Repeated-sprint ability in professional and amateur soccer players

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Abstract: This study investigated the repeated-sprint ability (RSA) physiological responses to a standardized, high-intensity, intermittent running test (HIT), maximal oxygen uptake ($VO_{2\ max}$), and oxygen uptake (VO_2) kinetics in male soccer players (professional (N = 12) and amateur (N = 11)) of different playing standards. The relationships between each of these factors and RSA performance were determined. Mean RSA time (RSA_{mean}) and RSA decrement were related to the physiological responses to HIT (blood lactate concentration ([La^-]), r = 0.66 and 0.77; blood bicarbonate concentration ([HCO_3^-]), r = –0.71 and –0.75; and blood hydrogen ion concentration ([H^+]),r = 0.61 and 0.73; all $p < 0.05$), $VO_{2\ max}$ (r = –0.45 and –0.65, $p < 0.05$), and time constant (τ) in VO_2 kinetics (r = 0.62 and 0.62, $p < 0.05$). $VO_{2\ max}$ was not different between playing standards (58.5 ± 4.0 vs. 56.3 ± 4.5 mL·kg^{-1}·min^{-1}; p = 0.227); however, the professional players demonstrated better RSA_{mean} (7.17 ± 0.09 vs. 7.41 ± 0.19 s; p = 0.001), lower [La^-] (5.7 ± 1.5 vs. 8.2 ± 2.2 mmol·L^{-1}; p = 0.004), lower [H^+] (46.5 ± 5.3 vs. 52.2 ± 3.4 mmol·L^{-1}; p = 0.007), and higher [HCO_3^-] (20.1 ± 2.1 vs. 17.7 ± 1.7 mmol·L^{-1}; p = 0.006) after the HIT, and a shorter τ in VO_2 kinetics (27.2 ± 3.5 vs. 32.3 ± 6.0 s; p = 0.019). These results show that RSA performance, the physiological response to the HIT, and τ differentiate between professional- and amateur-standard soccer players. Our results also show that RSA performance is related to $VO_{2\ max}$, τ, and selected physiological responses to a standardized, high-intensity, intermittent exercise.

Key words: high-intensity, sprint, performance, intermittent exercise, football, performance.

Résumé : Cette étude analyse l'aptitude à répéter un sprint (RSA) et les ajustements physiologiques au cours d'un test de course intermittente de forte intensité (HIT), au consommation d'oxygene maximale ($VO_{2\ max}$) et à la cinétique du consommation d'oxygene (VO_2) chez des joueurs de soccer professionnel (N = 12) et amateur (N = 11) de niveau différent. On évalue la relation entre ces variables et la performance au RSA. Le temps moyen consacré au RSA (RSA_{mean}) et la diminution de performance au RSA sont corrélés aux ajustements physiologiques au HIT ([La^-], r = 0,66 et 0,77; [HCO_3^-], r = –0,71 et –0,75; [H^+], r = 0,61 et 0,73; toutes à p < 0,05), au $VO_{2\ max}$ (r = –0,45 et –0,65, p < 0,05) et à la constante de temps (τ) dans la cinétique du VO_2 (r = 0,62 et 0,62, p < 0,05). Le $VO_{2\ max}$ ne varie pas en fonction du niveau de jeu (58,5 ± 4,0 mL·kg^{-1}·min^{-1} comparativement à 56,3 ± 4,5 mL·kg^{-1}·min^{-1}; p = 0,227). Cependant, les joueurs professionnels présentent une meilleure RSA_{mean} (7,17 ± 0,09 s comparativement à 7,41 ± 0,19 s; p = 0,001), un plus faible taux sanguin de lactate (5,7 ± 1,5 mmol·L^{-1} comparativement à 8,2 ± 2,2 mmol·L^{-1}; p = 0,004), une plus faible concentration sanguine d'ions d'hydrogène (46,5 ± 5,3 mmol·L^{-1} comparativement à 52,2 ± 3,4 mmol·L^{-1}; p = 0,007) et une plus forte concentration sanguine de bicarbonate (20,1 ± 2,1 mmol·L^{-1} comparativement à 17,7 ± 1,7 mmol·L^{-1}; p = 0,006) après le HIT et un plus bref τ en ce qui concerne la cinétique du VO_2 (27,2 ± 3,5 s comparativement à 32,3 ± 6,0 s; p = 0,019). D'après ces observations, les joueurs de soccer professionnel se démarquent des joueurs de soccer amateur en ce qui concerne la performance au RSA, les ajustements physiologiques au HIT et la τ. De plus, la performance au RSA est corrélée au $VO_{2\ max}$, à τ et à des variables données dans le test de course intermittente de forte intensité.

