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Sprint vs. Interval Training in Football

Authors

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Key words

- soccer
- aerobic power
- anaerobic training
- specific endurance

Abstract

▼
The aim of this study was to compare the effects of high-intensity aerobic interval and repeated-sprint ability (RSA) training on aerobic and anaerobic physiological variables in male football players. Forty-two participants were randomly assigned to either the interval training group (ITG, 4 × 4 min running at 90–95% of HR_{max}; n = 21) or repeated-sprint training group (RSG, 3 × 6 maximal shuttle sprints of 40 m; n = 21). The following outcomes were measured at baseline and after 7 weeks of training: maximum oxygen uptake, respiratory compensation point, football-specific endurance (Yo-Yo Intermittent Recovery Test, YYIRT), 10-m sprint time, jump

height and power, and RSA. Significant group × time interaction was found for YYIRT (p = 0.003) with RSG showing greater improvement (from 1917 ± 439 to 2455 ± 488 m) than ITG (from 1846 ± 329 to 2077 ± 300 m). Similarly, a significant interaction was found in RSA mean time (p = 0.006) with only the RSG group showing an improvement after training (from 7.53 ± 0.21 to 7.37 ± 0.17 s). No other group × time interactions were found. Significant pre-post changes were found for absolute and relative maximum oxygen uptake and respiratory compensation point (p < 0.05). These findings suggest that the RSA training protocol used in this study can be an effective training strategy for inducing aerobic and football-specific training adaptations.

Introduction

▼
Association football (soccer) is a physically demanding sport requiring the repetition of many diverse activities such as jogging, running and sprinting [5,33,42,45]. Match analysis studies have also demonstrated that football requires participants to repeatedly produce maximal or near maximal actions of short duration with brief recovery periods [40,45]. For these reasons, football training should commonly include physical exercises aimed to enhance both aerobic fitness and repeated-sprint ability (RSA).

A high aerobic fitness is reported to aid recovery during high-intensity intermittent exercise, typical of football performance and training [37]. Furthermore, the relevance of aerobic fitness for football players has also been confirmed by studies showing a relationship between aerobic power and competitive ranking [1], team level [44] and distance covered during a match [4,27]. Similarly, football-specific endurance, as measured using the Yo-Yo Intermittent Recovery Test (YYIRT), has been found to be related to the

amount of high-intensity activity completed during the match [27]. A study by Helgerud et al. [19] has also shown that high-intensity aerobic interval training is an effective training strategy for improving the aerobic fitness of football players with no negative effect on strength, power or sprint performance. Their results have been confirmed by Impellizzeri et al. [23] and McMillan et al. [32] who have shown that aerobic interval training, using both specific or generic exercises, is equally effective in enhancing aerobic fitness and football-specific endurance. Therefore, high-intensity aerobic interval training can be considered an effective training strategy for aerobic fitness development in football players.

RSA-based exercises are characterized by several sprints interspersed with brief recovery periods. Such exercise results in metabolic responses similar to those which occur during actual matches, such as a decrease in a muscle pH, phosphocreatine and ATP, activation of anaerobic glycolysis and a significant involvement of aerobic metabolism [36,40,46]. For this reason, the use of RSA-based exercises for the training and testing of

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team-sport athletes is increasing [40]. Various studies have shown that sprint training consisting of maximal or near-maximal short-term efforts (5 to 30 s) can produce improvements in the ability to repeat several sets of anaerobic exercise [8,11,30,34]. In addition, sprint training can also be effective in enhancing $\dot{V}O_{2\max}$ and aerobic enzyme activity [8,11,18,29,30,35,38]. Although most of the previous studies were conducted on sedentary or moderately-trained subjects (hence decreasing their external validity with respect to a highly trained population), these investigations support the effectiveness of sprint training for enhancing both the aerobic and anaerobic capacities.

