Table 2. Aerobic fitness variables assessed by the Yo-yo IR1 test, peak heart rate (HR) and vertical jump (CMJ) for all groups before and after the experimental and control periods. In the control period the group name remains, but no supplementary HIIT training was performed.

Variable	Group	Pre	Post	*p* Pre vs. Post	*d* Pre vs. Post	*Delta change*	*Delta* Change (%)	*p* Between deltas	*d* Between deltas
Distance (m)	**10s/10s**	2083 ± 411	2434 ± 345	**<0.001**	0.92 (large)	351 ± 192	18.5 ± 11.7	**0.039**	**0.85 (large)**
	15s/15s	2225 ± 262	2418 ± 275	**0.005**	0.72 (moderate)	194 ± 175	9.0 ± 8.5		
Control period	**10s/10s**	2166 ± 418	2083 ± 349	0.587	0.22 (small)	-83 ± 281	-2.2 ± 15.2	0.973	0.01 (trivial)
	15s/15s	2317 ± 275	2231 ± 289	0.443	0.31 (small)	-86 ± 162	-3.6 ± 7.1		
$\dot{V}O_{2max}$ (ml/kg/min)	**10s/10s**	53.9 ± 3.5	56.8 ± 2.9	**<0.001**	0.92 (large)	2.9 ± 1.6	5.6 ± 3.2	**0.039**	**0.85 (large)**
	15s/15s	55.1 ± 2.2	56.7 ± 2.3	**0.005**	0.72 (moderate)	1.6 ± 1.5	3.0 ± 2.7		
Control period	**10s/10s**	54.6 ± 3.5	53.9 ± 2.9	0.587	0.22 (small)	-0.7 ± 2.4	-1.1 ± 4.4	0.973	0.35 (small)
	15s/15s	55.9 ± 2.3	55.1 ± 2.4	0.443	0.31 (small)	-0.1 ± 0.4	-1.3 ± 2.4		
v$\dot{V}O_{2max}$ (km/h)	**10s/10s**	16.6 ± 0.6	17.1 ± 0.5	**<0.001**	0.92 (large)	0.5 ± 0.3	3.3 ± 1.9	**0.039**	**0.85 (large)**
	15s/15s	16.8 ± 0.4	17.1 ± 0.4	**0.005**	0.72 (moderate)	0.3 ± 0.3	1.8 ± 1.7		
Control period	**10s/10s**	16.7 ± 0.7	16.6 ± 0.5	0.587	0.22 (small)	-0.1 ± 0.4	-0.7 ± 2.7	0.973	0.00 (trivial)
	15s/15s	16.9 ± 0.4	16.8 ± 0.5	0.443	0.31 (small)	-0.1 ± 0.3	-0.8 ± 1.5		
HR(bpm)	**10s/10s**	198 ± 5	198 ± 5	0.705	0.15 (trivial	-0.7 ± 3.3	0.4 ± 1.7	0.152	**0.58 (moderate)**
	15s/15s	194 ± 6	195 ± 5	0.683	0.16 (trivial)	0.8 ± 1.7	-0.4 ± 0.9		
Control period	**10s/10s**	197 ± 5	197 ± 7	0.820	0.09 (trivial)	0.5 ± 2.5	-.02 ± 1.3	0.416	0.33 (small)
	15s/15s	195. ± 6	195 ± 6	0.949	0.03 (trivial)	-0.2 ± 1.6	0.1 ± 0.8		
CMJ (cm)	**10s/10s**	37.8 ± 3.1	37.5 ± 3.8	0.993	0.08 (trivial)	-0.3 ± 1.9	1.0 ± 5.0	0.893	0.06 (trivial)
	15s/15s	38.1 ± 2.7	37.9 ± 2.6	0.974	0.07 (trivial)	-0.2 ± 1.4	0.6 ± 3.8		
Control period	**10s/10s**	37.9 ± 3.6	37.0 ± 3.1	0.498	0.27 (small)	-0.9 ± 1.5	2.4 ± 4.3	0.896	0.05 (trivial)
	15s/15s	38.0 ± 3.2	37.2 ± 1.9	0.449	0.30 (small)	-0.8 ± 2.6	2.1 ± 7.3		

Exp: experimental condition; Con: Control condition; Distance (m): Distance covered in the Yo-yo IR1 expressed in meters, $\dot{V}O_2$max (ml/kg/min): maximum oxygen consumption, v$\dot{V}O_2$max (km/h): running speed at $\dot{V}O_2$max, HR (bpm): Heart Rate, CMJ (cm): Counter movement jump; *d*: Effect size. Delta values were calculated from Pre-and post- training values. Data are means and standard deviations (mean±SD).

