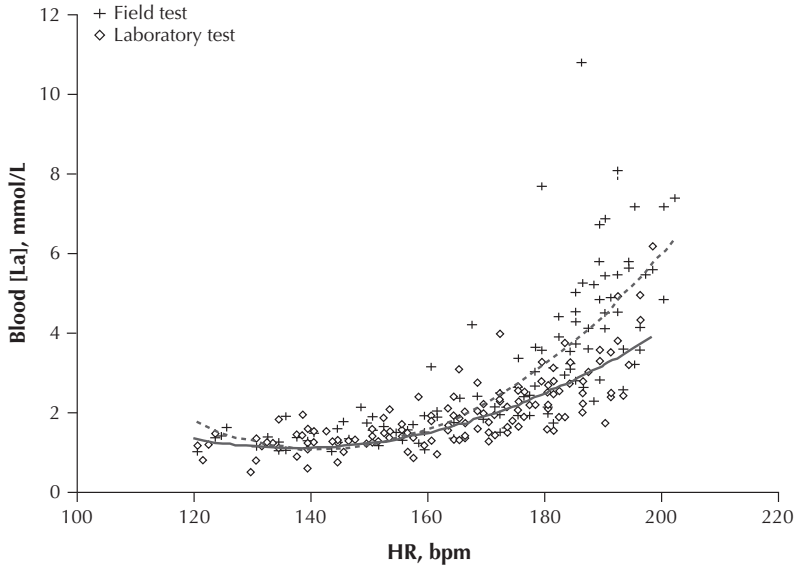


Fig 2. Blood [La] versus HR relationships obtained during laboratory and field testing. (Dotted line, field test; solid line, laboratory test.)



Values of 16 km·h^{-1} were excluded from the study because data were missing. The 95% confidence intervals (with the number of measurements within each analysis) and estimated coefficients of variation for the pairs of blood [La] and HR measurements obtained from each test are given in Table 4. Overall, the mean intermeasurement coefficient of variation was 4.8% (±0.9%) for HR. The lowest coefficient of variation (2.4%) was reported for HR at velocities corresponding to a fixed blood [La] of 4 mmol·L^{-1}. Bland-Altman plots of HR measurements taken at 15 km·h^{-1} and at the velocity corresponding to 4 mmol·L^{-1} are presented in Figures 3 and 4 as representative examples.

As shown in Figure 3, most observations are above the zero line, indicating higher HR values for field testing at 15 km·h^{-1}. This same observation is seen for all other velocities except 8 km·h^{-1}, which shows less variation around the zero line. Compared with velocity at 15 km·h^{-1}, a narrower spread of data is seen around the zero line, and no significant systematic bias is evident in Figure 4, indicating consistency in HR values between laboratory and field testing at velocities corresponding to a fixed blood [La] of 4 mmol·L^{-1}.

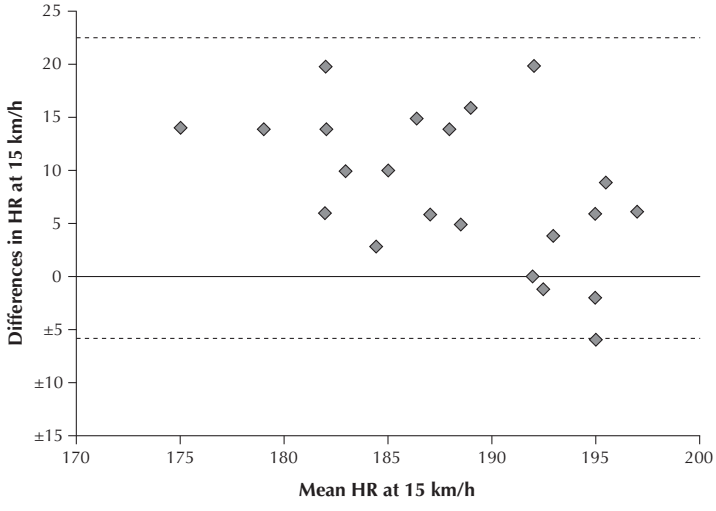
Table 4. 95% Confidence Intervals* and Estimated Coefficients of Variation for Pairs of Blood [La] and HR Measurements†