A recent study [36] has established the construct validity of an RSA shuttle-running test (six 40-m shuttle sprints interspersed with 20 s of recovery) by demonstrating a moderate relationship between total time to complete the RSA test and high-intensity running distance during a football match. Indeed, these authors showed a significant correlation between the performance in this RSA test and sprinting or high-intensity running distance covered during official matches in professional football players. These significant correlations confirm that during this RSA test the physical capacities actually taxed during the high-intensity phases of a match are involved. Furthermore, as this test included shuttle sprints, the muscular contractions required for decelerating and to reaccelerate body mass may potentially be beneficial to improve muscular power and the ability to change direction [28]. Therefore, the RSA test protocol used by Rampinini et al. [36] could be considered an appropriate training exercise for football players.

To the authors' knowledge, no studies have compared the effects of aerobic interval training and RSA-based training in football players. Therefore, the aim of this study was to compare the changes induced by these two training modalities on aerobic power, football-specific endurance, sprint and jumping ability, and RSA. We hypothesized that compared to aerobic interval training, RSA training would induce similar positive changes in $\dot{V}O_{2\max}$ and football-specific endurance but greater improvements in jumping, sprinting and RSA.

Material and Methods

Subjects recruitment

Forty-two participants were recruited from the junior football players of a professional team ($n = 22$, age 17.3 ± 0.6 years, body mass 71 ± 5.6 kg, height 179.3 ± 4.8 cm, estimated body fat $9.3 \pm 2.7\%$) and the amateur players of a first category team ($n = 20$, age 24.3 ± 5.4 years, body mass 76.5 ± 5.4 kg, height 179.4 ± 4.8 cm, estimated body fat $11.0 \pm 3.8\%$). No differences were found in the baseline test results between the two teams (data not shown). In order to be included in the study subjects had to 1) participate in at least 90% of the training sessions, 2) have regularly competed during the previous competitive season, and 3) possess medical clearance. Goalkeepers were excluded from the study. All field tests were completed outdoors on a grass pitch with players wearing football boots. Baseline tests started at 6:00 p.m. ($\sim 25^\circ\text{C}$), while post-assessments were carried out one hour before ($\sim 17^\circ\text{C}$). Ambient temperatures in the laboratory were 22°C for the incremental tests and 25°C for the vertical jump tests, in both the pre- and posttest sessions. An informed consent signed by the subjects or by their parents was required prior to participation in the study. The study protocol was approved by the Independent Institutional Review Board of

MAPEI Sport Research Center according to the Guidelines and Recommendations for European Ethics Committees by the European Forum for Good Clinical Practice and by the football clubs involved.

Study design

A parallel, two-group, randomized, longitudinal (pretest-posttest), single-blind experimental design was used. After baseline measurements, subjects were randomly allocated to either the interval training group (ITG) or the RSA training group (RSG). A balanced, restricted randomization was obtained using blocks with an allocation ratio of one-to one [39]. As the independent variable was "training type", no control group was used. The study lasted 12 weeks (from September to December, starting after the first match of the competitive season) and consisted of two weeks of tests (pretest), seven weeks of specific training (twice per week), one week of tapering and two weeks of tests (posttest). No additional strength, power and/or plyometric training was completed.

Training programs

During the competitive season players trained three to four times a week with sessions of ~ 90 min duration. Twice a week, part of the training was devoted to the training intervention. The experimental training sessions were never performed on two consecutive days. For ITG, the high-intensity aerobic interval training consisted of 4 sets of 4 min running at 90–95% of HR_{\max} (~ 4000 m per session without recovery), and with 3 min of active recovery at 60 to 70% of HR_{\max} , according to the protocol of Helgerud et al. [19]. HR was controlled using short-range telemetry systems (Vantage NV, XTrainer, S610 and S710 models, Polar, Kempele, Finland). For RSG, the training consisted of 3 sets of 6 40-m maximal shuttle sprints (~ 720 m per session without recovery) with 20 s of passive recovery between sprints and 4 min of passive recovery between sets. The shuttle sprints consisted of all-out sprints (40 m) with 180° direction change every 10 (first 3 training weeks) or every 20 m (remaining 4 weeks).