Mots-clés : forte intensité, sprint, performance, exercice intermittent, soccer.

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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). During match play, players change activity on average every 5 s and perform approximately 1300 actions, with 200 of these being completed at high intensity (Bangsbo et al. 2006). Additionally, many decisive phases during a soccer match require players to exercise at high intensity (Bangsbo et al. 2006). Therefore, the capacity to cope with repeated bouts of high-intensity exercise during

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soccer matches is important for improved performance (Bangsbo 1994).

Repeated sprint efforts often occur during soccer matches. Rampinini et al. (2007) have shown that the repeated-sprint ability (RSA) of high-standard soccer players relates to important measures of in-match physical performance such as distance covered during very high-intensity running. At present, it seems that soccer players at higher standards of competition are better able to cope with high-intensity, intermittent exercise (Bangsbo et al. 2008; Mohr et al. 2003) or repeated sprint bouts (Impellizzeri et al. 2008). Therefore, it is important to establish the physiological characteristics associated with improved RSA and high-intensity, intermittent exercise because it could be useful for guiding the development of specific training interventions for high-standard soccer players.

It has been shown that RSA performance is influenced by several physiological factors, such as maximal oxygen uptake ($\dot{V}O_{2\,max}$) (Aziz et al. 2000; Bishop et al. 2003; Bishop and Spencer 2004; Hamilton et al. 1991; Tomlin and Wenger 2001), oxygen uptake ($\dot{V}O_2$) kinetics (Dupont et al. 2005), hydrogen ion (H^+) buffering capacity (Bishop and Edge 2006; Bishop and Spencer 2004), and muscle glycogen concentration (Balsom et al. 1999). Many other factors that facilitate oxidative energy production during repeated sprint efforts are also important for improved RSA performance. For example, concentration of aerobic enzymes, mitochondrial size and number (Holloszy and Coyle 1984), and capillary density (Andersen and Henriksson 1977) could all be important for repeated-effort, high-intensity, intermittent exercise. Moreover, it has been reported that the first sprint performance is negatively related to the decrement in performance during the RSA test (Bishop and Edge 2006; Bishop et al. 2003; Hamilton et al. 1991; Wadley and Le Rossignol 1998). As a consequence, it seems important to also control these variables, to allow for an appropriate evaluation of the physiological determinants of the RSA in soccer players. However, although there has been recent interest in the factors that are associated with improved RSA and high-intensity, intermittent exercise in team sport athletes, at present these factors are not understood fully.

Several authors have suggested that soccer players demonstrate specific adaptations to the intermittent, high-intensity running (Drust et al. 2000; Krustrup et al. 2003) that is common to soccer training. It is therefore important to evaluate the physiological responses to this specific exercise, to determine if these factors discriminate between different standard soccer players (Bangsbo et al. 2008). However, to date, no studies have investigated whether the ability to cope with high-intensity, intermittent running is an important discriminating factor between soccer players from different standards of competition. Furthermore, no studies have investigated whether this ability is correlated with RSA performance.

Therefore, the aims of this study were (*i*) to examine differences in RSA between professional- and amateur-standard soccer players; (*ii*) to examine differences between playing standard in the physiological factors that might be important for RSA; (*iii*) to verify the relationship between these factors and RSA; and (*iv*) to examine these relationships by controlling the effect of the first sprint on RSA performance. It was hypothesized that professional-standard soccer players would have higher RSA and a better physiological response to the high-intensity, intermittent running bout (lower blood lactate concentration ([La^-]) and H^+ accumulation and higher blood bicarbonate concentration ([HCO_3^-]). It was also hypothesized that higher RSA would be associated with higher $\dot{V}O_{2\,max}$ and faster $\dot{V}O_2$ kinetics.