All Subjects (n=22)	Difference Between Field and Laboratory		95% Limit of Agreement (LoA)		Number of Measurements Within 95% LoA (of total 22)	Coefficient of Variation
	Average ($\bar{d}$)	SD	Lower	Upper		
Blood [La]						
8 km/h	0.067	0.409	–0.750	0.885	22	33.3
10 km/h	0.079	0.419	–0.758	0.916	22	32.5
12 km/h	0.398	0.337	–0.277	1.072	21	19.9
13 km/h	0.810	0.465	–0.120	1.739	21	20.7
14 km/h	1.689	0.889	–0.090	3.467	21	28.1
15 km/h	2.709	1.406	–0.104	5.522	21	31.8
HR						
8 km/h	–1.773	8.165	–18.102	14.556	21	6.0
10 km/h	1.909	8.269	–14.628	18.447	21	5.5
12 km/h	5.773	7.702	–9.632	21.178	22	4.6
13 km/h	8.773	8.343	–7.914	25.460	21	4.8
14 km/h	8.727	7.126	–5.525	22.979	20	3.9
15 km/h	8.318	7.101	–5.880	22.519	21	3.8
V4 mmol·L^{-1}	–2.045	4.562	–11.168	7.078	22	2.4

*With number of measurements within 95% limits of agreement.
†For all 22 subjects and all tests.

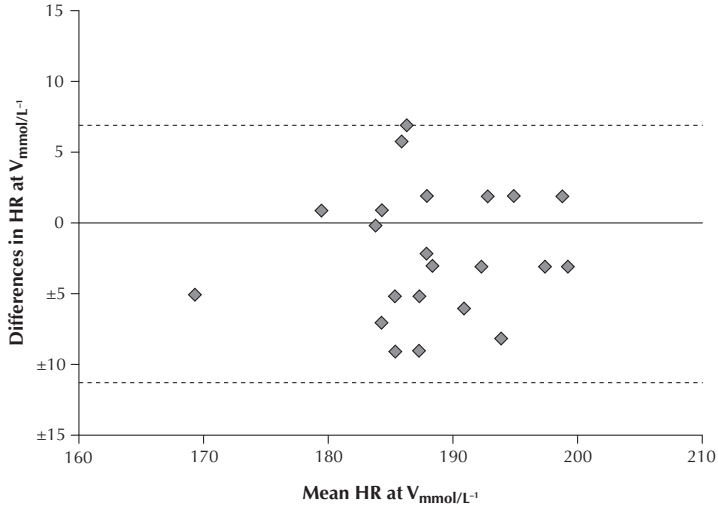
SD=standard deviation; V4 mmol·L^{-1}=velocity corresponding to a fixed blood [La] of 4 mmol·L^{-1}.

Fig 3. Bland-Altman plots for differences in HR at 15-km/h velocity.



The dotted lines represent the estimated 95% limits of agreement, which provide a range that is likely to capture 95% of the difference between any 2 measurements. The closer to the zero line, the less difference there is between the 2 tests.

Fig 4. Bland-Altman plots for differences in HR at velocities corresponding to the fixed blood [La] of 4 mmol·L^{-1}.



The dotted lines represent the estimated 95% limits of agreement, which provide a range that is likely to capture 95% of the difference between any 2 measurements. The closer to the zero line, the less difference is noted between the 2 tests. (V4 mmol·L^{-1}=velocity corresponding to a fixed blood [La] of 4 mmol·L^{-1}.)