Discussion

The aim of the current study was to evaluate the effect of short-HIIT in aerobic capacity and neuromuscular performance and RPE during competitive period on soccer players. Two formats of short-HIIT 10s/10s and 15s/15s were compared in a randomized design in two youth football teams twice per week during the in-season period. The main finding of the study was that Yo-yo IR1 performance significantly improved in both HIIT groups compared with control group (by 13.8% vs. no change in the control period), with no changes in HR and CMJ. The between HIIT formats difference indicated that the improvements in distance covered, $\dot{V}O_2$max and v$\dot{V}O_2$max were almost twice as high in the 10s/10s format compared with the 15s/15s format (18.5 vs. 9.0%), despite the longer bout duration and the changes of direction performed in the later. Moreover, RPE was lower in the 10s/10s format compared to the 15s/15s format. Another important finding was revealed when Yo-yo IR1 test performance of each team was examined over time (Figure 3). This comparison revealed that supplementary HIIT training, irrespective of format, is necessary to maintain a high level of aerobic/anaerobic fitness, as assessed by the Yo-yo IR1 test (Figure 4).

The large improvements of Yo-yo IR1 test performance following the application of HIIT is an important finding of the present study. Moreover, the decline in performance when players performed football training only was evident when observing the time-course of changes in Team A in Figure 4. Notably, there was no improvement in Yo-yo IR1 performance in Team B during the initial period (weeks 1 - 6). These findings are in line with previous studies which implemented HIIT during the in-season period (Dupont et al., 2004; Mohr and Krustrup, 2014; Thomakos et al., 2024). Aerobic capacity is improved when HIIT or small-sided games are implemented. However, HIIT may provide more control over the individual intensity of training, as some players may underperform

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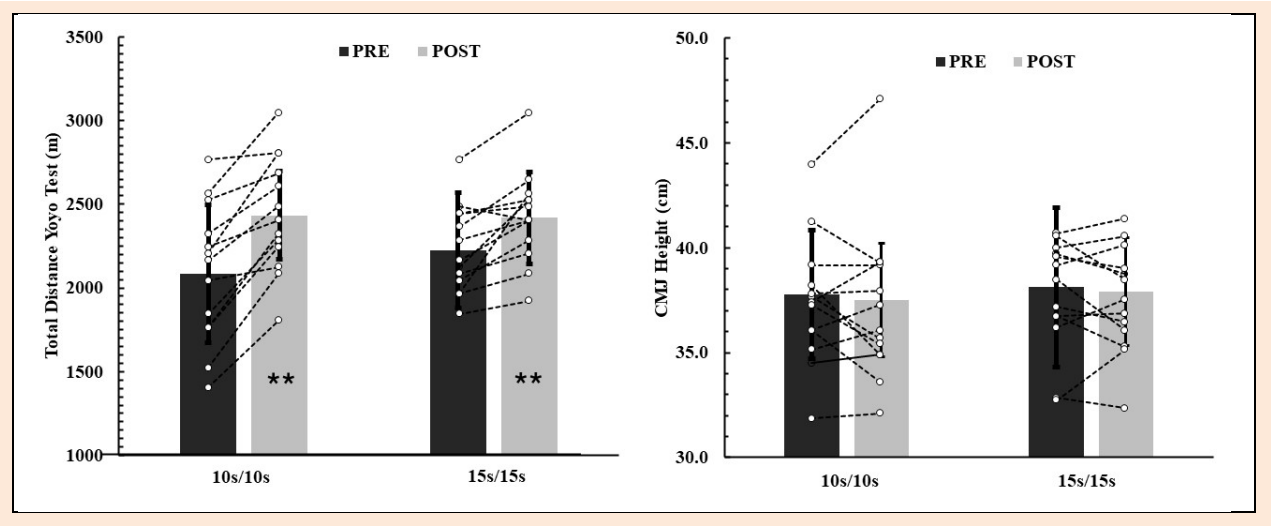

Figure 3. Distance covered during the Yo-Yo IR1 test (left panel) and countermovement jump (CMJ, right panel) before (pre) and after (post) the 10s/10s and 15s/15s supplementary high intensity interval training. ** p≤0.005 between pre and post at HIIT group.