Training outcomes

Before and after the training period, subjects performed three testing sessions in the same order: two sessions for the field tests (separated by at least 2 days) in the first week, and one session for the laboratory tests in the second week. The body mass, height, and body composition of the players were assessed using standard anthropometric techniques [24]. Before each testing session, subjects were instructed not to eat for at least three hours before testing and not to drink coffee or beverages containing caffeine for at least eight hours before physical testing. Tests were completed at the same time of the day, with the operators unaware of the subject's allocation.

Measurement of aerobic power and capacity

During the second week, $\dot{V}O_{2\max}$ was determined using an incremental running test on a motorized treadmill (Saturn 4.0, h/p/ Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany) at an inclination of 1%. After 3 min at $8 \text{ km}\cdot\text{h}^{-1}$, the test began at $9 \text{ km}\cdot\text{h}^{-1}$, and the velocity was increased by $1 \text{ km}\cdot\text{h}^{-1}$ every 1 min so that exhaustion was reached in 8–12 min. 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, 2) a respiratory exchange ratio above 1.10, and 3) a $HR \pm 10 \text{ beats}\cdot\text{min}^{-1}$ of age-predicted maximal HR ($220 -$

age) [20]. Expired gases were analyzed using a breath-by-breath automated gas-analysis system (VMAX29, Sensormedics, Yorba Linda, CA, USA). Before each test flow, volume and gases were calibrated according to the manufacturer's recommendations. The respiratory compensation point (RCP) was detected by combining three common methods for the determination of gas exchange thresholds as described by Gaskill et al. [15]: 1) ventilatory equivalent, 2) excess CO₂, and 3) V-slope method. Therefore, RCP was determined as the intensity corresponding to 1) an increase in both $\dot{V}_e/\dot{V}O_2$ and $\dot{V}_e/\dot{V}CO_2$, 2) the second sustained rise in excess CO₂, and 3) the second increase in the slope of $\dot{V}CO_2$ vs. $\dot{V}CO_2$ plot. RCP was detected by two independent experienced investigators. If the $\dot{V}O_2$ at the RCP determined by the two investigators was within 3%, the mean value of the two investigators was used. When the difference exceeded 3% a third experienced investigator was asked to determine RCP. The third value was then compared with those of the initial operators. If the value of the third operator was within 3% of either of the initial investigators, then those two values were averaged. The combination of these three detection methods for the gas exchange thresholds detection has been demonstrated to improve the accuracy and the reliability of their identification [15].

Football-specific endurance test

On the first testing day, players completed the level one version of the YYIRT [27]. All players were already familiar with the testing procedures as it was part of their usual fitness assessment program. The YYIRT consisted of 20-m shuttle runs performed at increasing velocities with 10 s of active recovery between runs until exhaustion. Audio cues of the YYIRT were recorded on a CD (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 unable to complete another shuttle at the dictated speed (subjective evaluation). The total distance covered during the YYIRT1 (including the last incomplete shuttle) was considered as the test score [3].

Vertical jumping

Countermovement (CMJ) and squat jumps (SJ) were measured 30 min before the treadmill-test protocol using a force platform (QuattroJump, Kisler, Winterthur, Switzerland). Subjects jogged for 10 min on a motorized treadmill before testing and then performed a self-administered submaximal CMJ (2–3 repetitions) as practice and additional specific warm-up. No stretching exercises were allowed prior to the test. Subjects were asked to keep their hands on their hips to prevent the influence of arm movements on vertical jump performance and to avoid the possibility of variations in coordination confounding this variable. Each subject performed at least five maximal CMJ and SJ starting from a standing position, with 2 min of recovery in-between. Players were asked to jump as high as possible. The mean jump height of the best three jumps was used for statistical analysis.

