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Heart rate based prediction of fixed blood lactate thresholds in professional team-sport players

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Abstract

The aim of this study was to investigate whether the speed associated with 90% of maximal heart rate (S90%HR_{max}) could predict speeds at fixed blood lactate concentrations of 3 mmol·L^{-1} (S3mM) and 4 mmol·L^{-1} (S4mM). Professional team-sport players of futsal (n = 10), handball (n = 16) and basketball (n = 10) performed a four-stage discontinuous progressive running test followed, if exhaustion was not previously achieved, by an additional maximal continuous incremental running test to attain maximal heart rate (HR_{max}). The individual S3mM,S4mM and S90%HR_{max} were determined by linear interpolation. S3mM (11.6 ± 1.5 km·h^{-1}) and S4mM (12.5 ± 1.4 km·h^{-1}) did not differ (p> 0.05) from S90%HR_{max} (12.0 ± 1.2 km·h^{-1}). Very large significant (p < 0.001) relationships were found between S90%HR_{max} and S3mM (r = 0.82; *SEE* = 0.87 km·h^{-1}), as well as between S90%HR_{max} and S4mM (r = 0.82; *SEE* = 0.87 km·h^{-1}). S3mM and S4mM inversely correlated with %HR_{max} associated with running speeds of 10 and 12 km·h^{-1} (r = 0.78 - 0.81; p < 0.001; *SEE* = 0.94 - 0.87 km·h^{-1}). In conclusion, S3mM and S4mM can be accurately predicted by S90%HR_{max} in professional team-sport players.

Keywords: OBLA, maximal lactate steady state, exercise testing, elite athletes, heart rate monitor

Introduction

Competitive team-sports such as handball, basketball and futsal are high-intensity intermittent team-sports that place heavy emphasis on aerobic fitness. Even though team sports are not endurance sports *per se*, a minimum level of aerobic fitness is crucial in the ability to maintain an elevated intensity work in order to play at top level professional leagues (Alvarez, D'Ottavio, Vera, & Castagna, 2009; Gorostiaga, Granados, Ibanez, & Izquierdo, 2005; Povoas et al., 2012; Ziv & Lidor, 2009). Aerobic improvement increases the number of sprints and the distance covered during a match, and promotes more ball involvement in soccer (Helgerud, Engen, Wisloff, & Hoff, 2001). Reduction of the time spent at high-intensity during the games observed in handball, basketball and futsal (Alvarez et al., 2009; Ben Abdelkrim, El Fazaa, & El Ati, 2007; Povoas et al., 2012) also indicates the potential benefit of aerobic conditioning in indoor team-sports. Therefore, it seems of paramount importance to frequently assess changes in aerobic capacity in professional team-sport players throughout the season.

The speed at the “maximal lactate steady state” (MLSS) is generally considered the gold standard for determination of aerobic capacity. However, MLSS determination is tedious and time consuming (Mann, Lamberts, & Lambert, 2013). In field testing of team-sports, fixed lactate thresholds, such as running speeds associated with 3 mmol·L^{-1} (S3mM) and 4 mmol·L^{-1} (S4mM), which is also termed OBLA (Sjödin & Jacobs, 1981), are often preferred to MLSS (Gorostiaga, Granados, Ibanez, Gonzalez-Badillo, & Izquierdo, 2006; Granados, Izquierdo, Ibanez, Ruesta, & Gorostiaga, 2008; Loures et al., 2015; McMillan et al., 2005) because they reduce the time and cost of the assessment procedure, are easy to measure in several athletes at the same time in field settings, and have been shown to reflect the speed at the MLSS as appropriate as other lactate thresholds (Beneke, 1995; Hauser, Adam, & Schulz, 2014). Unfortunately, the determination of the fixed lactate thresholds requires qualified personnel and involves blood sampling, which is an invasive technique that can be aversive to some participants. Moreover, when performing field testing of teams, typically composed of 10-25 players, the cost of blood sampling is high and requires the participation of several qualified professionals. These issues often hinder the appropriate monitoring of endurance capacity in team-sports.

In an attempt to monitor players and predict aerobic performance more regularly, sub-maximal non-invasive low-cost tests have been of general interest to sport teams and to the sport scientist’s community. Based on previous studies (Garcia-Tabar et al., 2013; Kindermann, Simon, & Keul, 1979; McMillan et al., 2005; Mujika & Padilla, 2001; Mujika, 2012) and personal observations from years of professional experience in the assessment of team-sports’ endurance (Gorostiaga et al., 2006; Gorostiaga et al., 2009; Granados et al., 2008), we have noticed that the S3mM and S4mM determined during a progressive maximal field test usually occur at a mean intensity close to 90% of maximal heart rate (HR_{max}). It also seems that this relationship is maintained despite alterations in the intensity of the individual or fixed lactate thresholds due to training, detraining or hypoxia (Foster, Fitzgerald, & Spatz, 1999; Helgerud et al., 2001; McMillan et al., 2005; Mujika, 2012; Friedmann, Bauer, Menold, & Bartsch, 2004; Hurley et al., 1984; Lucia, Hoyos, Perez, & Chicharro, 2000). Nevertheless, whether the intensity at 90%HR_{max} could be used as a simple variable to assess S3mM and S4mM has never been investigated. Being able to assess aerobic capacity by means of an easy and non-invasive estimation of the fixed lactate thresholds would certainly cheapen and facilitate the monitoring of aerobic performance. This would be of particular interest to teams and coaches with limited resources. Accordingly, the primary aim of the current study was to investigate the relationships between the running speeds associated with the broadly used 90% of HR_{max} (S90%HR_{max}) and the S3mM and S4mM (or OBLA). It was hypothesized that S90%HR_{max} would be related to fixed lactate thresholds in team-sport players.

