

## Physiological determinants of Yo-Yo intermittent recovery tests in male soccer players

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Accepted: 20 September 2009 / Published online: 11 October 2009  
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**Abstract** The physiological determinants of performance in two Yo-Yo intermittent recovery tests (Yo-YoIR1 and Yo-YoIR2) were examined in 25 professional ( $n = 13$ ) and amateur ( $n = 12$ ) soccer players. The aims of the study were (1) to examine the differences in physiological responses to Yo-YoIR1 and Yo-YoIR2, (2) to determine the relationship between the aerobic and physiological responses to standardized high-intensity intermittent exercise (HIT) and Yo-Yo performance, and (3) to investigate the differences between professional and amateur players in performance and responses to these tests. All players performed six tests: two versions of the Yo-Yo tests, a test for the determination of maximum oxygen uptake ( $\dot{V}O_{2\max}$ ), a double test to determine  $\dot{V}O_2$  kinetics and a HIT evaluation during which several physiological responses were measured. The anaerobic contribution was greatest during Yo-YoIR2.  $\dot{V}O_{2\max}$  was strongly correlated with Yo-YoIR1 ( $r = 0.74$ ) but only moderately related to Yo-YoIR2

( $r = 0.47$ ). The time constant ( $\tau$ ) of  $\dot{V}O_2$  kinetics was largely related to both Yo-Yo tests (Yo-YoIR1:  $r = 0.60$  and Yo-YoIR2:  $r = 0.65$ ). The relationships between physiological variables measured during HIT (blood  $La^-$ ,  $H^+$ ,  $HCO_3^-$  and the rate of  $La^-$  accumulation) and Yo-Yo performance (in both versions) were very large ( $r > 0.70$ ). The physiological responses to HIT and the  $\tau$  of the  $\dot{V}O_2$  kinetics were significantly different between professional and amateur soccer players, whilst  $\dot{V}O_{2\max}$  was not significantly different between the two groups. In conclusion,  $\dot{V}O_{2\max}$  is more important for Yo-YoIR1 performance, whilst  $\tau$  of the  $\dot{V}O_2$  kinetics and the ability to maintain acid-base balance are important physiological factors for both Yo-Yo tests.

**Keywords** High intensity · Professional · Performance · Acid–base balance · Intermittent exercise

Communicated by Susan Ward.

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### Introduction

Soccer is a team sport that requires prolonged, high-intensity, intermittent exercise (Bangsbo et al. 1991; Mohr et al. 2003; Stolen et al. 2005; Withers et al. 1982). For this reason, several authors have suggested that the capacity to cope with high-intensity intermittent exercise is important for physical performance in soccer (Bangsbo 1994; Wragg et al. 2000). The Yo-Yo intermittent recovery tests (Krustrup et al. 2003, 2006a) were specifically designed to evaluate the ability to perform high-intensity intermittent exercise and are extensively utilized by scientists and coaches in monitoring cardiorespiratory fitness of soccer players (Bangsbo et al. 2008). There are two versions of the Yo-Yo intermittent recovery test, level 1 (Yo-YoIR1) and level 2 (Yo-YoIR2), and these differ in protocol exercise intensity and

duration. Performance in these two tests may be determined by different physiological variables (Bangsbo et al. 2008). Krstrup et al. (2003) reported a relationship between performance in Yo-YoIR1 and the distance covered at high intensity during the match, whilst performance in Yo-YoIR2 was related to the peak distance of high-intensity running in a 5-min period during the match (Krstrup et al. 2006a).

Numerous studies have examined the physiological responses to Yo-YoIR1 and Yo-YoIR2 (Atkins 2006; Castagna et al. 2006a, b; Krstrup et al. 2003, 2006a; Thomas et al. 2006). A higher rate of muscle and blood lactate ( $\text{La}^-$ ) accumulation has been reported during Yo-YoIR2 compared with Yo-YoIR1 (Krstrup et al. 2006a). Furthermore, Yo-YoIR2 elicits a higher peak blood  $\text{La}^-$  concentration, lower levels of creatine phosphate and lower muscle pH than Yo-YoIR1 (Bangsbo et al. 2008; Krstrup et al. 2006a), suggesting a higher anaerobic contribution in Yo-YoIR2. However, these differences were derived from the results of two different studies, performed on two different cohorts. Therefore, in order to limit the influence of inter-subject variability, it is necessary to confirm these findings by comparing physiological responses to Yo-YoIR1 and Yo-YoIR2 in the same population.

Previous studies investigating the physiological determinants of Yo-Yo tests have focused mainly on  $\dot{V}\text{O}_{2\text{max}}$ . In a recent review, Bangsbo et al. (2008) reported that  $\dot{V}\text{O}_{2\text{max}}$  is more closely correlated to performance in Yo-YoIR1 ( $r = 0.70$ ) than Yo-YoIR2 ( $r = 0.58$ ). Again, these conclusions were derived by summarizing the findings of studies involving different populations. To our knowledge, only one study confirms the relationship between Yo-YoIR1, Yo-YoIR2 and  $\dot{V}\text{O}_{2\text{max}}$  using the same sample of subjects (Thomas et al. 2006). The subjects used in this study included Australian Rules Footballers, hockey and cricket players but not soccer players.

In addition to  $\dot{V}\text{O}_{2\text{max}}$ , the time constant ( $\tau$ ) derived from  $\dot{V}\text{O}_2$  kinetics evaluation could also be a physiological determinant for Yo-Yo performance. Recent work has shown that this parameter is important for high-intensity intermittent performance such as repeated sprint ability (Dupont et al. 2005); however, to date, no studies have established the importance of  $\tau$  for Yo-Yo performance.