Materials and methods

Participants and study design

Soccer players from a third-division professional team (N = 12, 3 centre defenders, 4 midfielders, 3 fullbacks, and 2 attackers; age 25 ± 4 years, body mass 73.9 ± 4.5 kg, stature 180 ± 3 cm) and a sixth-division amateur soccer team (N = 11, 3 central defenders, 3 midfielders, 3 fullbacks, and 2 attackers; age 26 ± 6 years, body mass 70.6 ± 7.5 kg, stature 177 ± 5 cm) were involved in the study. The professional soccer players usually trained 6 times per week and took part in an official match, whereas the amateur soccer players usually trained 3 times per week and took part in an official match.

The participants completed 4 different tests ($\dot{V}O_{2\,max}$ test; RSA test; high-intensity, intermittent running test (HIT); and $\dot{V}O_2$ kinetics assessment) during 3 visits, each at the same time of the day during the competitive season. All the tests were separated by at least 48 h and were completed within 2 weeks. The first test was an incremental test on the treadmill to determine $\dot{V}O_{2\,max}$, peak speed, and maximal heart rate (HR_{max}). The second test was an RSA test performed on an outdoor grassed field (Rampinini et al. 2007), and the third was a HIT performed on the treadmill. Before the RSA and HIT tests, the players performed a 10-min run on the treadmill at 60% of the peak speed reached during the incremental test for the determination of the $\dot{V}O_2$ kinetics. The participants were instructed to consume their final meal at least 3 h before each test, to avoid drinking coffee or beverages containing caffeine for 8 h, and to avoid intense exercise for 24 h. The study 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.

Incremental treadmill test protocol

After a 10-min warm-up consisting of low-intensity running, $\dot{V}O_{2\,max}$ was determined using an incremental running test on a motorized treadmill (Saturn 4.0, h/p/Cosmos Sports and Medical Gmbh, Nussdorf-Traunstein, Germany) at an inclination of 4%. The test started at 10 km·h^{-1}, and the speed was increased by 1 km·h^{-1} every minute. Achievement of $\dot{V}O_{2\,max}$ was considered as the attainment of at least 2 of the following criteria (Howley et al. 1995): (*i*) a plateau in $\dot{V}O_2$ despite increasing speed (<80 mL·min^{-1}); (*ii*) a respiratory exchange ratio above 1.10; and (*iii*) a heart rate (HR) ± 10 beats·min^{-1} of age-predicted HR_{max} (220-age). Expired gases were analyzed using a breath-by-breath automated gas-analysis system (VMAX29, Sensormedics, Yorba Linda, Calif.). Flow and volume and gases were calibrated according to the manufacturer's recommendations before and immediately after each test. The HR was recorded every 5 s (Vantage NV, Polar Electro, Kempele, Finland).

RSA and sprint test protocol

Immediately after the 10-min warm-up, each player completed a single 40-m (20 m + 20 m) shuttle sprint test measured by a photocells system (Microgate, Bolzano, Italy). This sprint trial was used as the criterion score during the subsequent 6 × 40-m RSA sprint test (Rampinini et al. 2007). Participants were then rested for 5 min before the start of the RSA test. The RSA test consisted of six 40-m (20 m + 20 m) shuttle sprints separated by 20 s of passive recovery. This test was designed to measure both repeated-sprint and change-in-direction abilities. The athletes started from a line, sprinted for 20 m, touched a cone with a hand, and then returned to the starting line as fast as possible. After 20 s of passive recovery, the soccer player started again. Five seconds before the start of each sprint, participants assumed the start position and waited for the start signal. If performance in the first sprint of the RSA test was slower than the criterion score (i.e., an increase in time >2.5%), the test was ended and participants were required to repeat the RSA test with maximal effort after a further 5-min rest. The shortest time in a single sprint (RSA_{best}), mean time (RSA_{mean}), and percent decrement (RSA_{dec}) during the RSA test were determined according to Rampinini et al. (2007). The RSA and sprint tests were completed on an outdoor grassed surface during days without wind, and the air temperature ranged from 19 °C to 24 °C.