Sprint test

On the second testing day, after a 15-min warm-up of low-intensity running and striding followed by three submaximal 10-m sprints, players performed three maximal 10-m sprints (each separated by at least 2 min of recovery). Sprint times were recorded using a photocells system (Microgate, Bolzano, Italy) and the best sprint time was used for the statistical analyses.

Repeated-sprint ability shuttle test

In the same session, after about 45 min, subjects completed a 10-min re-warm-up of low-intensity running and striding, followed by three submaximal 40-m shuttle sprints (20 + 20 m). To measure RSA, we used a test consisting of six 40-m (20 + 20 m) sprints. The athletes started from a line, sprinted for 20 m, touched a line with a foot and then came back to the starting line as fast as possible. After 20 s of passive recovery, the football player restarted again. Each player completed a preliminary single shuttle sprint test using a photocells system (Microgate, Bolzano, Italy). This trial was used as the criterion score during the subsequent 6 × 40-m shuttle sprint test. After the first preliminary single shuttle sprint, subjects rested for 5 min before the start of the RSA test. If performance in the first sprint of the RSA test was worse than the criterion score (i.e., an increase in time greater than 2.5%), the test was immediately terminated and subjects were required to repeat the RSA test with maximum effort after a 5-min rest. Five seconds before the start of each sprint, subjects assumed the ready position and waited for the start signal. This test was designed to measure both repeated-sprint and change in direction abilities. The mean time (RSA_{mean}) and percent decrement (RSA_{dec}) during the RSA test were calculated [36]. The reliability (typical error expressed as a coefficient of variation) for the best shuttle sprint time, the mean time and percent decrement has been reported to be 1.3, 0.8 and 25.0%, respectively [14]. Despite the low reliability of the percent decrement, it was included in the statistical analysis because the intersubject variability was higher than for the other variables [14].

Statistical analysis

Data are reported as means ± standard deviation (SD). Before using parametric tests, the assumption of normality was verified using the Shapiro-Wilk W test. We tested the null hypothesis of no difference between groups in all baseline measures using multiple unpaired *t*-tests. The unpaired *t*-test was also used to assess differences between drop-outs and subjects included in the final analysis. A two-way mixed analysis of variance (ANOVA) was used on each continuous dependent variable. The independent variables included one between-subjects factor, training intervention, with two levels (ITG and RSG), and one within-subject factor, time, with two levels (pretest and post-test). We used these ANOVAs to test the null hypothesis of no difference in the change over time between ITG and RSG (training intervention × time interaction) groups and the null hypothesis of no difference in the change over time in response to the training intervention (main effect for time). To allow a better interpretation of the results, effect sizes were also calculated (eta squared, η^2). Values of 0.01, 0.06 and above 0.15 were considered small, medium and large, respectively [21]. Statistical analyses were performed using the software package SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). The level of statistical significance was set at $p \leq 0.05$.

Results



Subjects

Forty-two football players were randomly allocated to the two training groups. Sixteen of these subjects (~35% drop-outs) were excluded from the final analysis due to missed follow-up tests, injuries, illness or absence from more than 10% of the

Table 1 Effects of high-intensity aerobic interval training and repeated sprint training on aerobic fitness, jumping and sprinting abilities