The ability to maintain acid–base balance during intermittent exercise may also be of importance. Distance covered in both Yo-YoIR1 and Yo-YoIR2 has been significantly related to the rate of blood  $\text{La}^-$  accumulation during these tests ( $r = -0.46$  to  $-0.81$  in Yo-YoIR1 and  $r = -0.50$  to  $-0.72$  in Yo-YoIR2) (Krstrup et al. 2003, 2006a), but peak blood  $\text{La}^-$  measured at the end of each test was not related to performance (Atkins 2006). Therefore, a player who performs better in the Yo-Yo test should show lower physiological strain during a sub-maximal high-intensity intermittent effort than a player with a lower

performance in the test. In order to obtain blood measurements that may reflect the muscle accumulation of metabolites, it is important to use a standardized intermittent protocol which contains exercise bouts of sufficient duration and with minimal random variation (Krstrup et al. 2006b). Such a protocol makes it possible to examine the relationship between physiological responses to sub-maximal intermittent exercise and Yo-Yo performance. Furthermore, since it is well known that professional soccer players perform better than amateurs in Yo-YoIR1 and Yo-YoIR2 (Bangsbo et al. 2008), professional players should also be able to cope better with a standardized high-intensity intermittent exercise protocol than their amateur counterparts.

Identifying the physiological determinants of performance in both the Yo-Yo tests is important if such tests are used as outcomes in intervention studies or for longitudinal fitness monitoring of players on a routine basis. If different physiological determinants are confirmed for each test, the utilization of both Yo-Yo tests may be useful in order to better understand training adaptations in soccer players. Therefore, in order to address a more specific use of the two versions of the Yo-Yo test, the aims of this study were to examine: (1) the differences in physiological responses to Yo-YoIR1 and Yo-YoIR2 in the same population of soccer players; (2) the relationship between aerobic parameters and performance in Yo-YoIR1 and Yo-YoIR2; (3) the relationship between physiological responses to standardized high-intensity intermittent exercise with performance in Yo-YoIR1 and Yo-YoIR2; and finally (4) the differences between professional and amateur soccer players in aerobic parameters and physiological responses to standardized high-intensity intermittent exercise.

## Methods

### Subjects and study design

Thirteen professional (3 central defenders, 4 midfielders, 4 fullbacks and 2 attackers; age  $25 \pm 4$  years, body mass  $73.9 \pm 4.5$  kg, height  $180 \pm 3$  cm) and 12 amateur soccer players (3 central defenders, 4 midfielders, 3 fullbacks and 2 attackers; age  $25 \pm 5$  years, body mass  $72.4 \pm 6.0$  kg, height  $179 \pm 5$  cm) were involved in the study. All subjects provided written informed consent before participating in the study which was approved by an Independent Institutional Review Board according to the Guidelines and Recommendations for European Ethics Committees by the European Forum for Good Clinical Practice and by the soccer clubs involved. The professional soccer players usually trained six times per week plus an official match, whilst the amateur soccer players trained three times per

week plus an official match. Training volume (calculated from training session duration) of the professional athletes was  $\sim 70\%$  higher than those of amateur players. The subjects completed six tests on four separate occasions during the competitive season, each at the same time of day. All test sessions were separated by at least 48 h and were completed within 2 weeks. Subjects were instructed to rest the day before each test, to have their last meal at least 3 h before the test and to avoid drinking coffee or beverages containing caffeine in the 8 h prior to each test.

On the first testing day, each subject performed an incremental test on the treadmill for determination of  $\dot{V}O_{2\max}$ , peak running speed and maximum heart rate. A high-intensity intermittent test (HIT) was performed on the treadmill on the second testing day, followed by the Yo-YoIR1 (Krustrup et al. 2003) and Yo-YoIR2 (Krustrup et al. 2006a) tests on the third and fourth days, respectively. Before the start of each Yo-Yo test, all players performed a 10-min run on the treadmill at 60% of their peak speed reached during the incremental test performed on the first testing day.

#### Incremental treadmill test protocol

Following a 10-min warm-up consisting of low-intensity running, maximal oxygen uptake was determined using an incremental running test (starting speed 10 km h<sup>-1</sup>, increment 1 km h<sup>-1</sup> every minute, inclination 4%) on a motorized treadmill (Saturn 4.0, h/p/Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany). Achievement of  $\dot{V}O_{2\max}$  was considered as the attainment of at least two of the following criteria: (1) a plateau in  $\dot{V}O_2$  despite increasing speed ( $<80$  ml min<sup>-1</sup>); (2) a respiratory exchange ratio above 1.10; (3) a HR  $\pm 10$  beats/min of age-predicted maximal HR (220 – age) (Howley et al. 1995). Expired gases were analysed using a breath-by-breath automated gas analysis system (VMAX29, SensorMedics, Yorba Linda, CA). Heart rate was recorded every 5 s (Vantage NV; Polar Electro, Kempele, Finland).

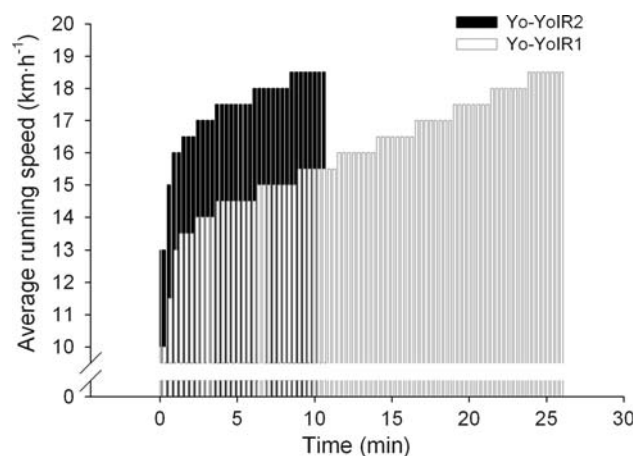
#### HIT protocol

The protocol began with a 10-min warm-up consisting of low-intensity running during which subjects completed three bouts of 10 s at 14, 16 and 18 km h<sup>-1</sup> with 20 s of recovery between each bout walking at 5 km h<sup>-1</sup>. Following the warm-up, subjects completed a HIT protocol (total duration = 5 min) consisting of 10  $\times$  10 s of running at 18 km h<sup>-1</sup> with 20 s of recovery walking at 5 km h<sup>-1</sup> between each bout. Throughout the entire test, the treadmill was inclined at 8%. Blood hydrogen ion (H<sup>+</sup>) and bicarbonate (HCO<sub>3</sub><sup>-</sup>) were measured immediately after the test using a blood-gas analyser (GEM Premier 3000,