Methods

Experimental Approach to the Problem

A cross-sectional study was carried out to investigate the relationships between S90%HR_{max} and fixed blood lactate thresholds (S3mM and S4mM). Professional team-sport players performed a four-stage discontinuous progressive running test followed, if exhaustion was not previously achieved, by an additional maximal continuous incremental running test to attain HR_{max}. The individual S3mM, S4mM and S90%HR_{max} were determined by linear interpolation and relationships examined.

Subjects

Players from three professional teams of futsal (n = 10), handball (n = 16) and basketball (n = 10) participated in this study. The teams belonged to the Spanish First Divisions of futsal and handball, and the Spanish National Second Division of basketball. All participants were free of known cardiovascular, respiratory and circulatory dysfunctions, and they were not taking any drug or medication known to influence physical performance. Please see Table 1 for participant characteristics.

The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures were approved by the Local Institutional Review Board. Athletes and coaches were carefully informed about the possible risks and benefits of the project, and written informed consent was obtained from every volunteer.

Table 1 Anthropometric characteristics of the studied professional sport teams (n = 36)

	Handball team (n = 16)	**Basketball team (n = 10)**	**Futsal team (n = 10)**
Age (years)	26 ± 5	26 ± 4	24 ± 5
Body mass (kg)	90.1 ± 9.2*	93.4 ± 11.8*	72.8 ± 4.9
Height (cm)	189.1 ± 7.6*	194.2 ± 7.8*	177.4 ± 5.7
Body mass index ($kg \cdot m^{-2}$)	25.1 ± 1.5*	24.6 ± 2.0	23.1 ± 1.4

*Significantly different from futsal ($p < 0.05$)

Procedures

The study was conducted during the first 2-3 days of the pre-season training period, i.e. 4-6 weeks before the start of official competitions. Testing was integrated into the training schedule. Participants refrained from vigorous exercise during the previous 24 h and were instructed to fast for at least 2 h before the exercise test. They were also instructed to abstain from caffeinated and alcoholic beverages during the testing day. The pre-exercise meal for each participant was the same in an effort to standardize nutritional intake. All testing sessions were carried out in the same indoor court and at the same time of the day to lessen circadian variability.

After a non-standardized 15-min warm-up period, participants performed a four-stage discontinuous progressive running test around the indoor court (40x20 m) (Gorostiaga et al., 2005; Gorostiaga et al., 2006). Each stage was 5 min long, with a 3 min resting period between stages. The running speeds at each stage were 10, 12, 14 and 16 $km \cdot h^{-1}$. This incremental test protocol was the test protocol routinely used for regular testing by all these three sport teams. The choice of the running speeds was made to assure blood lactate concentration ($[La^-]$) values lower and similar or slightly higher than 4 $mmol \cdot L^{-1}$, based on previous endurance assessments performed for exercise prescription purposes with these teams (Gorostiaga et al., 2005; Gorostiaga et al., 2006).Five min long stage duration protocol was used because it is the minimum stage duration needed to reach a lactate equilibrium between muscle and blood at exercise intensities approaching S4mM (Rusko et al., 1986), and because S4mM approximates MLSS better with 5 min stage duration protocols than with lower stage duration protocols (Kuipers, Rietjens, Verstappen, Schoenmakers, & Hofman, 2003). To ensure a constant speed during each stage, participants were instructed to even pace their running following an audio signal connected to a pre-programmed laptop (Balise Temporelle, Bauman, Switzerland). Heart rate (HR) was recorded every 15 s (Polar Electro Oy, Sport Tester, Kempele, Finland) and averaged for the last 3 min of every completed stage. Immediately after each stage, and until participants attained a $[La^-]$ above 5 $mmol \cdot L^{-1}$, capillary blood samples from an hyperaemic earlobe were taken and $[La^-]$ amperometrically determined (Arkray KDK Corporation, Lactate Pro LT-1710, Shiga, Japan).

The participants (3 futsal players) who did not reach volitional exhaustion during the discontinuous running test were required to rest for 5-8 min after the completion of the final stage, and then began a maximal continuous incremental test to obtain their HR_{max}. Starting speed in this additional test was 13.6 $km \cdot h^{-1}$, and it was increased by 0.8 $km \cdot h^{-1}$ every min until players could no longer maintain the required speed. Either in the discontinuous or continuous protocol, volunteers were vigorously encouraged to complete exhaustion. HR_{max} was considered to be the highest HR value recorded, and it coincided in most cases with the voluntary termination of exercise (Nes, Janszky, Wisloff, Stoylen, & Karlsen, 2013).