DISCUSSION

Blood [La] assessment through incremental exercise tests, based on a duration of 3 min, has been shown to be a sensitive indicator of changes in aerobic fitness over a specified period.[2,5,13,14] Laboratory and field blood [La] tests may fulfill the practical demands of soccer coaches by allowing them to assess the fitness of players in the field.[15] A motorized treadmill provides the most natural means of locomotion, such as walking, jogging, or running, and the most appropriate mode of exercise by which to test soccer players.[8,16] Furthermore, it is very difficult to standardize testing conditions such as the nature of the turf, temperature, and wind during field tests over a whole season. Thus, with field tests, it has been difficult to monitor some parameters of interest, for instance, running economy at submaximal exercise intensities and aerobic threshold, longitudinally during the whole season.[17] Treadmill testing, therefore, is thought to be the standard method of measuring the endurance capacity of soccer players; however, studies suggest that if a laboratory test mimics as closely as possible the field exercise usually performed by the athlete, it can be used as a consistent predictor of the anaerobic threshold in the field.[18] This point is especially important during ballgames, in that laboratory settings cannot fully simulate the physiologic characteristics of sports activities.[14]

On the other hand, most laboratories have suggested that it might be problematic to conduct laboratory tests for motivational reasons, or because of the substantial time and expense involved.[17,19] The treadmill test also does not offer one of the advantages of field assessment, that is, that relatively large numbers of subjects can be assessed at the same time.[20] Despite these disadvantages, both methods are commonly used; however, several studies have emphasized the importance of exercise and protocol specificity for intensity prescription on the basis of the relationship of blood [La] and HR.[9,21] The primary concern of the present study was how this relationship was affected if the test was performed in the laboratory or in the field using an identical protocol. Answering this question would suggest that data obtained from laboratory testing are acceptable to use for field-training purposes, or to confirm that it is necessary to determine the relationship between blood [La] and HR under field conditions, when an appropriate exercise intensity has been set.

In this study, it was observed that blood [La] and HR values were higher during field testing than during treadmill tests at the same running velocity. Significant differences in velocities were reported at a fixed blood [La] of 4 $mmol \cdot L^{-1}$ between treadmill and field tests. Running velocities during field testing were slower than during treadmill testing. It may be true that greater force has to be applied to move the body on the field than on the treadmill at the same running velocity. The turns on a hexagonal track would also slow the velocity of soccer players.

When treadmill and field tests are compared, factors that can influence the transferability of laboratory data to field conditions, such as running duration, diet, time, wind resistance, ambient temperature, and humidity or player/surface interaction on field and treadmill, must be taken into consideration.[22-24] The investigators chose an incremental running protocol with a 3-min step duration, as is commonly used in sports medicine laboratories.[2,5,13,14] When the subject was required to stop for 30 s, however, sampling of capillary blood made the test intermittent. Intervals, nevertheless, may help to replicate soccer match-play movements more closely than continuous running. Air resistance during outdoor running has been thought to be

an important reason for the significant difference in running velocities at specified HR and blood [La] values.[25]

Lack of treadmill inclination might be considered a limitation of the present study in that treadmill running does not incur air resistance. The treadmill is motor driven, so the subject can spare some energy that would be needed in the field test to propel the body along the field and against air resistance.[22,23] This factor could contribute to a faster accumulation of blood [La], and testing at zero gradient during treadmill testing may lead to an overestimation of performance under laboratory conditions. When it is considered that even in this practical and more widely preferred form of treadmill running, which includes no inclination, agreement between tests was good, it seems reasonable to expect that a 2% or 3% increase in treadmill gradient, which represents a level that matches the biologic load of track running, as suggested by previous studies,[26] would lead to closer agreement.

As a noninvasive substitute for a given estimate of blood [La], HR monitoring, which can be performed for training regulation in a field setting, has been largely accepted as a valid measure of actual exercise intensity and physiologic adaptation during aerobic training.[13,27-29] HR associated with 4 mmol·L^{-1} blood [La] provides a reasonable marker of the intensity of training.[27] The present study showed that the blood [La] versus HR relationship differed during laboratory versus field testing. The blood [La] curve as a function of HR attained during field testing was shifted upward compared with that attained during treadmill running, which indicates that for a given HR value, blood [La] was higher in the field than in the laboratory (Fig 2). Statistical analyses (paired *t* tests) revealed, however, that HR at a fixed blood [La] of 4 mmol·L^{-1} was not significantly different between treadmill and field. Running velocities at this concentration tended to be lower during field versus treadmill exercise, but HRs were similar on both tests.