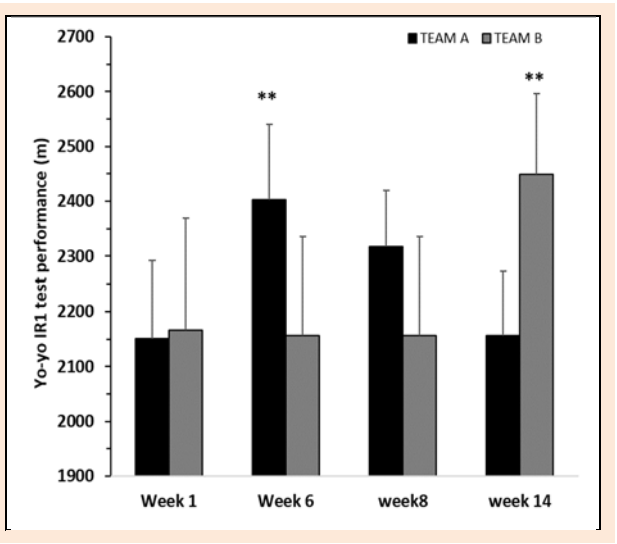

Figure 4. Yo-yo IR test performance (total distance) in Team A (which performed the HIIT protocol in the first 6 weeks) and Team B (which performed the HIIT protocol in the last 6 weeks). ** p<0.01 from all time points of the same team.

during small-sided games (Dellal et al., 2012; Thomakos et al., 2024). During the in-season period, coaches prefer to focus on technical and tactical drills, whereas physical qualities are maintained through games and the tactical exercises, to avoid overloading or temporary fatigue (Dupont et al., 2004). However previous studies showed that individual training intensity can be controlled better when using HIIT compared with SSG (Dellal et al., 2008; Engel et al., 2018). In fact, the HIIT has been shown to induce greater improvements in both aerobic and anaerobic capacity compared with continuous training of similar duration (Dellal et al., 2008; Engel et al., 2018). However, the counter-argument is that HIIT involving running only is much less football-specific, and several coaches prefer to perform high intensity drills with the ball instead of HIIT. Nevertheless, HIIT as a form of supplementary training, performed once per week has been shown to improve not only fitness but also match performance (i.e., match results and scoring-conceding goals) (Dupont et al., 2004; Thomakos et al., 2024).

The metabolic demands and, in turn, the adaptations to HIIT depend, among other parameters, on bout duration, with shorter bouts providing less metabolic load (i.e. lactate production) with a similar cardiorespiratory load (Bogdanis et al., 2022). HIIT has been shown to promote muscle oxidative capacity through increased mitochondrial biogenesis (Daussin et al., 2008). However, a recent study indicated that high lactate concentration may impair the process of mitochondrial biogenesis, thus reducing its effectiveness to promote aerobic adaptations (Bishop et al., 2019). Although blood lactate was not assessed in the present study, previous work clearly shows that when the same distance in HIIT is covered with a change of direction, the blood lactate responses and RPE are higher compered to linear HIIT (Dellal et al., 2010; 2012). Thus, the 15s/15s format which included back and forth running, may have a greater anaerobic component and the higher lactate and RPE may explain the lower improvement in Yo-yo IR1 test performance with the mechanism described above. In previous studies comparing HIIT formats the intensity was not the same at both modes of short-HIIT (Buchheit and Laursen, 2013; Dellal et al., 2008; 2015), while in the present study where the intensity was set to 100% of $v\dot{V}O_2max$ for both protocols. For example, Dellal et al. (2015) compared HR during a repeated sprints protocol, small-sided games and two short HIIT formats (15s/15s) performed either linearly or with 180° COD. Their findings showed that HR was higher at the 15s/15s with 180° COD protocol compared with the other exercises. In the present study the participants had higher RPE when running 15s/15s with changes of direction vs. the linear 10/10 s format. This may be because bout duration was longer and also because the 15s/15s format included a 180° change of direction (Bogdanis et al., 2022; Dellal et al., 2010).