S3mM and S4mM were determined by linear interpolation. S90%HR_{max} was calculated following identical procedures. The test-retest intraclass correlation coefficients of S3mM, S4mM and HR_{max} have been shown to range between 0.94 and 0.99, and coefficients of variation (CV) between 1.2 and 1.7% (Borch, Ingjer, Larsen, & Tomten, 1993; Weltman et al., 1990; Pfitzinger & Freedson, 1998).

Statistical Analyses

Statistical analyses were performed using SPSS 17.0 (SPSS Inc., Chicago, USA). Gaussian distribution was verified by Shapiro-Wilk's test when appropriate. Multiple comparisons between teams were evaluated using the Kruskal-Wallis test. Linear regression analyses were performed to determine the relationships between the variables of interest. Assumptions of linear regressions were checked and met. Evaluation of Cook's Distance revealed minimal influence of the individual data points on the regression models. Pearson product-moment correlation coefficients (*r*) were used to indicate the magnitude and direction of each linear relationship. The magnitudes of the correlations were interpreted as follows: 0.1-0.3 small, 0.3-0.5 moderate, 0.5-0.7 large, 0.7-0.9

very large and > 0.9 extremely large (Hopkins, Marshall, Batterham, & Hanin, 2009). The accuracy of each linear regression was evaluated using the standard error of the estimates (*SEE*), the 95% confidence intervals (CI) for the slope and the 90% CI for the correlation coefficients. The slopes of the regression lines were compared using analysis of covariance (ANCOVA). *Post hoc* power calculation for the linear regressions, assuming type I error of 0.05, indicated a power of above 99%. Statistical significance was set at $p < 0.05$. Data in the text, tables and figures are reported as mean and standard deviation (SD).

Results

Figure 1 illustrates [La^-] and $\%HR_{max}$ at the 10, 12 and 14 $km{\cdot}h^{-1}$ exercise stages. Absolute HR values did not differ among the teams at any of the exercise stages (p >0.05). HR values for all the teams as a whole were 156 ± 10, 171 ± 10 and 182 ± 9 $b{\cdot}min^{-1}$ at completion of the 10, 12 and 14 $km{\cdot}h^{-1}$ stages, respectively. Basketball players reached significantly lower HR_{max} values (184 ± 9 $b{\cdot}min^{-1}$) compared to futsal (192 ± 5 $b{\cdot}min^{-1}$; p = 0.038; 95%CI -14.60 to -0.33) and handball (192 ± 6 $b{\cdot}min^{-1}$; p = 0.046; 95%CI -16.71 to -0.10) players. Every participant fulfilled the criterion of HR_{max} above 90% of age-predicted HR_{max} (Nes et al., 2013).

Descriptive features of S3mM, S4mM and S90%HR_{max} are summarized in Table 2. Mean S3mM significantly differed from mean S4mM (p = 0.027; 95% CI -1.75 to -0.08). There were no significant differences between mean S90%HR_{max} and mean S3mM (p = 0.51; 95% CI -1.20 to 0.38). Mean S90%HR_{max} neither differed from mean S4mM (p = 0.32; 95% CI -0.28 to 1.29).

Figure 2 shows the linear relationships between S90%HR_{max} and S3mM (Figure 2A), as well as between S90%HR_{max} and S4mM (Figure 2B). The rate of increase did not differ between the basketball, handball and futsal teams (p >0.05). Regression equations of Figure 2 are reported in Table 3.

Unplanned regression analyses revealed significant linear relationships between $\%HR_{max}$ at 10 and 12 $km{\cdot}h^{-1}$ and S3mM and S4mM (Figure 3). There were no differences in the rate of decline between the teams (p >0.05). Very large and significant (p <0.001) correlations between S3mM and $\%HR_{max}$ at S3mM (r = 0.67; *SEE* = 1.14 $km{\cdot}h^{-1}$; 95% CI 0.16 to 0.39; 90% CI ±0.16), and between S4mM and $\%HR_{max}$ at S4mM (r = 0.68; *SEE* = 1.09 $km{\cdot}h^{-1}$; 95% CI 0.14 to 0.34; 90% CI ±0.16) were also found.