Instrumentation Laboratory, USA), calibrated according to manufacturer's specification. Capillary blood samples were drawn from the hyperaemic earlobe and collected into 100  $\mu$ l heparinized capillary tubes. Prior to sampling, the skin was cleansed with alcohol, dried and the first post-puncture drop excluded from the sample. The sample was immediately analysed using an IQM<sup>TM</sup> cartridge. Blood La<sup>-</sup> was measured using a portable amperometric microvolume lactate analyser (LactatePro, Arkray, Japan). Capillary blood samples (5  $\mu$ l) were collected from the earlobe. Before each test, the analyser was calibrated following the instructions of the manufacturer. The rate of perceived exertion (RPE) was collected using a printout of Borg's CR10 scale (Borg 1998) at the end of the HIT. All athletes were familiarized with the scale before the start of the study and followed standardized instructions for providing RPE (Borg 1998).

#### Yo-Yo intermittent recovery tests

Soccer players completed Yo-YoIR1 (Krustrup et al. 2003) and Yo-YoIR2 (Krustrup et al. 2006a) on the third and fourth testing days, respectively. The tests were completed on days without wind. Air temperature ranged from 19 to 24°C. Both tests consisted of 20-m shuttle runs performed at increasing velocities with 10 s of active recovery (consisting of 2  $\times$  5 m of jogging) between runs until exhaustion. However, Yo-YoIR1 began at a speed of 10 km h<sup>-1</sup> whilst Yo-YoIR2 began at 13 km h<sup>-1</sup>, with the increase in speed more gradual during Yo-YoIR1 than in Yo-YoIR2 (Fig. 1). Audio cues for Yo-YoIR1 and Yo-YoIR2 were recorded on a CD (<http://www.teknosport.com>, Ancona, Italy) and broadcasted using a portable CD player (Philips, Az1030 CD player, Eindhoven, Holland). The end of the test was considered when the participant twice failed to reach the front line in time (objective evaluation) or he felt



**Fig. 1** Schematic representation of Yo-Yo intermittent recovery test level 1 (Yo-YoIR1) and level 2 (Yo-YoIR2)

unable to complete another shuttle at the dictated speed (subjective evaluation). The total distance covered during Yo-YoIR1 and Yo-YoIR2 was considered as the test 'score'. Before each test, subjects performed a warm-up consisting of 5 min of low-intensity running followed by the first four running bouts in the test. All players were familiarized with the test procedures since both tests form part of their usual fitness assessment program.

#### Oxygen uptake kinetics

$\dot{V}O_2$  kinetics, as described by Dupont et al. (2005), were calculated from expired gas collected during the 10-min run performed at the start of the third and fourth testing sessions. Treadmill speed during these two runs was set at 60% of the peak speed reached during the incremental test. Breath-by-breath raw  $\dot{V}O_2$  data were linearly interpolated to yield  $\dot{V}O_2$  values every second during the test. Data from the two trials were aligned by time and averaged for each subject. To determine the time constant ( $\tau$ ), the first 20 s of data from the beginning of exercise were first excluded from the analysis to eliminate cardiodynamic phase, whilst the remaining data were fitted using a mono-exponential function:

$$\dot{V}O_2(t) = \dot{V}O_{2(b)} + A(1 - \exp^{-(t-\delta)/\tau})$$

where  $t$  is time,  $\dot{V}O_{2(b)}$  is baseline  $\dot{V}O_2$ ,  $A$  is the amplitude of  $\dot{V}O_2$  above baseline value,  $\delta$  is the time delay and  $\tau$  is the time constant.

#### Statistical analyses

All data are presented as mean  $\pm$  standard deviation (SD). Differences in blood  $La^-$ ,  $H^+$  and  $HCO_3^-$  measured before and after the Yo-Yo tests in professional and amateur players were verified using a three-way mixed ANOVA. The independent variables included two within-subject factors: (1) type of Yo-Yo test with two levels (Yo-YoIR1 and Yo-YoIR2); (2) sampling time with two levels (before and after the tests) and one between-subject factor: soccer players rank with two levels (professional and amateur). Differences in rate of blood  $La^-$  accumulation, distance covered, test duration and peak heart rate recorded during Yo-Yo tests between professional and amateur players were verified using a two-way ANOVA. The independent variables included one within-subject factor: type of Yo-Yo test with two levels (Yo-YoIR1 and Yo-YoIR2) and one between-subject factor: soccer players rank with two levels (professional and amateur). A two-way ANOVA was also used to analyse differences in blood  $La^-$ ,  $H^+$  and  $HCO_3^-$  measured before and after the HIT. The independent variables included one within-subject factor: time of sample with two levels (before and after the HIT) and one