High-intensity, intermittent test protocol

During a 10 min warm-up, the soccer players completed three 10-s bouts at 14, 16, and 18 $km \cdot h^{-1}$ with 20 s of walk recovery (at 5 $km \cdot h^{-1}$) between each bout. After the warm-up, the soccer players completed a HIT protocol consisting of 10 × 10 s of running at 18 $km \cdot h^{-1}$ with 20 s of walking recovery at 5 $km \cdot h^{-1}$ between each bout. The accelerations and the decelerations of the treadmill were very fast (~3.7 $m \cdot s^{-2}$). The time needed to change the treadmill speed during each stage of the test was ~1 s. The treadmill was inclined at 8% throughout. HR was recorded every 5 s throughout the test (Vantage NV). Immediately after the test, 100 μL capillary blood samples were drawn into heparinized capillary tubes and analyzed for blood hydrogen ion concentration ($[H^+]$) and $[HCO_3^-]$ using a calibrated emogas analyzer (GEM Premier 3000, Instrumentation Laboratory, Milan, Italy) with an Intelligent Quality Management System cartridge. Capillary blood samples (5 μL) were also analyzed for $[La^-]$ using a portable amperometric microvolume lactate analyzer (LactatePro, Arkray, Kyoto, Japan). The perceived exertion relative to the HIT was also recorded using Borg's CR10 scale (Borg 1998) immediately upon finishing the test. All the athletes had been habituated to this scale before the start of the study and followed standardized instructions for rating perceived exertion (Borg 1998).

$\dot{V}O_2$ kinetics

The $\dot{V}O_2$ kinetics were calculated from two 10-min runs at 60% of peak speed reached during the incremental test (Dupont et al. 2005). Breath-by-breath $\dot{V}O_2$ data were measured using a calibrated automated gas-analysis system (VMAX29, Sensormedics). Raw $\dot{V}O_2$ data were linearly interpolated to yield $\dot{V}O_2$ values for every second during the test. Data from the 2 trials were time aligned and averaged for each subject. To determine the time constant (τ), the first 20-s data from the beginning of the exercise were excluded from the analysis to eliminate the cardiodynamic phase, whereas the remaining data were fitted using a monoexponential function:

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

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, δ is the time delay, and τ is the time constant.

Statistical analyses

Verification of underlying assumptions for each statistical procedure was conducted prior to analysis. The unpaired t test was used for the comparisons between professional and amateur soccer players in $\dot{V}O_{2\,max}$, RSA test performance (RSA_{best}, RSA_{mean}, and RSA_{dec}), physiological responses during HIT, and $\dot{V}O_2$ kinetics. The effect sizes (d) were also determined, as (mean value trial 2 – mean value of trial 1)/pooled standard deviation(SD), and were classified as small, moderate, and large for values of 0.2, 0.5, and 0.8, respectively. The relationships between $\dot{V}O_{2\,max}$, physiological responses during HIT, $\dot{V}O_2$ kinetics, and RSA test performance were calculated using the Pearson's product moment correlation coefficient (r). To control the influence of the initial sprint performance on the RSA_{dec}, the correlations between physiological variables and RSA_{dec} were also re-examined using the semipartial correlations, adjusting for the influence of the initial sprint performance. Confidence intervals (90%) for correlations were calculated. The magnitude of the correlations was also determined using the modified scale by Hopkins (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 $p < 0.05$. In the multiple comparisons between professional and amateur players, the Bonferroni procedure for controlling the type I error rate was used. The resulting criterion α level for this analysis was $p < 0.017$. All data are presented as means ± SD.