Variables	Interval training group (n = 13)		Repeated sprint group (n = 13)		Inter- action p level	Effect size η^2
	Pre	Post	Pre	Post		
Aerobic fitness						
$\dot{V}O_{2max}$ (L·min ⁻¹)	3.94 ± 0.32	4.21 ± 0.42	3.99 ± 0.48	4.18 ± 0.56	0.404	0.029
$\dot{V}O_{2max}$ (mL·kg ⁻¹ ·min ⁻¹)	52.8 ± 3.2	56.3 ± 3.1	55.7 ± 2.3	58.5 ± 4.1	0.581	0.013
$\dot{V}O_{2max}$ (mL·kg ^{-0.75} ·min ⁻¹)	155.0 ± 7.8	165.4 ± 9.1	161.9 ± 7.9	169.9 ± 12.4	0.524	0.017
$\dot{V}O_2$ at RCP (L·min ⁻¹)	3.25 ± 0.27	3.39 ± 0.36	3.26 ± 0.34	3.35 ± 0.43	0.631	0.010
$\dot{V}O_2$ at RCP (mL·kg ⁻¹ ·min ⁻¹)	43.6 ± 3.3	45.2 ± 3.0	45.6 ± 3.2	46.9 ± 4.1	0.796	0.003
$\dot{V}O_2$ at RCP (mL·kg ^{-0.75} ·min ⁻¹)	127.9 ± 8.2	133.0 ± 8.9	132.4 ± 8.4	136.2 ± 11.5	0.749	0.004
Power measurements						
Countermovement jump height (cm)	48.5 ± 3.8	48.1 ± 3.8	46.1 ± 3.5	46.1 ± 3.0	0.567	0.014
Countermovement jump peak power (W·kg ⁻¹)	54.2 ± 5.0	54.4 ± 4.6	53.8 ± 4.6	55.0 ± 5.1	0.486	0.020
Squat jump height (cm)	41.9 ± 4.4	42.8 ± 3.6	40.7 ± 5.1	40.6 ± 3.1	0.457	0.023
Squat jump peak power (W·kg ⁻¹)	53.3 ± 4.7	53.7 ± 4.0	51.8 ± 5.7	53.4 ± 4.6	0.335	0.039
10-m sprint time (s)	1.77 ± 0.06	1.77 ± 0.06	1.77 ± 0.06	1.76 ± 0.06	0.458	0.023

$\dot{V}O_{2max}$: maximal oxygen uptake; RCP: respiratory compensation point. Values are mean ± standard deviation

training sessions. None of the injuries occurred during the experimental training or testing sessions. Thus, only 26 subjects (age 21.1 ± 5.1 years, body mass 73.2 ± 7.8 kg, height 178.6 ± 5.0 cm, estimated body fat 10.2 ± 3.2%), were included in the final analysis. The baseline characteristics of the drop-outs were not significantly different from those who completed the study (data not shown). No differences were found between the final training group for any of the baseline measures except for relative $\dot{V}O_{2max}$. The proportion of defenders, fullbacks, midfielders, attackers in ITG (4, 2, 4, and 3, respectively) and RSG (5, 3, 3, and 2, respectively) was similar. The proportion of starters and non-starters in ITG was not different from RSG. The mean ± SD and total time spent playing official matches for the duration of the study was 431 ± 240 and 5605 min for ITG, and 423 ± 248 and 5495 min for RSG, respectively (p = 0.93).

Aerobic fitness

No group × time interaction was found for $\dot{V}O_{2max}$ or RCP (Table 1), indicating no effect of training type on the selected parameters of aerobic fitness. $\dot{V}O_{2max}$ and $\dot{V}O_2$ at RCP significantly increased from pre to post by 5.9% (from 3.96 ± 0.40 to 4.20 ± 0.49 L·min⁻¹; p < 0.001; η^2 = 0.482), and 3.6% (3.25 ± 0.30 to 3.37 ± 0.41 L·min⁻¹; p < 0.028; η^2 = 0.186), respectively. $\dot{V}O_{2max}$ and $\dot{V}O_2$ at RCP scaled by body mass significantly increased from pre to post by 5.8% (from 54.3 ± 3.1 to 57.4 ± 3.7 mL·kg⁻¹·min⁻¹; p < 0.001; η^2 = 0.496), and 3.3% (44.6 ± 3.3 to 46.1 ± 3.6 mL·kg⁻¹·min⁻¹; p = 0.042; η^2 = 0.161), respectively. $\dot{V}O_{2max}$ and $\dot{V}O_2$ at RCP scaled by body mass raised to 0.75 significantly increased from pre to post by 5.8% (from 158.4 ± 8.5 to 167.6 ± 11.0 mL·kg^{-0.75}·min⁻¹; p < 0.001; η^2 = 0.495), and 3.4% (130.2 ± 8.5 to 134.5 ± 10.2 mL·kg^{-0.75}·min⁻¹; p = 0.038; η^2 = 0.168), respectively.