between-subject factor: soccer players rank with two levels (professional and amateur). When a significant  $F$  value was found, Bonferroni post hoc was applied. The unpaired  $t$  test was used for the comparisons between professional and amateur soccer players in other physiological responses during HIT (rate of blood  $La^-$  accumulation, mean heart rate and RPE),  $\dot{V}O_{2max}$  and  $\dot{V}O_2$  kinetics (amplitude and  $\tau$ ). Effect sizes ( $d$ ) were determined as: (mean value trial 2 – mean value of trial 1)/pooled SD. A modified scale by Hopkins (<http://www.sportsci.org/resource/stats/2002>) was used for interpretation of  $d$ : trivial,  $<0.2$ ; small,  $0.2$ – $0.6$ ; medium,  $0.6$ – $1.2$ ; and large,  $>1.2$ . The relationships between Yo-Yo distance (Yo-YoIR1 and Yo-YoIR2) and physiological responses to HIT (blood  $La^-$ ,  $H^+$  and  $HCO_3^-$  after HIT, rate of blood  $La^-$  accumulation, mean heart rate and RPE),  $\dot{V}O_{2max}$  and  $\dot{V}O_2$  kinetics parameters (amplitude and  $\tau$ ) were calculated using the Pearson's product moment correlation coefficient ( $r$ ). Confidence intervals (90%) for correlations were calculated. The magnitude of the correlations was determined using the modified scale by Hopkins (<http://www.sportsci.org/resource/stats/2002>):  $r < 0.1$ , trivial;  $0.1$ – $0.3$ , small;  $0.3$ – $0.5$ , moderate;  $0.5$ – $0.7$ , large;  $0.7$ – $0.9$ , very large;  $>0.9$ , nearly perfect; and 1 perfect. Statistical significance was set at  $p \leq 0.05$ .

#### Results

##### Yo-Yo intermittent recovery test performance and physiological responses

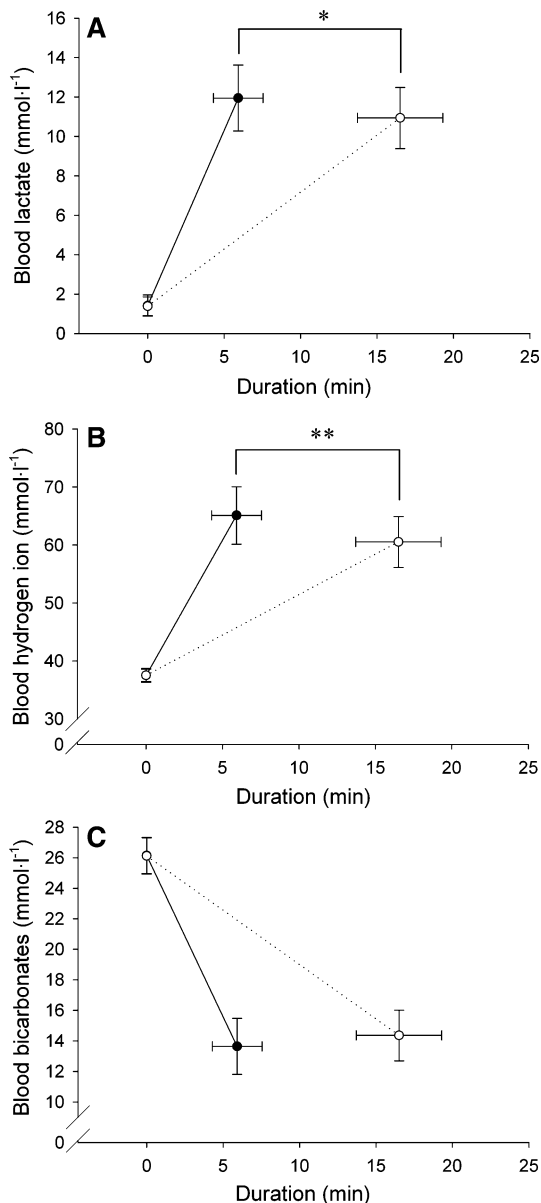
No significant interactions were found between the type of Yo-Yo test performed and the competitive level of soccer players ( $p = 0.401$ ) for any of the variables investigated. Differences and relative effect sizes in performance and maximum heart rate recorded during the Yo-Yo intermittent recovery tests between professional and amateur soccer players are presented in Table 1. The distance covered in Yo-YoIR1 and in Yo-YoIR2 was significantly higher for professional soccer players compared to amateur soccer players ( $2231 \pm 294$  vs.  $1827 \pm 292$  m,  $p = 0.002$ ,  $d = 1.14$  and  $958 \pm 99$  vs.  $613 \pm 125$  m,  $p < 0.001$ ,  $d = 1.66$ , respectively). Maximum heart rate (absolute and percent of HR treadmill peak) was not different between professional and amateur soccer players ( $p = 0.978$ ) or between Yo-YoIR1 and Yo-YoIR2 ( $p = 0.151$ ).

Blood  $La^-$ ,  $H^+$  and  $HCO_3^-$  before and after Yo-YoIR1 and Yo-YoIR2 are shown in Fig. 2. There were significant interactions between the type of Yo-Yo test performed and the sample time for blood  $La^-$  ( $p = 0.001$ ) and for blood  $H^+$  ( $p < 0.001$ ), whilst no interactions were found for the competitive level of soccer players for blood  $La^-$  ( $p = 0.569$ ) or blood  $H^+$  ( $p = 0.875$ ). In fact, blood  $La^-$

**Table 1** Differences between professional and amateur soccer players in performance and peak heart rate ( $HR_{peak}$ ) recorded during Yo-Yo intermittent recovery test level 1 (Yo-YoIR1) and level 2 (Yo-YoIR2)

	Yo-Yo intermittent recovery test level 1 (Yo-YoIR1)				Yo-Yo intermittent recovery test level 2 (Yo-YoIR2)					
	Professional ( <i>N</i> = 13)	Amateur ( <i>N</i> = 12)	<i>p</i> value	<i>d</i>	Professional ( <i>N</i> = 13)	Amateur ( <i>N</i> = 12)	<i>p</i> value	<i>d</i>		
Distance covered (m)	2231 ± 294	1827 ± 292	0.002	1.14	Medium	958 ± 99	613 ± 125	<0.001	1.66	Large
Test duration (min)	18.0 ± 2.3	15.6 ± 2.3	0.002	0.87	Medium	7.2 ± 0.8	5.2 ± 1.0	<0.001	1.23	Large
$HR_{peak}$ (bpm)	188 ± 5	191 ± 8	0.302	0.42	Small	189 ± 6	189 ± 7	0.904	0.05	Trivial
$HR_{peak}$ (% of $HR_{peak}$ treadmill)	99.2 ± 1.4	99.9 ± 1.4	0.240	0.48	Small	99.4 ± 1.7	98.8 ± 1.7	0.347	0.38	Small