Results

Differences and effect sizes in the physiological and performance measures between professional and amateur soccer players are presented in Table 1. The RSA_{mean} was lower (7.17 ± 0.09 vs. 7.41 ± 0.19, –3.2%) for professional soccer players than for amateur soccer players ($p = 0.001$) and the effect size was large. The differences in the RSA_{best} and RSA_{dec} between the 2 groups of soccer players approached significance ($p = 0.075$ and $p = 0.064$, respectively) with moderate effects sizes. With the exclusion of the mean HR (% HR_{max}) recorded during HIT, all the physiological responses ($[H^+]$, $[HCO_3^-]$, and $[La^-]$) measured at the end of the HIT and the rating of perceived exertion (RPE) of the intermittent test were significantly different between profes-

Table 1. Differences between professional and amateur soccer players in performance measures from the repeated-sprint ability test, physiological responses during high-intensity, intermittent test, and cardiorespiratory measurements.

	Professional (N = 12)	Amateur (N = 11)	p value	d value
RSA				
RSA_{best} (s)	6.86±0.13	6.97±0.15	0.075	0.74 (moderate)
RSA_{mean} (s)	7.17±0.09	7.41±0.19	0.001	1.30 (large)
RSA_{dec} (%)	4.5±1.9	6.0±1.9	0.064	0.77 (moderate)
HIT				
$HIT_{[H^+]}$ (mmol·L^{-1})	46.5±5.3	52.2±3.4	0.007	1.06 (large)
$HIT_{[HCO3-]}$ (mmol·L^{-1})	20.1±2.1	17.7±1.7	0.006	1.09 (large)
$HIT_{[La^-]}$ (mmol·L^{-1})	5.7±1.5	8.2±2.2	0.004	1.13 (large)
HIT_{HRmean} (% of max)	87.4±3.8	87.6±4.5	0.887	0.06 (trivial)
HIT_{RPE} (CR10)	4.4±0.7	6.4±1.0	<0.001	1.48 (large)
Cardiorespiratory measurements				
$\dot{V}O_{2\ max}$ (mL·kg^{-1}·min^{-1})	58.5 ±4.0	56.3 ±4.5	0.227	0.51 (moderate)
Amplitude (mL·min^{-1})	2519 ±211	2511 ±329	0.949	0.03 (trivial)
τ (s)	27.2 ±3.5	32.3 ±6.0	0.019	0.95 (large)

Note: d, effect size; RSA, repeated-sprint ability; dec, decrement; HIT, high-intensity, intermittent test; [H$^+$], blood hydrogen ion concentration; [HCO_3^-], blood bicarbonate concentration; [La$^-$], blood lactate concentration; HRmean, mean heart rate; RPE, rating of perceived exertion; $\dot{V}O_{2\ max}$, maximal oxygen uptake; τ, time constant.

sional and amateur soccer players (all $p < 0.008$; all effect sizes were large). For professional players, [H$^+$] and [La$^-$] were 10.9% and 30.5% lower, whereas [HCO_3^-] was 13.6% higher and RPE was 31.3% lower. The $\dot{V}O_{2\ max}$ and the amplitude calculated in the 2 submaximal tests at 60% of the peak speed were not significantly different between the 2 groups of athletes (all $p > 0.226$), whereas effect size was moderate for $\dot{V}O_{2\ max}$ and trivial for amplitude. The difference in the time constant between professional and amateur players was very close to significance (p = 0.019) and the effect size was large.

Correlations between RSA test performance and physiological responses during HIT, $\dot{V}O_{2\ max}$, and τ are presented in Table 2. None of the variables measured were significantly related to RSA_{best} time and the correlations ranged from trivial to small (r between 0.01 and 0.14). The RSA_{mean} was significantly related to physiological responses during HIT (r = 0.61 with [H$^+$], r = –0.71 with [HCO_3^-], and r = 0.66 with [La$^-$], all $p < 0.05$). RSA_{mean} was also significantly related to $\dot{V}O_{2\ max}$ and to τ (r = –0.45 and r = 0.62, respectively). Table 2 shows that the correlations with the RSA_{mean} were very large for [HCO_3^-] (large to very large), large for [La$^-$], [H$^+$], and τ (moderate to very large), and moderate for $\dot{V}O_{2\ max}$ (small to very large). The RSA_{dec} was related to physiological responses during HIT (r = 0.73 with [H$^+$], r = –0.75 with [HCO_3^-], and r = 0.77 with [La$^-$], all $p <$ 0.05), to $\dot{V}O_{2\ max}$ (r = –0.65, $p < 0.05$), and to τ (r = 0.62, $p < 0.05$) (Table 2). The correlations with RSA_{dec} were very large for physiological responses ([H$^+$], [HCO_3^-], and [La$^-$]) during HIT (large to nearly perfect) and large for $\dot{V}O_{2\ max}$ and τ (moderate to very large).