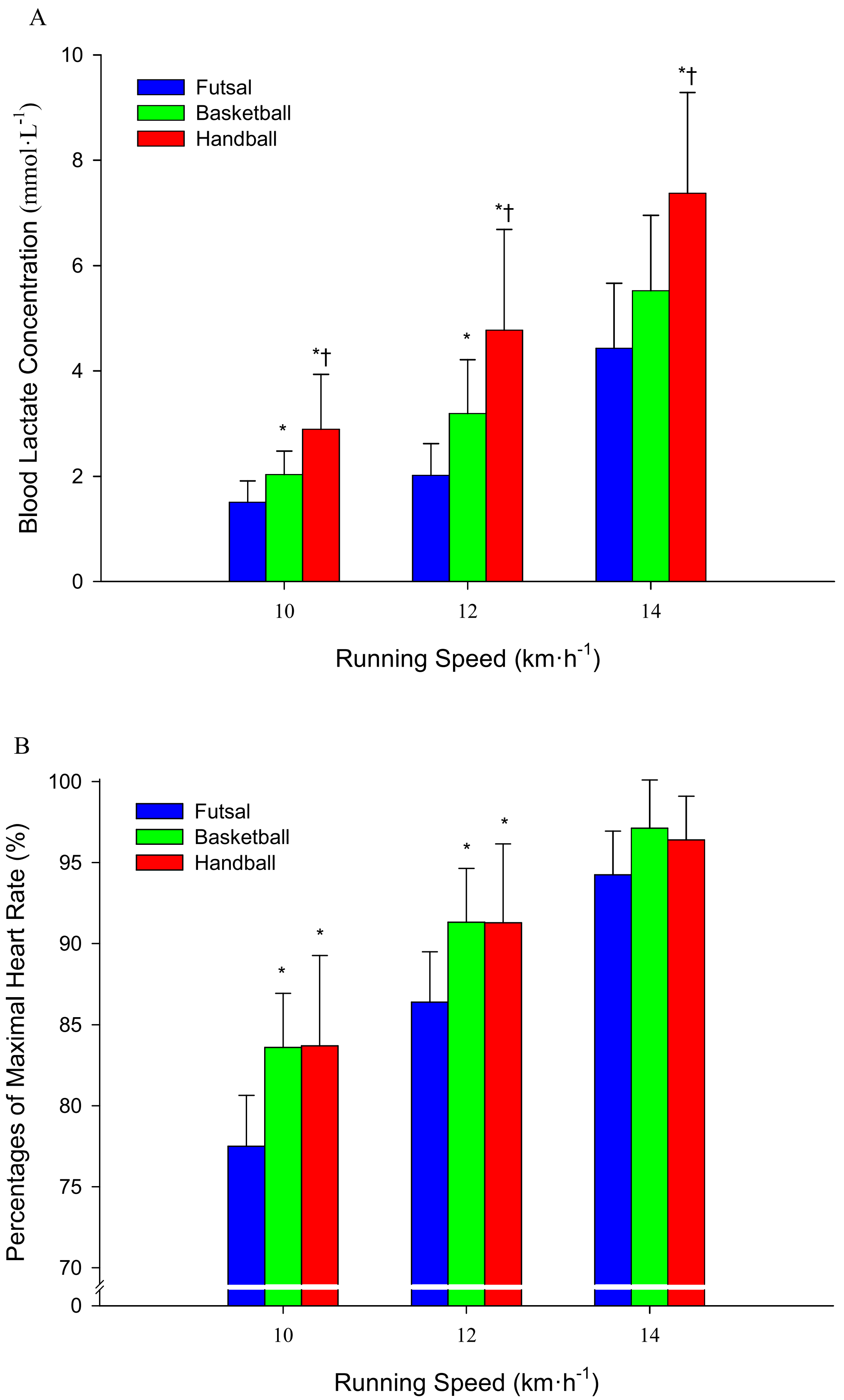


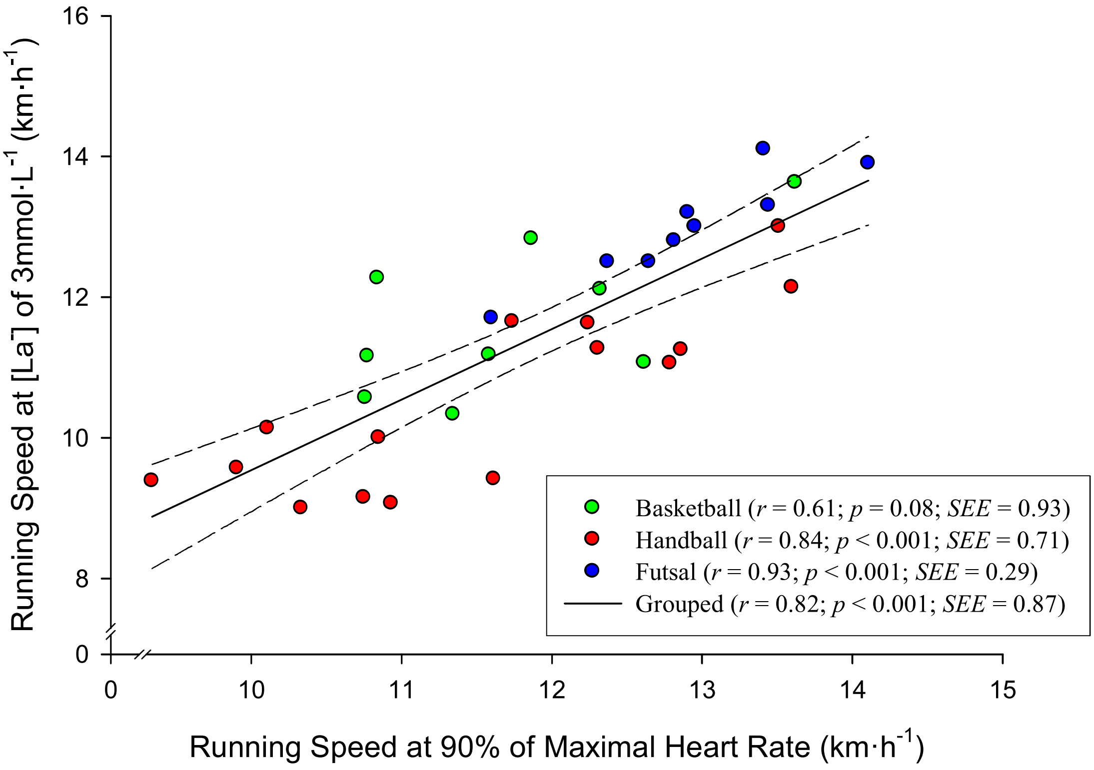
Figure 1: Mean (SD) blood lactate concentrations (A) and percentages of maximal heart rate (B) at 10, 12 and 14 km·h^{-1} stages for each sport team. *Significantly different from futsal (p < 0.05); †Significantly different from basketball (p < 0.05)