*d* effect size



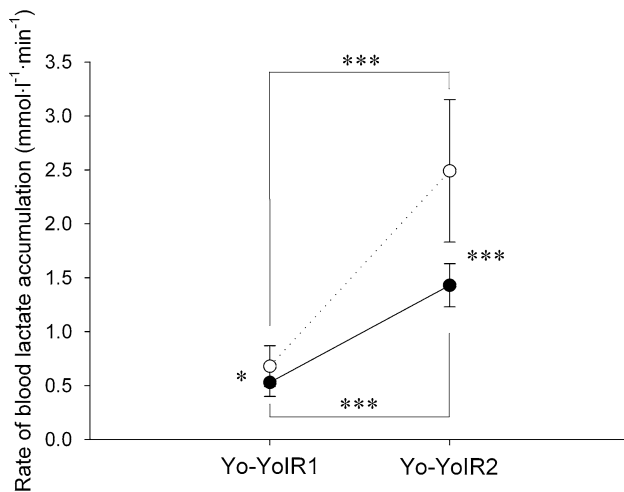
**Fig. 2** Blood lactate (a), blood hydrogen ion (b) and blood bicarbonates (c) before and after Yo-YoIR1 (open symbols) and Yo-YoIR2 (filled symbols) in 25 soccer players. \* $p = 0.032$ , significant difference between Yo-YoIR1 and Yo-YoIR2;  $d = 0.60$ . \*\* $p = 0.001$ , significant difference between Yo-YoIR1 and Yo-YoIR2;  $d = 0.88$

and blood  $H^+$  were higher after Yo-YoIR2 compared with the values measured after Yo-YoIR1 ( $12.0 \pm 1.7$  vs.  $10.9 \pm 1.5$   $mmol\ l^{-1}$ ,  $p = 0.032$ ,  $d = 0.60$  and  $65.1 \pm 4.9$  vs.  $60.5 \pm 4.4$   $mmol\ l^{-1}$ ,  $p = 0.001$ ,  $d = 0.88$ , respectively). No interaction was found for blood  $HCO_3^-$  between the type of Yo-Yo test performed, time of sample and competitive level of soccer players ( $p = 0.163$ ). Blood  $HCO_3^-$  was significantly lower after both Yo-Yo tests compared with the pre-exercise value ( $p < 0.001$ ) but no significant difference was found between Yo-YoIR1 and Yo-YoIR2 ( $14.4 \pm 1.7$  vs.  $13.6 \pm 1.8$   $mmol\ l^{-1}$ ,  $p = 0.065$ ,  $d = 0.41$ ).

As shown in Fig. 3, a significant interaction was found for the rate of blood  $La^-$  accumulation between the type of Yo-Yo test performed and the competitive level of soccer players ( $p < 0.001$ ). In Yo-YoIR1, the rate of blood  $La^-$  accumulation was greater for amateur soccer players than professional soccer players ( $0.68 \pm 0.19$  vs.  $0.53 \pm 0.13$   $mmol\ l^{-1}\ min^{-1}$ ,  $p = 0.035$ ,  $d = 0.83$ ). The rate of blood  $La^-$  accumulation was greater in Yo-YoIR2 compared with Yo-YoIR1 ( $p < 0.001$ ,  $d = 1.61$ ) and the difference between professional and amateur players was higher ( $2.49 \pm 0.66$  vs.  $1.43 \pm 0.20$   $mmol\ l^{-1}\ min^{-1}$ ,  $p < 0.001$ ,  $d = 1.49$ ).

#### Relationships between Yo-Yo intermittent recovery test performance and selected physiological determinants

The correlation coefficients between Yo-Yo intermittent recovery test performance (Yo-YoIR1 and Yo-YoIR2) and selected physiological determinants are presented in Table 2. All parameters measured during HIT were significantly related to the distance covered in Yo-YoIR1. Correlations were very large for blood  $La^-$ ,  $H^+$  and  $HCO_3^-$  measured after the test ( $r = -0.82$ ,  $-0.81$  and  $0.73$ , respectively, all  $p < 0.05$ ), large for RPE ( $r = -0.62$ ,  $p < 0.05$ ) and only moderate for mean heart rate measured during HIT ( $r = -0.50$ ,  $p < 0.05$ ). Performance in Yo-YoIR2 was significantly related to the same parameters measured during and after HIT (from large to very large,  $r = -0.66$  to  $-0.79$ , all  $p < 0.05$ ) with the exception of



**Fig. 3** Rate of blood lactate accumulation in professional (open symbols) and amateur (filled symbols) soccer players during Yo-YoIR1 and Yo-YoIR2. \* $p = 0.035$ , significant difference; \*\*\* $p < 0.001$ , significant difference. Between professional and amateur soccer players in Yo-YoIR1,  $d = 0.83$ . Between professional and amateur soccer players in Yo-YoIR2,  $d = 1.49$ . Between Yo-YoIR1 and Yo-YoIR2 in professional soccer players,  $d = 1.84$ . Between Yo-YoIR1 and Yo-YoIR2 in amateur soccer players,  $d = 1.74$

mean heart rate ( $r = -0.21$ ,  $p > 0.05$ ). The correlation between  $\dot{V}O_{2\max}$  and Yo-YoIR1 was significant and very large ( $r = 0.74$ ,  $p < 0.05$ ), whereas whilst still significant, the correlation with Yo-YoIR2 was only moderate ( $r = 0.47$ ,  $p < 0.05$ ). Amplitude was not significantly related to Yo-YoIR1 and Yo-YoIR2 ( $r = 0.17$  and  $-0.06$ , respectively,  $p > 0.05$ ), whilst  $\tau$  was significantly related to distance covered in both Yo-YoIR1 and Yo-YoIR2 and with large correlations ( $r = -0.60$  and  $-0.65$ , respectively,  $p < 0.05$ ).