The semipartial correlations (controlling for the effect of the RSA_{best} on RSA_{dec}), between the RSA_{dec} and physiological responses during HIT, $\dot{V}O_{2\ max}$, and τ are shown in Table 1. The correlation was very large for [H$^+$] (r = 0.77, $p <$ 0.05), [HCO_3^-] (r = –0.83, $p < 0.05$), and [La$^-$] (r = 0.81, $p < 0.05$) measured after the HIT (large to nearly perfect), was very large (r = 0.70, $p < 0.05$) for τ (large to very large), and was large (r = –0.66, $p < 0.05$) for $\dot{V}O_{2\ max}$ (moderate to very large). No relationship was found between the % HR_{max} during the HIT, the amplitude of $\dot{V}O_2$ above baseline values, and performance indices in the RSA test ($r < 0.36$, $p > 0.05$).

Discussion

In agreement with our initial hypotheses, the findings of this study show that RSA_{mean} and physiological responses to standardized, high-intensity, intermittent exercise distinguish between the professional- and amateur-standard soccer players with similar $\dot{V}O_{2\ max}$. The professional-standard soccer players also tended to have shorter RSA_{best} and lower RSA_{dec} than the amateur players (p = 0.075 and p = 0.064 for RSA_{best} and RSA_{dec}, respectively). Our results also show that RSA performance (RSA_{mean} and RSA_{dec}) is related to $\dot{V}O_{2\ max}$, τ, and selected physiological responses to a standardized, high-intensity, intermittent exercise. Collectively, these results suggest that good RSA, faster $\dot{V}O_2$ kinetics, and the ability to buffer [H$^+$] during high-intensity, intermittent activity are important characteristics for soccer players.

The present results show that despite having similar $\dot{V}O_{2\ max}$, the professional-standard soccer players have a lower physiological and perceptual response to the standardized HIT than their amateur counterparts. Indeed, the professional-standard players had lower [La$^-$], lower [H$^+$], and higher [HCO_3^-] responses to the HIT, suggesting a lower anaerobic contribution and (or) a better buffering capacity. Although it is well known that muscle pH is not the only cause of fatigue during brief, high-intensity exercise (Bangsbo et al. 2007; Westerblad et al. 2002), a low muscle

Table 2. Correlation coefficients between repeated-sprint ability test scores (RSA_{best}, RSA_{mean}, and RSA_{dec}) and physiological responses to high-intensity, intermittent test and cardiorespiratory measurements (N = 23).

	$HIT_{[H^+]}$ (mmol·L^{-1})	$HIT_{[HCO_3^-]}$ (mmol·L^{-1})	$HIT_{[La^-]}$ (mmol·L^{-1})	$\dot{V}O_{2\ max}$ (mL·kg^{-1}·min^{-1})	τ_1 (s)
Correlation coefficients					
RSA_{best} (s)	0.01 (–0.34 to 0.36)	0.12 (–0.24 to 0.45)	0.03 (–0.33 to 0.38)	0.09 (–0.27 to 0.43)	0.14 (–0.22 to 0.47)
RSA_{mean} (s)	0.61* (0.33 to 0.79)	–0.71* (0.48 to 0.85)	0.66* (0.40 to 0.82)	–0.45* (–0.12 to –0.69)	0.62* (0.34 to 0.80)
RSA_{dec} (%)	0.73* (0.51 to 0.86)	–0.75* (–0.54 to –0.87)	0.77* (0.57 to 0.88)	–0.65* (–0.39 to –0.82)	0.62* (0.34 to 0.80)
Semipartial correlations					
RSA_{dec} (%)	0.77* (0.57 to 0.88)	–0.83* (–0.68 to –0.91)	0.81* (0.64 to 0.90)	–0.66* (–0.40 to –0.82)	0.70* (0.46 to 0.84)