Table 2. Descriptive features of the running speeds at blood lactate concentrations ($[La^-]$) of 3mmol·L^{-1} (S3mM), 4mmol·L^{-1} (S4mM) and 90% of maximal heart rate (S90%HR_{max})

	S3mM			**S4mM**			**S90%HR_{max}**		
	Speed (km·h^{-1})	**HR (b·min^{-1})**	**%HR_{max} (%)**	**Speed (km·h^{-1})**	**HR (b·min^{-1})**	**%HR_{max} (%)**	**Speed (km·h^{-1})**	**HR (b·min^{-1})**	**$[La^-]$ (mmol·L^{-1})**
Handball Team	10.5 ± 1.2*†	163 ± 7*	85.1 ± 3.0*†	11.5 ± 1.2*†	169 ± 9*	89.3 ± 4.2*†	11.5 ± 1.3*	173 ± 5	4.3 ± 1.1*†
Basketball Team	11.8 ± 1.1*	164 ± 7*	90.1 ± 2.9	12.8 ± 1.0	171 ± 8*	93.5 ± 2.8	11.7 ± 1.0*	166 ± 8	3.1 ± 0.7
Futsal Team	13.0 ± 0.7	175 ± 6	90.4 ± 1.2	13.7 ± 0.7	181 ± 6	93.2 ± 1.2	12.9 ± 0.7	173 ± 5	2.9 ± 0.3
Mean	11.6 ± 1.5‡	167 ± 8‡	87.9 ± 3.6	12.5 ± 1.4	173 ± 9	91.0 ± 4.1	12.0 ± 1.2	171 ± 7	3.6 ± 1.0

*Significantly different from futsal ($p < 0.05$); †Significantly different from basketball ($p < 0.05$); ‡Significantly different from S4mM ($p < 0.05$)

A



B

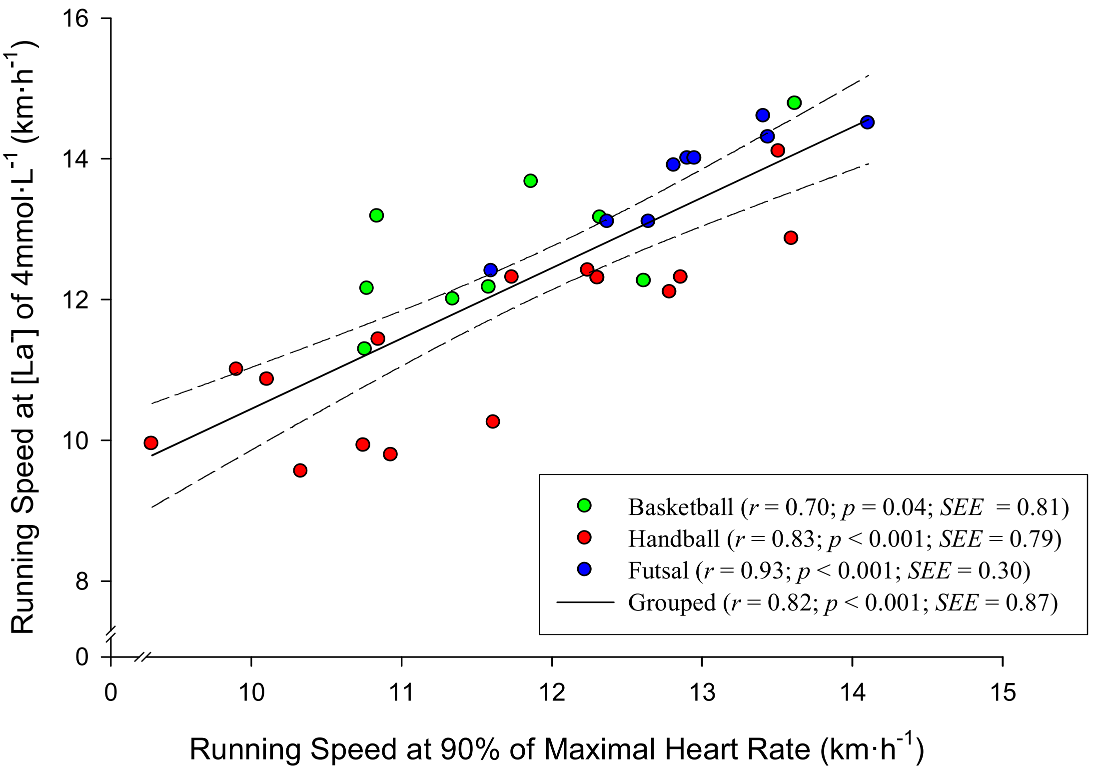


Figure 2: Relationships between the running speed at 90% of maximal heart rate and the running speeds at blood lactate concentration ($[La^-]$) of 3 $mmol \cdot L^{-1}$ (A) and 4 $mmol \cdot L^{-1}$ (B). Grouped linear regressions solid lines (-); 95% confidence intervals dashed lines (- -)