One of the hypotheses tested in the present study was that HIIT with changes of direction could have a positive effect on CMJ performance. However, there were no changes in CMJ in all conditions, suggesting that both HIIT

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interventions, as well as the control periods, do not result in an increase or decrease in lower limb explosive performance. This would suggest that a specific power training program would be required to improve CMJ during the in-season period (Meylan and Malatesta, 2009; Ramírez-Campillo et al., 2014). During the in-season, training load should be adjusted accordingly so that a high level of performance is maintained during official matches. In a previous study, the authors observed that when training load was heavy, i.e. resistance training combined with HIIT in the pre-season, CMJ performance was depressed (Thomakos et al., 2023). Thus, a possible addition of resistance training in combination with HIIT performed twice per week could increase the risk of overreaching or overtraining, but this warrants further investigation.

Previous studies have shown that RPE reflects training load assessed by a combination of HR and blood lactate concentration, thus making it a fairly accurate global index of internal load during training (Foster et al., 2001; Snyder et al., 1993; Gabbett, 2016). Thus, RPE is a very useful tool to monitor and control training. In the present study, we could not obtain measurements of blood lactate after the HIIT program, as this was not practically possible because it would delay the training process. The finding that RPE was higher after the 15s/15s compared to 10s/10s format, may be explained by the higher mechanical load of the changes of direction in the later format, the acceleration and deceleration involved to perform a 180o turn, combined with the longer duration of the bout (15s vs. 10s) (Dellal et al. 2010; Dellal et al., 2012; Bogdanis et al., 2022). These would induce a higher glycolytic contribution and mechanical loading (Dellal et al., 2012), which are linked with higher RPE.

One of the interesting findings of the present study was the responsiveness of the players' organisms to HIIT, as shown in Figure 4 Specifically, Team A, which performed the HIIT training first irrespective of format, improved Yo-yo IR1 test performance in the first 6 weeks but could not maintain it until the end of the 14-week period. In contrast, team B, which performed HIIT training in weeks 8 - 14, improved Yo-yo IR1 test performance only after that period. These changes demonstrate the rapid responses of the player's to HIIT, as well as the relatively fast detraining (Mujika and Padilla, 2000). Thus, supplementary HIIT may be necessary to improve performance during in-season, while the two times per week schedule seems to be not only well tolerated, but also very effective in improving Yo-yo IR1 performance.

The current study has some limitations. We could not obtain HR or global positioning system data during training and match play, except from playing time per players. Also, blood lactate responses could not be obtained due to practical reasons in such those teams. This information would have been useful to assess training load differences between the two periods in detail. Also, it was not practically possible to perform other field or laboratory tests (e.g. sprints, change of direction tests, cardiopulmonary testing on a treadmill), because it would disrupt the in-season training program of the teams and it was not practically possible. However, the design of this study, using two teams who followed a control and an intervention period in an alternated manner, as well as the standardized training procedures followed by both teams in an equated manner, ensures that the differences in test performance observed are reliable. Also, game participation time was similar between the two periods (intervention and control), which further adds to the controlled conditions under which this intervention was performed. It is important to highlight that these results may not directly apply to women and professional soccer players. Also, the level of readiness of the players before implementing a HIIT program may interact with the magnitude of adaptations. Further studies should address these issues.

Conclusion

The present study showed that in-season supplementary short-HIIT training improves endurance performance without any change in neuromuscular performance. Both intermittent running modes (i.e., 10s/10s and 15s/15s) improved Yo-Yo IR1 test performance following the intervention program. However, the 10s/10s HIIT format induces greater improvements in performance with a lower RPE during training compared with the 15s/15s format. Young soccer players may benefit by adding a short HIIT program twice-per week during the competitive season, when the aim is to further improve aerobic fitness without compromising neuromuscular performance.

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Key points

- Both supplementary HIIT programs improved Yo-Yo IR1 performance in young soccer players
- However, training with the 10s/10s format resulted in 45-50% greater improvement in Yo-Yo IR1 performance, while rating of perceived exertion during training was lower than the 15s/15s format.
- CMJ performance remains unaffected by supplementary HIIT performed twice weekly during the in-season in young soccer players.

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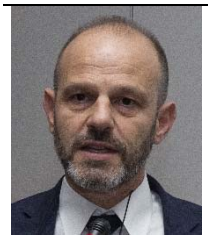

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