Note: Semipartial correlations using best sprint time in the repeated-sprint ability test as a controlled variable between repeated-sprint ability percent decrement and physiological responses during the high-intensity, intermittent test and cardiorespiratory measurements (N = 23). HIT, high-intensity, intermittent test; [H^+], blood hydrogen ion concentration; HCO_3^-, blood bicarbonate concentration; [La^-], blood lactate concentration; $\dot{V}O_{2\ max}$, maximal oxygen uptake; τ_1, time constant; RSA, repeated-sprint ability; dec, decrement.

*$p < 0.05$.

pH has been shown to reduce muscle contractibility (Metzger and Moss 1990) and to inhibit glycolytic activity (Hollidge-Horvat et al. 1999; Spriet 1991). These factors could provide some explanation for the reduced ability to cope with the HIT and the reduced RSA performance in the lower-standard players, and this, in turn, might be due to the lower training dose completed by this group or to the lower physical aptitude.

The lower RPE reported by the professional soccer players during HIT confirms the physiological data that demonstrated a lower internal stress. In contrast, however, there was no difference in the % HR_{max} recorded during HIT between the different-standard soccer players. The lower [La^-] and lower RPE, but similar HR response, to the HIT in the professional-standard players suggest that these players have a lower anaerobic contribution to high-intensity, intermittent exercise. However, caution should be taken when interpreting these data because the physiological measurements were performed in the blood and not in the muscle. Future invasive studies are needed to confirm these preliminary observations. These results also highlight that HR can be a poor marker of exercise intensity during very high-intensity, intermittent exercise that has a considerable anaerobic contribution.

A new finding from this study is that the professional-standard players demonstrated a shorter τ than the amateur-standard players, despite similar $\dot{V}O_{2\ max}$. The comparable $\dot{V}O_{2\ max}$ between the 2 playing standards in this study is in contrast to previous research that has shown increased $\dot{V}O_{2\ max}$ with higher playing standard (Stølen et al. 2005). However, others have suggested that, in agreement with the present findings, $\dot{V}O_{2\ max}$ might not be the most suitable indicator of aerobic fitness for soccer players because they train for intermittent, rather than continuous, exercise (Bangsbo et al. 2006, 2008; Drust et al. 2000; Krustrup et al. 2003). The present findings also show that the RSA has a stronger association with $\dot{V}O_2$ kinetics and the ability to tolerate metabolic acidosis than does $\dot{V}O_{2\ max}$. These results suggest that coaches should ensure that training programs concentrate on developing $\dot{V}O_2$ kinetics and [H^+] buffering when aiming to improve RSA in aerobically fit soccer players. As a consequence, high-intensity interval training would be recommended (Bailey et al. 2009; McKay et al. 2009) for soccer training to improve player performance. However, caution should be used in choosing the exercise intensity of training to avoid adverse effects on physiological adaptation (Bishop et al. 2008).

The present study showed that higher-standard soccer players benefit from faster $\dot{V}O_2$ kinetics. This new finding is supported by previous research that has shown that shorter τ is important for improved RSA (Dupont et al. 2005). Indeed, the improved τ in the professional-standard players could be advantageous for the metabolic adjustment of oxidative processes required when transitioning from rest to work that is common in soccer. It is possible that the improved $\dot{V}O_2$ kinetics in the professional-standard players in this study are related to their greater training requirements. Several studies have shown that training status influences $\dot{V}O_2$ kinetics in endurance athletes (Ingham et al. 2007; Koppo et al. 2004); however, few data are available on team sport athletes who complete high-intensity, intermittent exercise (Dupont et al. 2005). Therefore, it is recommended that soccer players train to improve $\dot{V}O_2$ kinetics. Previous studies have reported that repeated short-duration, high-intensity interval training with brief recovery periods between efforts may be effective methods for improving $\dot{V}O_2$ kinetics (Bailey et al. 2009; McKay et al. 2009).