Table 3. Linear regression equations for prediction of the running speeds at $[La^-]$ of 3 (S3mM) and 4 $mmol \cdot l^{-1}$ (S4mM) by the running speed at 90% of maximal heart rate (S90%HR_{max})

		n	*r*	r^2	*SEE*	*p*	Regression Equation	95% CI	90% CI
S3mM	Basketball	10	0.61	0.37	0.93	0.08	S3mM = 0.6893(S90%HR_{max}) +3.5857	-0.11 to 1.50	±0.39
	Handball	16	0.84	0.71	0.71	< 0.001	S3mM = 0.8024(S90%HR_{max}) +1.2681	0.49 to 1.11	±0.14
	Futsal	10	0.93	0.87	0.29	< 0.001	S3mM = 0.9647(S90%HR_{max}) + 0.5387	0.63 to 1.32	±0.10
	Grouped	36	0.82	0.67	0.87	< 0.001	S3mM = 1.0013(S90%HR_{max}) - 0.4698	0.74 to 1.26	±0.10
S4mM	Basketball	10	0.70	0.49	0.81	0.04	S4mM = 0.7623(S90%HR_{max}) + 3.784	0.06 to 147	±0.33
	Handball	16	0.83	0.69	0.79	< 0.001	S4mM = 0.8339(S90%HR_{max}) + 1.798	0.49 to 1.17	±0.15
	Futsal	10	0.93	0.87	0.30	< 0.001	S4mM = 0.9622(S90%HR_{max}) + 1.337	0.62 to 1.33	±0.10
	Grouped	36	0.82	0.67	0.87	< 0.001	S4mM = 0.9998(S90%HR_{max}) + 0.4512	0.74 to 1.26	±0.10

$[La^-]$, blood lactate concentration; *SEE*, standard error of the estimate; 95% CI, 95% confidence intervals for the slope; 90% CI, 90% confidence intervals for the Pearson product-moment correlation coefficients (*r*)