Since the baseline relative $\dot{V}O_{2max}$ values were different between the final training groups, an additional unplanned analysis was completed to control for the effect of pretraining $\dot{V}O_{2max}$. Therefore, we applied the analysis of covariance (ANCOVA) using the pretraining $\dot{V}O_{2max}$ values as covariate. These ANCOVAs confirmed the previous analysis. Indeed, no differences in post-values were found for absolute and relative $\dot{V}O_{2max}$ (p > 0.400).

Football-specific endurance

A significant group × time interaction was found in the YYIRT performance (p = 0.003; η^2 = 0.321) (Fig. 1). Post hoc analysis showed a greater increase in RSG (28.1%) compared to ITG (12.5%).

Effect on sprint and jump tests

No group × time interaction was found for jumping and sprinting performances (Table 1). Similarly, no pre to post changes were found in CMJ height (from 47.3 ± 3.8 to 47.1 ± 3.5 cm; p = 0.704; η^2 = 0.006), CMJ power (from 54.3 ± 4.7 to 54.4 ± 4.8 W·kg⁻¹; p = 0.841; η^2 = 0.002), SJ height (from 41.3 ± 4.7 to 41.7 ± 3.5 cm; p = 0.570; η^2 = 0.014) or SJ power (from 52.5 ± 5.2 to 53.6 ± 4.2 W·kg⁻¹; p = 0.072; η^2 = 0.129).

RSA test

Significant group × time interactions (p = 0.006; η^2 = 0.28) were found in RSA mean time but not in RSA decrement (p = 0.364; η^2 = 0.034) (Fig. 2). The RSG group showed a decrease in RSA mean time by 2.1% (from 7.53 ± 0.21 to 7.37 ± 0.17 s; p = 0.001), while the ITG did not show performance improvements (from 7.42 ± 0.22 to 7.40 ± 0.22 s; p = 0.55). The RSA decrement did not change between pre and post (from 4.8 ± 2.0 to 4.3 ± 1.6%; p = 0.139).

Discussion



The results of this study showed that the improvement in aerobic power and capacity was similar between training groups. However, compared to the high-intensity interval training, the RSA-based training induced greater improvement in football-specific endurance and RSA. Neither training strategy induced any effects on jumping or sprinting ability.

Aerobic fitness

Consistent with our hypothesis, both RSA-based and running interval training induced similar changes in aerobic fitness. Indeed, the improvements in $\dot{V}O_{2max}$ and RCP were similar between groups (-6 and 3%, respectively). These changes in aerobic fitness are lower than the improvements found by Helgerud

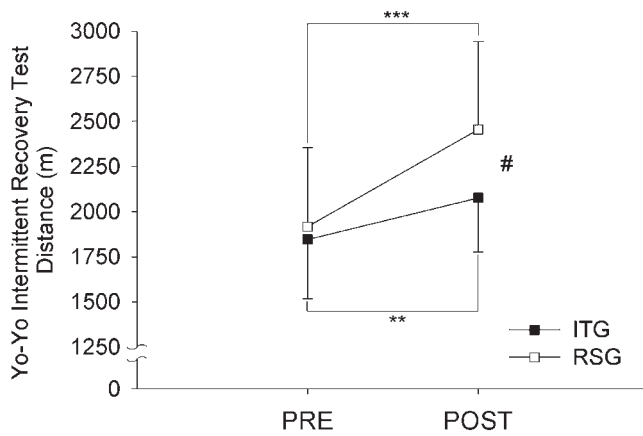


Fig. 1 Changes in football-specific endurance performance for the interval training group (ITG) and the repeated-sprint training group (RSG). ** $p < 0.01$; *** $p < 0.001$; # $p < 0.01$, significant group \times time interaction.