### Differences between professional and amateur soccer players in selected physiological determinants

Blood  $La^-$ ,  $H^+$  and  $HCO_3^-$  before and after the HIT are shown in Fig. 4. Blood  $La^-$  and blood  $H^+$  measured after HIT were lower in professional soccer players compared to amateur players ( $8.4 \pm 2.0$  vs.  $5.7 \pm 1.4$   $mmol\ l^{-1}$ ,  $p = 0.001$ ,  $d = 1.24$  and  $52.1 \pm 5.1$  vs.  $46.6 \pm 3.3$   $mmol\ l^{-1}$ ,  $p = 0.003$ ,  $d = 1.10$ , respectively), whereas blood  $HCO_3^-$  after HIT in professional players was higher than in amateurs ( $20.1 \pm 2.1$  vs.  $17.7 \pm 1.6$   $mmol\ l^{-1}$ ,  $p = 0.004$ ,  $d = 1.09$ ). The rate of blood  $La^-$  accumulation during HIT as well as the RPE for the same intermittent test (Table 3) was significantly lower for professional players compared with amateur athletes ( $p = 0.001$ ,  $d = 1.20$  and  $p < 0.001$ ,  $d = 1.30$ , respectively). No significant difference was found in mean heart rate during HIT between the two groups ( $p = 0.867$ ,  $d = 0.07$ ). From the cardiorespiratory measurements displayed in Table 3, only  $\tau$  of the  $\dot{V}O_2$  kinetics was significantly faster for professional players ( $p = 0.011$ ,  $d = 0.98$ ). No significant differences were found in  $\dot{V}O_{2\max}$  and amplitude values ( $p = 0.188$ ,  $d = 0.53$  and  $p = 0.944$ ,  $d = 0.03$ , respectively).

### Discussion

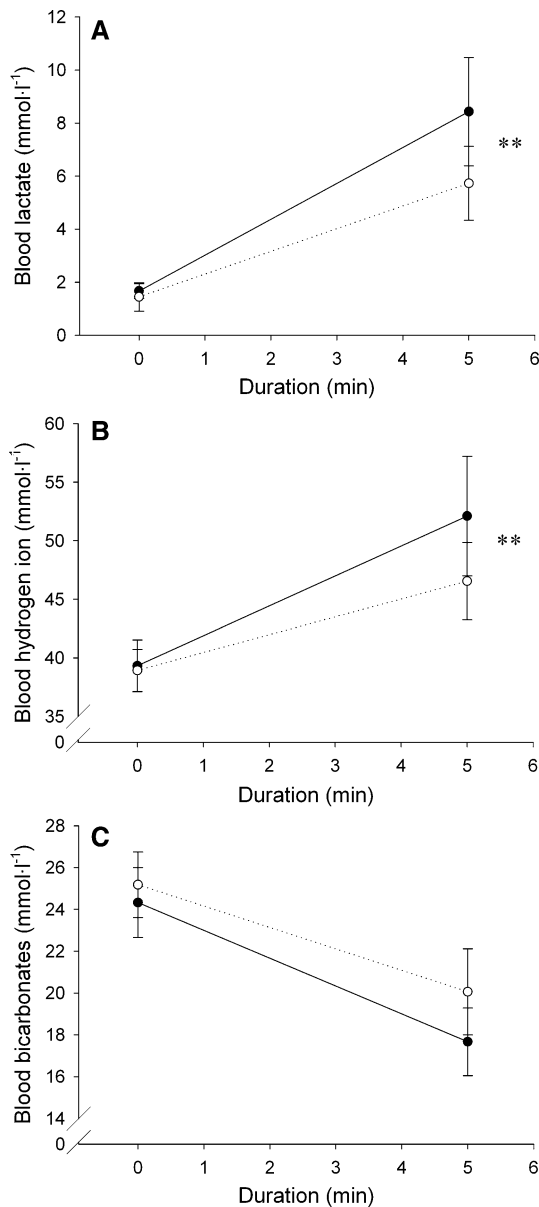
The main finding of this study was that, amongst soccer players, the physiological determinants of Yo-YoIR1 and Yo-YoIR2 are different. In addition, Yo-Yo test performance along with the physiological responses to HIT and the  $\tau$  of the  $\dot{V}O_2$  kinetics are all useful parameters to distinguish between professional and amateur soccer players.

**Table 2** Correlation coefficients between Yo-Yo intermittent recovery tests performance level 1 (Yo-YoIR1) and level 2 (Yo-YoIR2) and (1) physiological responses to high-intensity intermittent test (HIT) and (2) aerobic parameters