Speed at 90% HR_{max}

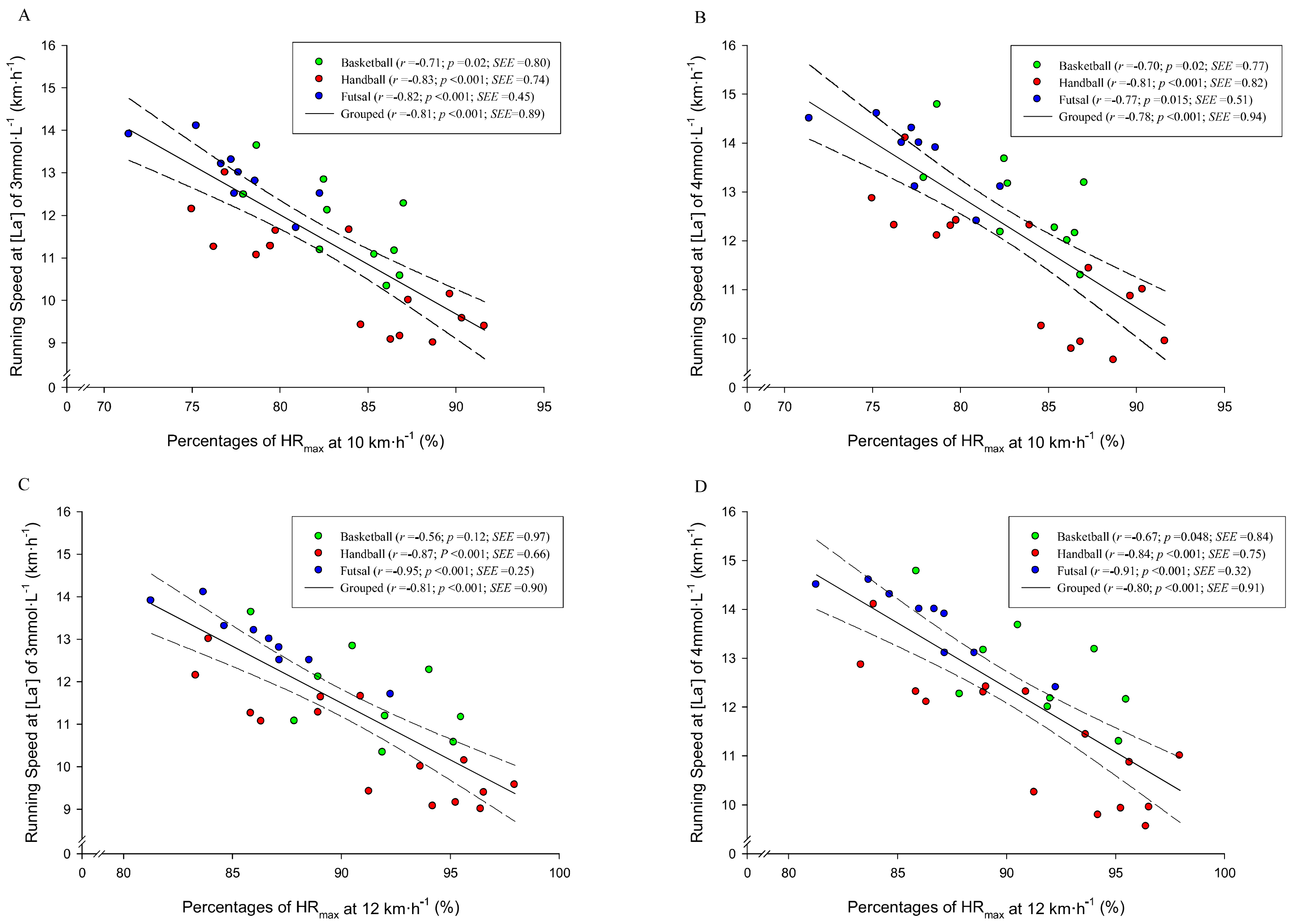


Figure 3: Linear regressions between percentages of maximal heart rate (HR_{max}) at 10 (A, B) and 12 $km \cdot h^{-1}$ (C, D) and the running speeds at blood lactate concentration ($[La^-]$) of 3 $mmol \cdot L^{-1}$ and 4 $mmol \cdot L^{-1}$. Grouped linear regressions solid lines (-); 95% confidence intervals dashed lines (- -)

Discussion

The main finding of this study was that S90%HR_{max} accurately predicted S3mM and S4mM in professional handball, basketball and futsal players. This is the first study reporting the potential of S90%HR_{max} to be used as a simple, low-cost and non-invasive performance variable to frequently assess and monitor aerobic capacity in professional team-sport players.

A careful analysis of the existing literature revealed that S3mM and S4mM, as well as MLSS, usually occur at a mean intensity close to 90% HR_{max} (Mujika, 2012; Kindermann et al., 1979; McMillan et al., 2005; Mujika & Padilla, 2001; Garcia-Tabar et al., 2013; Jones & Doust, 1998). Although it has been suggested that there might be a steady-state relationship between the intensity at a fixed [La^-] and %HR_{max} (Foster et al., 1999; Mujika, 2012), the intensity at a given %HR_{max} as a simple performance variable to predict S3mM and S4mM had never been investigated before. In the present study S90%HR_{max} was close to S3mM and S4mM (Table 2), and it was found to be a good predictor of both fixed lactate thresholds in homogeneous groups of professional team-sport players, particularly in futsal and handball (Figure 2). Likewise, %HR_{max} at 10 and 12 $km \cdot h^{-1}$ were observed to accurately estimate both fixed lactate thresholds (Figure 3). The magnitudes of these correlations are similar to those observed between S4mM and MLSS (Vobejda, Fromme, Samson, & Zimmermann, 2006; Jones & Doust, 1998), and similar or even higher than those observed between individual or fixed lactate thresholds and heart rate deflection points, which, unlike S90%HR_{max}, are not always possible to determine (Bodner & Rhodes, 2000; Vachon, Bassett, Jr., & Clarke, 1999; Hofmann, Bunc, Leitner, Pokan, & Gaisl, 1994). These results indicate that S90%HR_{max} can be used as a non-invasive and easy method to estimate S3mM and S4mM during a progressive running test in professional indoor team-sport players.

The estimations of S3mM and S4mM from S90%HR_{max} were less accurate in basketball than in futsal and handball (Figure 2). Similar results were found when %HR_{max} at 10 and 12 $km \cdot h^{-1}$ were taken as predictor variables (Figure 3). It is well known that the correlation coefficients are influenced by the range in the predictor and responding variables; the greater the range or the heterogeneity of a group the greater the magnitude of the correlation coefficient. In this study, grouped CVs (a normalized measure of dispersion) for S3mM, S4mM and S90%HR_{max} ranged between 10.3 and 12.6% (Table 2). However, when we examined each teams' linear relationships separately, therefore narrowing the range in S3mM, S4mM and S90%HR_{max} (e.g. futsal CVs ranged between 5.2 and 5.5% in S3mM, S4mM and S90%HR_{max}; Table 2), it can be observed that correlation magnitudes augmented in futsal and handball but not in basketball (Figure 2). The non-attainment of a true HR_{max} in some basketball players is suggested to be the main factor explaining these less accurate estimations. Mean differences between HR_{max} and age-predicted HR_{max} (211-0.64·age) were well within ±10.8 $b \cdot min^{-1}$*SEE* reported for the HR_{max} vs. age relationship (Nes et al., 2013) in every sport team, including basketball. Nevertheless, mean absolute HR_{max} was 8 $b \cdot min^{-1}$ lower ($p < 0.05$) in basketball than in futsal and handball, despite athletes being of similar age. Furthermore, basketball players' mean absolute HR_{max} only corresponded to 95% of their age-predicted HR_{max}, which is lower than the 98% and 99% observed in our futsal and handball players, as well as lower than the 97% to 101% values previously reported in soccer players (Helgerud et al., 2001), long-distance runners (Friedmann et al., 2004), cross-country skiers (Kindermann et al., 1979), amateur or professional cyclists (Mujika & Padilla, 2001) and basketball players (Narazaki, Berg, Stergiou, & Chen, 2009). Lack of motivation and participants' lack of familiarity with this kind of running tests could have also partly hampered the achievement of a real HR_{max} (Whipp, Davis, Torres, & Wasserman, 1981).While most of the futsal (80%) and handball (77%) players were well accustomed to the exercise protocol, since they were previously tested using the same testing procedures, 70% of the basketball players were not familiar with this test. Other factors such as the effect of the non-standardized warm-up (each team performed their own warm-up routine supervised by their respective physical trainer) or anthropometric, speed and strength characteristics, are thought to be less plausible factors to explain these differences.