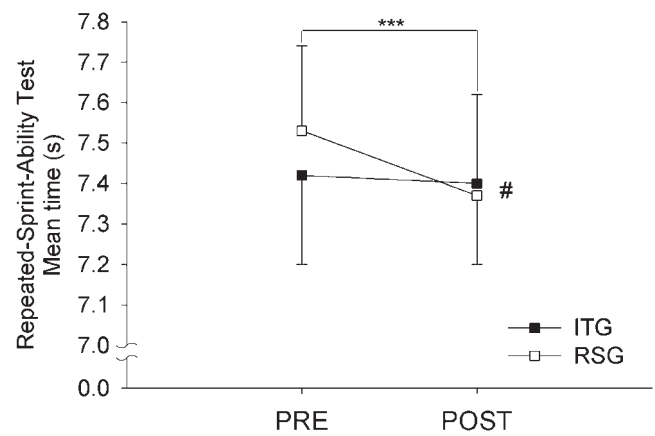


Fig. 2 Changes in the repeated-sprint ability test for the interval training group (ITG) and the repeated-sprint training group (RSG). *** $p < 0.001$; # $p < 0.01$, significant group \times time interaction.

et al. [19] using the same interval training protocol. These authors reported large increases in $\dot{V}O_{2\max}$ and the lactate threshold (11 and 16%, respectively) after 8 weeks of running interval training completed at the start of the season by a junior football team. The current changes in aerobic fitness are, however, similar to those reported by Impellizzeri et al. [23] (~7% improvements in $\dot{V}O_{2\max}$ and the lactate threshold) after 4 weeks of training before the start of a competitive season using both small-sided games and running interval training. However, after a further 8 weeks of training completed during the start of the competitive season (as in the present and the study by Helgerud et al. [19]), they did not report any further improvement in aerobic fitness. These different responses to training are probably related to the pre-intervention fitness and training level.

The improvements in aerobic fitness after the RSA training are consistent with the findings of previous studies using high volumes of sprint-based training [11, 29, 30, 38]. However, in our experience, the volume of sprint training used in these previous studies (number of sessions per week and total distance) is higher than that commonly used in soccer. For example, the healthy subjects involved in the study of Dawson et al. [11] performed three training sessions a week with each session including from 22 to 42 sprints at maximal or near maximal intensity. In our study, to increase the ecological validity, we decided to adopt a protocol similar to that currently used by teams (two sessions a week with 18 shuttle sprints at maximal intensity each session). Interestingly, despite the lower volume of sprints, we found significant improvements in the selected parameters of aerobic fitness in the RSG. The present RSA protocol (work:rest ratio of 1:3 with passive recovery) therefore provided an adequate stimulus to induce improvement in aerobic fitness [2, 12, 13, 17]. Indeed, during a single set of this RSA protocol, average HR values of 93% of maximum with blood lactate concentrations of ~14 mmol/L and a blood pH level of ~7.19 are reached (unpublished data). Furthermore, this RSA protocol also elicited improvements in aerobic fitness similar to the running interval training. Given the lower training volume required by the RSG (~10 min and 720 m) compared to the ITG (~18 min and 4000 m), the RSA-based training might provide a time-efficient strategy to induce aerobic adaptations, as suggested by Gibala et al. [16]. However, since the starting $\dot{V}O_{2\max}$ of our subjects was relatively low compared to the values reported in the litera-

ture [41], it is possible that the similar improvement in aerobic power was related to the low pretraining fitness level of the players involved in the study. Before our findings can be generalized to elite football players, future studies should confirm our results with athletes characterized by a higher $\dot{V}O_{2\max}$.