In both field and treadmill testing, as an unexpected finding of the present study, estimated HR values of subjects corresponding to a lactate level of 4 mmol·L^{-1} were significantly higher than expected.[30,31] Unfortunately, no additional data based on experimental design can explain this discrepancy with the literature. Former experience with similar protocols in older (mean age, 26.6±3.2 y) and higher-level elite football players (unpublished data) did not reveal similar results. The calculated coefficient of variation for HR at velocities corresponding to a fixed blood [La] of 4 mmol·L^{-1} was 2.4%, which indicates strong agreement between measurements. At first glance, similar HRs can be interpreted as favoring treadmill test data as applied to field data. The results also suggest that exercise tests performed on the field are reliable—provided that HR is used to monitor the intensity of exercise. Closer examination of the data, however, necessitated a more rigorous statistical approach.[31]

Bland and Altman's limit of agreement was used to investigate levels of agreement among HR values, which were believed to be more appropriate for HR comparisons in the present study.[12] In this analysis, too, very strong agreement was observed between laboratory and field measurements (Table 4). It can be argued that the degree of agreement may be interpreted as evidence supporting the interchangeability of tests; however, individual differences between tests in the recommended target HR range were slightly greater for precise quantification of training intensity. The limits of agreement for HR at velocities corresponding to a fixed blood [La] of 4 mmol·L^{-1} indicated a fairly wide range of HRs (up to 9 beats per min [bpm]$^{-1}$ for

1 subject), which is more than acceptable for subjects who were being asked to keep HR inside a 5- or 10-bpm^{-1} target range. This wide range emphasizes that the use of HR to prescribe exercise intensity has severe limitations; however, the results of the limited number of studies that have investigated reproducibility of the lactate response to treadmill running have not revealed narrower ranges.[31]

Thus, careful consideration is necessary if the present results are accepted as evidence to support the rationale that field tests may be more applicable than laboratory tests for coaches.[30] Very high test–retest reliability coefficients (r=0.96) were noted for HR at 4 mmol·L^{-1}, and a similarly high correlation (r=0.99) for running velocities corresponded to a blood [La] of 4 mmol·L^{-1}.[32] On the other hand, shortcomings in statistical analyses included lack of limits of agreement. In accordance with this view, poor sensitivity of laboratory [La] test data was identified through limits of agreement analysis.[31] In this study, limits of agreement for HR at 4 mmol·L^{-1} (–11 to +7) were closer than those in an earlier reproducibility investigation (–15 to +11),[31] which compared measurements obtained during 2 identical incremental treadmill tests.

The use of measurements obtained during incremental tests for real fieldside training purposes remains questionable, as was shown by previous studies in which a continuous increase in blood [La] during a prolonged steady state test at a velocity corresponding to 4 mmol·L^{-1} was reported.[5] These findings further obscure this issue. Future research is needed to compare laboratory versus field tests with respect to applicability of results to soccer training conditions.

CONCLUSIONS

The present study found that blood [La] and HR values were higher during field than treadmill tests at the same running velocities. Although velocities corresponding to a fixed blood [La] of 4 mmol·L^{-1} tended to be lower during field exercise, HRs at 4 mmol·L^{-1} were not significantly different between treadmill and field. The similarity of HR values, as shown by limit of agreement analysis, was the most noteworthy observation of this study. For practical applications, differences between individual field and laboratory HR values were considerably greater. This range, however, is similar to that reported in previous studies undertaken to investigate the reproducibility of lactate tests. Future research is needed to compare laboratory versus field tests with respect to applicability of results to soccer training conditions.

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