The observed relationships between S90%HR_{max} and both fixed lactate thresholds (Figure 2) and the non-significant differences between S90%HR_{max} and S3mM and S4mM (Table 2) do not necessarily imply that exercise intensity at either of the fixed lactate thresholds must coincide with the intensity at 90%HR_{max}. In fact, the large correlations between S3mM or S4mM and %HR_{max} at which S3mM or S4mM occurred, suggest that team-sport players with higher fixed lactate thresholds achieve the thresholds at higher %HR_{max} compared to those with lower fixed lactate thresholds. This is in agreement with previous studies showing that endurance-trained individuals achieve their fixed lactate thresholds at a higher relative load (expressed either as percentage of maximal oxygen uptake or HR_{max}) than less fit individuals (Garcia-Tabar et al., 2013; Hurley et al., 1984). Nonetheless, due to the fact that S3mM and S4mM explained <50% of the variance in %HR_{max} at their respective fixed lactate thresholds, other factors such as age (Rusko, Rahkila, & Karvinen, 1980) could influence these relationships.

The present study is limited in some aspects. The use of maximal secondary criteria (e.g. perceived exertion or peak [La^-] measures) or a maximal confirmation test could have helped to verify non-attainment of HR_{max}, particularly in basketball. Besides, because steady-state [La^-] can vary among athletes, the assessment of the MLSS may have led to a greater accuracy in the determination of endurance capacities. Nevertheless, the intensity at a given sub-maximal [La^-] accurately predicts endurance capacity (Borch et al., 1993; Heck et al., 1985; Kindermann et al., 1979) and lessens the testing burden on the participant and researcher associated with the MLSS (Mann et al., 2013). The type of exercise protocol used is unlikely to have influenced S3mM or S4mM vs. %HR_{max} relationships (Whipp et al., 1981), although further corroboration is recommended. Finally, this investigation was conducted on team-sport players with an S4mM between 9.6 $km \cdot h^{-1}$ and 14.8 $km \cdot h^{-1}$ during a specific time of the season that limited the applicability of the results. Due to the fact that individual or fixed lactate thresholds, as well as the MLSS, usually occur at a mean intensity close to 90% HR_{max} regardless of the level of aerobic capacity of the individuals (Garcia-Tabar et al., 2013; Jones & Doust, 1998; Kindermann et al., 1979; McMillan et al., 2005; Mujika & Padilla, 2001; Mujika, 2012), and that this relationship is maintained despite alterations in the intensity of the individual or fixed lactate thresholds due to training, detraining or hypoxia (Foster et al., 1999; Friedmann et al., 2004; Helgerud et al., 2001; Hurley et al., 1984; Lucia et al., 2000; Mujika, 2012; McMillan et al., 2005), S90%HR_{max} might be a useful variable to predict and monitor fixed lactate thresholds during an entire competitive season and in other populations with an S4mM lower than 9.6 $km \cdot h^{-1}$ or higher than 14.8 $km \cdot h^{-1}$. However, whether a steady-state relationship between fixed lactate thresholds and %HR_{max} is maintained throughout an entire competitive season, in athletes of other sports, in athletes with different level of aerobic capacity or under other conditions (e.g. glycogen depleted state or hypoxia) remains unclear, is beyond the scope of this study, and deserves further research.

Practical Applications

This study supports that aerobic capacity can be assessed and monitored through S90%HR_{max} in basketball, handball and futsal players with an S4mM between 9.6 $km \cdot h^{-1}$ and 14.8 $km \cdot h^{-1}$. The use of S90%HR_{max} as an endurance performance variable could facilitate the assessment and monitoring of aerobic capacity in team-sports and coaches with limited resources. Indeed, this variable is a simple, low-cost and non-invasive variable that allows investigation of several players at the same time without the need of expensive equipment or technical expertise to administer the test. Further research to confirm these results in other sports composed of athletes with an S4mM lower than 9.6 $km \cdot h^{-1}$ or higher than 14.8 $km \cdot h^{-1}$ and to explore the possible physiological mechanisms underpinning the fixed lactate thresholds and S90%HR_{max} relationships is warranted.

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