Football-specific endurance

Contrary to our hypothesis, the RSG showed greater improvement in football-specific endurance compared to the ITG. Although previous studies have shown that performance in the YYIRT is correlated to $\dot{V}O_{2\max}$ [9, 26, 27], this relationship is moderate. Therefore, it is unlikely that the low pretraining fitness level might explain this finding. In addition, the $\dot{V}O_{2\max}$ values of the two groups were similar. A possible explanation of this finding could be related to the physiological requirements of the YYIRT compared to the incremental tests. Indeed, this test of football-specific endurance highly taxes both aerobic and anaerobic energy systems [9, 19], while the $\dot{V}O_{2\max}$ test protocol is designed to measure mainly the aerobic power of the subjects. As sprint training can induce improvements in both aerobic and anaerobic metabolism [8, 11, 30, 34], this may explain the greater improvement in football-specific endurance (as measured by the YYIRT). In addition, as both the RSA training protocol and the YYIRT included direction changes (i.e., shuttle running), specific improvement in the ability to change direction may have positively influenced the performance in the football-specific endurance test [28, 47].

Jumping and sprinting

The RSA training protocol used in this study included 40-m sprints with 180° direction changes. Compared to straight-line sprints, the directional changes require players to further exert high levels of muscular strength and power to decelerate from a speed of more than 20 km·h⁻¹ [10] and then to maximally reaccelerate. For this reason, we hypothesized greater improvement in activities requiring muscular power such as jumping and short-distance sprinting after the RSA training. However, contrary to our hypothesis, no effect of training types, and no pre to post changes were found in jump height, power or 10-m sprint time. While the lack of improvement in sprinting and jumping ability for ITG confirmed previous findings on football players after aerobic running interval training [19], the absence of im-

improvements in sprinting and jumping ability after the RSA-based training was not expected. Indeed, sprint training has been reported to enhance both sprinting and jumping ability [11,31]. However, these previous studies have used greater volumes of sprint training than used in the present study [11,31]. Furthermore, it is possible that the work:rest ratio used in this study was not sufficient to improve sprinting and jumping ability in football players, but was adequate to stimulate the aerobic energy system. Our results are similar to those reported by Dawson et al. [11] who reported an increase in RSA and 40-m sprint time but not in 10-m sprint performance after six weeks of high-volume sprint training. Our results also seem to confirm the findings by Young et al. [47] who showed that straight speed and agility training methods produce limited transfer to the other directional running modes [47]. Given the importance of the ability to accelerate in football, additional power and strength training may be required to improve muscular power and hence short-sprint ability [22,43,44].

Repeated-sprint ability

Consistent with our hypothesis, only RSG showed improvements in the RSA tests. This improvement in RSA mean time in RSG does not appear to be mediated by the enhanced aerobic fitness as both groups showed moderate but significant improvement in $\dot{V}O_{2\max}$ and RCP. Although RSA may be partially related to aerobic power [6,7], the improvement in RSA mean time may reflect enhanced anaerobic metabolism which is also an important determinant of RSA and can be increased with sprint training [25]. This conclusion is supported by the observed decrease in the RSA_{mean} concurrent with unchanged RSA_{dec} . This suggests an increase in overall anaerobic performance but not in the ability to recover between sprints. In addition, the improvement in RSA performance of the RSG may also be explained by the specific changes induced by shuttle-sprint training [47].

Conclusion

In conclusion, this study showed that RSA-based and aerobic running interval training are equally effective in enhancing the aerobic fitness of football players. Moreover, both training programs used in this study did not negatively influence either jumping or straight-line sprint performance. Football-specific endurance, as measured with the YYIRT, improved in both groups but the RSA-based training induced a greater increase. Finally, only the sprint-based training induced improvements in RSA. However, given the limited transfer between improvements in sprint ability characterized by different direction changes, it should be investigated if the use of direction changes other than 180° (i.e., from 0 to 90° which are more typical of football performance) may induce more specific effects for football performance. Whether these differences in the adaptations to training will result in differences in physical performance during actual match-play also requires further investigation. In addition, given that several physiological systems are involved during football, the effects of combining different training strategies, shown to be effective in isolation, warrants future studies.

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