The physiological measures taken in this study did not correlate with the best single 40-m sprint effort during the RSA test. These results suggest that single sprint performance in soccer players is influenced by physiological factors other than aerobic fitness and (or) buffering capacity. However, in agreement with our initial hypothesis, we observed moderate to large relationships between both RSA_{mean} and RSA_{dec} with the cardiorespiratory measurements and physiological responses during HIT. The correlation between $\dot{V}O_{2\ max}$ and RSA_{mean} was moderate, and was large between $\dot{V}O_{2\ max}$ and RSA_{dec}. These findings agree with those of other studies that have shown low, nonsignificant to moderate-strength correlations between $\dot{V}O_{2\ max}$ and RSA_{mean} performance (Aziz et al. 2000; Bishop and Edge 2006; Bishop et al. 2003; Bishop and Spencer 2004; McMahon and Wenger 1998) and suggest that physiological factors other than $\dot{V}O_{2\ max}$ are more important for improved RSA in trained soccer players.

Dupont et al. (2005) previously reported moderate relationships between τ with RSA_{mean} and RSA_{dec} from a generic RSA test consisting of fifteen 40 m sprints alternated with 25 s of active recovery. We have extended these findings and confirm that similar relationships exist between τ with RSA_{mean} and RSA_{dec} in a specific RSA test that has been shown to be a valid test of match-related physical performance in soccer (Rampinini et al. 2007). These results, combined with the present finding of shorter τ in the professional-standard players, indicate that $\dot{V}O_2$ kinetics may be an important physiological contributor to improved physical performance during intense periods of a soccer match.

It appears that the physiological factors underlying the reduced anaerobic contribution during the HIT could be important to improve RSA. In this study, moderate correlations were found between [La^-], [H^+], and [HCO_3^-] with RSA_{mean} and RSA_{dec}. These results show that players with a lower anaerobic contribution (i.e., lower [La^-], lower [H^+], and higher [HCO_3^-]) after the HIT are able to perform better during maximal exercise, such as the specific RSA test used in this study. In support of these results, others have also reported that the ability to buffer [H^+] is important for good RSA (Bishop and Spencer 2004). The semipartial correlation analysis (controlling for the influence of the first sprint on the decrement in the RSA test) increased the strength of the relationships between RSA_{dec} and cardiorespiratory and physiological measures after HIT. However, the physiological variables measured in this study only explained between 44% and 69% of the variance in $RSA_{dec.}$ These findings suggest that physiological factors other than those measured in this study may be important for RSA (e.g., strength and (or) neuromuscular characteristics) (Edge et al. 2006).

Conclusion

This study showed that the specific RSA test performance differentiates professional-standard soccer players from their amateur counterparts. Moreover, professional-standard soccer players demonstrate a different physiological response (i.e., lower [La^-], lower [H^+], and higher [HCO_3^-]) to a standardized, high-intensity, intermittent exercise and have faster $\dot{V}O_2$ kinetics than amateur soccer players with similar $\dot{V}O_{2\ max}$. In addition, results from the correlation analysis suggest that the physiological responses to intermittent exercise, τ, and $\dot{V}O_{2\ max}$ (to a lesser extent), are important determinants of RSA performance in soccer players, even when accounting for the effect of RSA_{best} on RSA_{dec}. Our findings suggest that to improve RSA, trained soccer players could benefit from training for better $\dot{V}O_2$ kinetics and improving the ability to tolerate metabolic acidosis during intense intermittent exercise, rather than training for greater $\dot{V}O_{2\ max}$. Further studies are needed to determine other physiologically important factors for RSA not investigated in this study, the effect of specific training (i.e., aerobic, anaerobic, and strength training) on these physiological determinants, and their consequent influence on RSA in soccer players.

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