	Yo-YoIR1 (m)			Yo-YoIR2 (m)		
	$r$	CI 90%	Descriptors	$r$	CI 90%	Descriptors
HIT <sub>La<sup>-</sup></sub> (mmol l <sup>-1</sup> )	-0.82*	(-0.91 to -0.67)	Very large	-0.75*	(-0.87 to -0.55)	Very large
HIT <sub>H<sup>+</sup></sub> (mmol l <sup>-1</sup> )	-0.81*	(-0.90 to -0.65)	Very large	-0.79*	(-0.89 to -0.62)	Very large
HIT <sub>HCO<sub>3</sub><sup>-</sup></sub> (mmol l <sup>-1</sup> )	0.73*	(0.52–0.86)	Very large	0.70*	(0.48–0.84)	Large
HIT La <sup>-</sup> rate (mmol l <sup>-1</sup> min <sup>-1</sup> )	-0.82*	(-0.91 to -0.67)	Very large	-0.74*	(-0.86 to -0.54)	Very large
HIT <sub>HRmean</sub> (% of max)	-0.50*	(-0.72 to -0.20)	Moderate	-0.21	(-0.51 to 0.14)	Small
HIT <sub>RPE</sub> (CR10)	-0.62*	(-0.79 to -0.36)	Large	-0.66*	(-0.82 to -0.42)	Large
$\dot{V}O_{2\max}$ (ml kg <sup>-1</sup> min <sup>-1</sup> )	0.74*	(0.54–0.86)	Very large	0.47*	(0.16–0.70)	Moderate
Amplitude (ml min <sup>-1</sup> )	0.17	(-0.18 to 0.48)	Small	-0.06	(-0.39 to 0.28)	Trivial
$\tau$ (s)	-0.60*	(-0.78 to -0.33)	Large	-0.65*	(-0.81 to -0.40)	Large

(HIT<sub>La<sup>-</sup></sub>, HIT<sub>H<sup>+</sup></sub> and HIT<sub>HCO<sub>3</sub><sup>-</sup></sub>, blood lactate, hydrogen ion and bicarbonates after HIT; HIT La<sup>-</sup> rate, rate of blood lactate accumulation during HIT; HIT<sub>HRmean</sub>, mean heart rate during HIT; HIT<sub>RPE</sub>, rating perceived exertion after HIT;  $\dot{V}O_{2\max}$ , maximum oxygen uptake;  $\tau$  time constant of  $\dot{V}O_2$  kinetics

\*  $p < 0.05$ , for the classification of the magnitude descriptors of correlations (see text)



**Fig. 4** Blood lactate (a), blood hydrogen ion (b) and blood bicarbonates (c) before and after the high-intensity intermittent test (HIT) in professional (open symbols) and amateur (filled symbols) soccer players.  $**p < 0.01$ , significant difference between professional and amateur soccer players. Between professional and amateur soccer players in blood lactate,  $d = 1.24$ . Between professional and amateur soccer players in blood hydrogen ion,  $d = 1.10$ . Between professional and amateur soccer players in blood bicarbonates,  $d = 1.09$

The present study is the first to describe the differences in physiological responses to Yo-YoIR1 and Yo-YoIR2 as well as the physiological determinants of these tests, using the same population. Similar to previous research (Krustrup et al. 2006a), both Yo-Yo tests succeeded in maximally taxing the player's aerobic metabolism and cardiovascular system. In fact, the maximum heart rates reached in Yo-YoIR1 and Yo-YoIR2 were similar to those achieved in

**Table 3** Differences between professional and amateur soccer players in (1) rate of blood lactate accumulation ( $\text{La}^-$  rate,  $\text{mmol l}^{-1} \text{min}^{-1}$ ), mean heart rate (% of max) and rating of perceived exertion (RPE, CR10) during the high-intensity intermittent test (HIT), (2) maximum oxygen uptake ( $\dot{V}\text{O}_{2\text{max}}$ ,  $\text{ml kg}^{-1} \text{min}^{-1}$ ) and (3) amplitude ( $\text{ml min}^{-1}$ ) and time constant ( $\tau$ , s) calculated during  $\dot{V}\text{O}_2$  kinetics test

	Professional ( $N = 12$ )	Amateur ( $N = 11$ )	$p$ value	$d$	
High-intensity intermittent test (HIT)					
$\text{La}^-$ rate ( $\text{mmol l}^{-1} \text{min}^{-1}$ )	$0.86 \pm 0.23$	$1.35 \pm 0.42$	0.001	1.20	Large
Mean heart rate (% of max)	$87.3 \pm 3.6$	$87.6 \pm 4.3$	0.867	0.07	Trivial
RPE (CR10)	$4.5 \pm 1.1$	$6.2 \pm 1.0$	<0.001	1.30	Large
Cardiorespiratory measurements					
$\dot{V}\text{O}_{2\text{max}}$ ( $\text{ml kg}^{-1} \text{min}^{-1}$ )	$58.5 \pm 3.8$	$56.3 \pm 4.3$	0.188	0.53	Small
Amplitude ( $\text{ml min}^{-1}$ )	$2519 \pm 202$	$2511 \pm 314$	0.944	0.03	Trivial
$\tau$ (s)	$27.2 \pm 3.3$	$32.3 \pm 5.7$	0.011	0.98	Medium

$d$  effect size

the incremental laboratory test. However, the anaerobic contribution to the task was greater in Yo-YoIR2 compared with Yo-YoIR1. Peak blood  $\text{La}^-$  and blood  $\text{H}^+$  as well as the rate of blood  $\text{La}^-$  accumulation during the second level of the Yo-Yo test were significantly higher than the values measured during and after Yo-YoIR1. In addition, the anaerobic contribution of amateur soccer players was more pronounced than for professional soccer players, as demonstrated by the rate of blood  $\text{La}^-$  accumulation during the tests.

Performance in Yo-YoIR1 was significantly related to the performance in Yo-YoIR2 ( $r = 0.70$ ,  $p < 0.05$ ); yet only 48% of the shared variance may explain the variation in these tests. In addition,  $\dot{V}\text{O}_{2\text{max}}$  was well correlated to Yo-YoIR1 performance, whilst the relationship with Yo-YoIR2 was only moderate. Similar results were obtained from analysis of the  $\dot{V}\text{O}_2$  data at the respiratory compensation point (data not shown). Our results support previous studies (Bangsbo et al. 2008) which suggest that physiological factors other than maximum aerobic power may be important for Yo-YoIR2 performance. For example, we found the time constant of  $\dot{V}\text{O}_2$  kinetics to be well correlated with performance in both Yo-Yo tests investigated. This finding suggests that the ability to quickly activate the aerobic system to support the intermittent exercise, and thereby reducing the anaerobic contribution, may be an important factor for delaying fatigue and improving performance.

The physiological response to a standardized high-intensity intermittent exercise test (in particular blood  $\text{La}^-$  and  $\text{H}^+$  measured after the HIT and the rate of  $\text{La}^-$  accumulation during HIT) was strongly related to both Yo-Yo performances. As a consequence, the ability to maintain acid–base balance during sub-maximal intermittent exercise

(i.e. non-exhaustive trial) was also important for performance in both tests. These results support the work of previous researchers who report a significant relationship between the level of blood  $\text{La}^-$  accumulation during the execution of the Yo-Yo tests and the final performance (Krustrup et al. 2003, 2006a). Mean heart rate (expressed as a percent of maximal heart rate) measured during HIT was only moderately related to Yo-YoIR1 performance and not to Yo-YoIR2 performance. Collectively, these results suggest that some anaerobic characteristics of soccer players may be evaluated using a sub-maximal protocol such as HIT. However, further research is needed to verify the relationship between the physiological responses to intermittent exercise (such as HIT) and actual physical soccer match performance (i.e. the relationship to high-intensity running distance during the match). Furthermore, the sensitivity of these parameters as indicators of fitness throughout a competitive season should also be investigated.

As hypothesized, and confirming the work of others (Bangsbo et al. 2008), the professional soccer players in the present study had a better performance in both Yo-Yo tests compared to their amateur counterparts. Similarly, the professionals demonstrated a lower physiological and perceptual response to standardized high-intensity intermittent exercise than the amateurs. Specifically, the professional soccer players were characterized by a lower blood  $\text{La}^-$ , lower  $\text{H}^+$  and higher  $\text{HCO}_3^-$  following HIT as well as a lower rate of blood  $\text{La}^-$  accumulation during HIT suggesting a lower anaerobic contribution to the test. The lower blood  $\text{H}^+$  and higher  $\text{HCO}_3^-$  may also reflect a greater buffering capacity of professional players compared to amateurs. Although it is well known that muscle pH is not the sole cause of fatigue during brief high-intensity exercise (Bangsbo et al. 2007), a low muscle pH has been shown to reduce muscle contractibility (Fabiato and Fabiato 1978; Metzger and Moss 1990; Westerblad et al. 2002) and to inhibit glycolytic activity (Hollidge-Horvat et al. 1999; Spriet 1991). These factors may provide some explanation for both the reduced ability to cope with the demands of HIT and the reduced Yo-Yo test performance shown in the amateur players.

The lower RPE reported by the professional soccer players during HIT supports the physiological data that indicated a lower internal stress during the standardized intermittent exercise bout. Notably, however, there was no difference in the mean heart rate (% of max) recorded during HIT between professional and amateur soccer players suggesting a low sensitivity of heart rate as an indicator of intermittent exercise intensity when a significant anaerobic contribution is required (Balsom et al. 1992).

$\dot{V}\text{O}_{2\text{max}}$  criteria were met by all the athletes involved in the study, and surprisingly the two groups of soccer players

showed a similar  $\dot{V}\text{O}_{2\text{max}}$  mean value. Furthermore,  $\dot{V}\text{O}_2$  at the respiratory compensation point was not different between the two groups (data not shown). Interestingly, the professional players demonstrated a faster time constant in  $\dot{V}\text{O}_2$  kinetics than the amateur players. These results are in contrast with previous research that has reported a different  $\dot{V}\text{O}_{2\text{max}}$  in soccer players of higher playing levels (Stolen et al. 2005). However, it has been previously suggested that  $\dot{V}\text{O}_{2\text{max}}$  may not be the most suitable indicator of aerobic fitness for soccer players, since they train primarily for intermittent exercise rather than continuous work (Bangsbo et al. 2006, 2008; Drust et al. 2000; Kirkendall 2000; Krustrup et al. 2003). In addition, some authors (Demarle et al. 2001; Phillips et al. 1995) have reported that  $\tau$  is positively influenced by endurance training even when  $\dot{V}\text{O}_{2\text{max}}$  was unchanged. The present results provide further support to the reported benefits of faster  $\dot{V}\text{O}_2$  kinetics in soccer players (Dupont et al. 2005). Future studies should investigate methods for improving this capacity in soccer players.

In conclusion, professional soccer players performed better in both Yo-Yo tests than their amateur counterparts. Similarly, the physiological responses to HIT (blood  $\text{La}^-$ ,  $\text{H}^+$ ,  $\text{HCO}_3^-$  and RPE measured after HIT and the rate of  $\text{La}^-$  accumulation during HIT) and the  $\tau$  of the  $\dot{V}\text{O}_2$  kinetics were significantly different between the two groups of soccer players. The anaerobic contribution required for Yo-YoIR2 was greater than Yo-YoIR1. Furthermore, the physiological determinants of these two tests were different. More specifically,  $\dot{V}\text{O}_{2\text{max}}$  was more important for Yo-YoIR1 performance than Yo-YoIR2; however, the time constant of  $\dot{V}\text{O}_2$  kinetics was an important physiological quality for both tests. Moreover, the ability to maintain acid–base balance during intermittent exercise may also have contributed to good Yo-Yo performance. Our findings suggest that the use of both tests in fitness monitoring of soccer players is warranted, since performance in each test may be influenced by different adaptations to training. However, Yo-YoIR2 seems more appropriate when anaerobic training adaptations are to be evaluated.

**Acknowledgments** The authors would like to thank Andrea Bosio, Dott. Stefano Mazzoni and Aaron J. Coutts for their valuable suggestions, Andrea Morelli, Maurizio Fanchini, Ivan Ferraresi and Andrea Petruolo for their valuable support in the data collection and Laura Garvican for her English revision. The authors would also like to thank all the athletes involved in the study for their contribution.

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