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REVIEW ARTICLE

Performance Adaptations to Intensified Training in Top-Level Football

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Abstract
Because physical demands are surging in football (soccer, USA), clubs are more and more seeking players who have a high capacity to perform repeated intense exercise. High-intensity interval training (HIIT), comprising exercise performed at intensities near or exceeding the capacity of aerobic energy systems, effectively enhances the physical conditioning of players. But given that HIIT imposes high loads, it increases the risk of overload-associated match performance decline and injury. This makes some coaches inclined to conduct HIIT in the weeks leading up to the season and during the season. Therefore, the challenge is how to optimize and dose HIIT during these phases, as they can be decisive. Studies have highlighted the utility of conducting periods of intensified training to overcome the risk of overload while at the same time enhancing performance. During intensified training periods of typically a few weeks, intensity is increased by enlarging the amount of HIIT, for example, aerobic high-intensity training or speed endurance training, while volume at low-to-moderate intensity is significantly reduced. The outcome depends on training composition and prescription—most notably, intensity and duration of bouts and recovery. When work intervals are prescribed for a few minutes at intensities > 90% heart rate max (i.e., aerobic high-intensity training), then beneficial adaptations pertaining to aerobic power and capacity are apparent. But when work intervals are conducted at much higher intensities, as all-out efforts or sprinting of typically 10- to 40-s duration with longer recovery periods (i.e., speed endurance training), beneficial adaptations pertaining to anaerobic energy systems, ion handling, and fatigue resilience are commonly observed. In this review, we discuss the utility of conducting intensified training periods to enhance performance in elite football players during the late preparation phase and competitive season.

1 Introduction

The physical demands are ever increasing in football (US: soccer) [1–3]. While the total distances covered remain fairly stable, the number of high-intensity actions, such as high-speed runs and sprints has increased [4–6]. From the 2006/2007 English Premier League season to the 2012/13 season, the mean distances of high-intensity running ($> 19.8\ \mathrm{km} \times \mathrm{h}^{-1}$) with and without ball possession increased from 373 to 478 m and 451 to 589 m, respectively [7, 8]. And analyses of UEFA (Union of European Football Associations) Champions League matches underscore a trend for an increase in the number of sprints performed. For instance, players performed twice as many sprints (defined as $> 30\ \mathrm{km} \times \mathrm{h}^{-1}$) as in prior years during the 2018/2019 Champions League season [4]. Along these lines, analyses of FIFA (Federation Internationale de Football Association) World Cup Finals from 1966 to 2010 revealed that game speed increased by 15%, which as highlighted by Wallace and Norton, emphasizes the need for fast and skillful players [9]. Football clubs ever more rely on performance-related data and the development of players' ability to perform repeated high-speed runs [10, 11].

Although a team's physical performance is just one aspect of predicting team success, it is important for several reasons. Aside from the fact that less fit players perform fewer high-intensity actions throughout a match [12–14], the more rapid progression of fatigue in unfit players has consequences for technical and presumably also tactical performance [15]. For instance, data show that technical performance declines faster in unfit players as match fatigue develops [16–18]. Low-tier teams and amateur players perform fewer high-intensity runs and sprints than high-tier teams and professional players [3, 14]. And most goals happen after a high-speed run or sprint of both the goal-scorer and

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Key Points

The evolution of football imposes great demands on players, in particular in terms of their ability to cope with high exercise intensities with and without the ball and tolerate fatigue.

Managers more and more seek fast and skillful players who have a high capacity to perform repeated high-intensity exercise and can tolerate large weekly training and match loads.

Constraints of a busy match schedule impose challenges for coaches to conduct physical training during the season. However, periods of intensified training appear effective to enhance players' ability to perform intermittent exercise at high intensities with only small doses of high-intensity interval training during the late preparation phase and competitive season.

Given the risk of overload and injuries, periods with intensified training should be carefully planned with consideration of the season plan, match schedule, and player load. Thus, the volume of low-to-moderate intensity training is substantially reduced during periods of intensified training.

assisting player [19]. For example, a sprint preceded half the goals during a half-season of the 2007/2008 Bundesliga [19]. For these reasons, players need to develop a high capacity to perform intense actions and sustain fatigue.

High-intensity interval training (HIIT) is an effective tool to enhance multiple physiologic parameters of importance for performance, including cardiometabolic function, oxygen uptake kinetics, anaerobic power and capacity, ion transport capacity, and muscle fatigue resilience [20–22]. HIIT encompasses exercise training performed at intensities near or exceeding the capacity of aerobic energy systems, and its outcome depends on how the training is structured and how it is prescribed to the players—most notably, the intensity and duration of bouts and recovery periods [22]. When bouts are performed for a few minutes at intensities corresponding to around 90% of maximal oxygen consumption ($\dot{V}O_{2\,max}$) or > 90% of heart rate max, HIIT is highly beneficial in improving aerobic power and capacity (e.g., with aerobic high-intensity training) [22–26]. When HIIT is conducted at much higher intensities, as all-out efforts or sprinting of typically 10- to 40-s duration with longer recovery periods (such as sprint interval training or speed endurance training), beneficial adaptations pertaining to anaerobic energy systems and ion handling are commonly observed [21, 27].

But given that HIIT imposes high internal (psycho-physiological stress) and external (physical performance output) loads, prolonged depression of neuromuscular function, and micro-tears of muscle [28–31], it increases the risk of overload-associated match performance decline and injury if not dosed properly and players are not fully recovered [32–36]. Therefore, HIIT is predominantly conducted during the early preparation phase of the pre-season when match load is low, hence allowing for an intensification of training load as compared to the typical weekly microcycles in-season [37, 38]. Because coaches and players may be inclined to train too hard in the weeks leading up to the start of the season or during periods with a busy match schedule in-season [39–42], the key challenge is how to optimize and dose HIIT during these phases, as they can be decisive and provide an edge for well-prepared teams [43]—not only in terms of preparing players for the loads imposed during various periods of the competitive season [44] but also because match-related physical performance, such as the amount of running at high intensities, is lowest during the first half of the season [45, 46]. Dosing is paramount and should be done with careful consideration of the match schedule and by monitoring player load [34, 35, 47].

Studies have highlighted the utility of performing periods of intensified training to overcome the risk of overload while at the same time enhancing performance [48–50]. Intensified training refers to a period of typically a few weeks where the intensity is increased, while the overall training volume is retained or preferably lowered [48, 50]. In interval-dominated sports, such as football, this is done by introducing sets of HIIT-based drills. Intensified training is time-efficient and only a small dose of high-intensity training elicits beneficial adaptations pertaining to cardiovascular and neuromuscular function and enhances intermittent exercise performance, repeated sprint ability, and performance during continuous exercise at high intensity [20, 21, 48].

In this review, we discuss the utility of conducting intensified training periods to enhance performance in elite football players during the late preparation phase and competitive season. First, we describe the physical match demands in football. Then, we present the training characteristics of periods with intensified training conducted in the late preparation phase and competitive season. This is followed by an overview of the effect of HIIT modalities utilized where we also discuss putative physiological mechanisms underlying performance enhancements. Finally, we provide some practical applications of various forms of HIIT. The review mainly focuses on studies performed with elite players. Studies performed with sub-elite and amateur players are only occasionally included to underpin key concepts.

2 Physical Demands in Top-Level Football

2.1 Metabolic Demands

Knowledge about the physical demands of match-play is a prerequisite to composing appropriate training. During a match, professional football players cover 10–13 km with around 1400 activity changes, i.e. a change in activity every 4 s [51]. While the majority of player actions impose a low metabolic and mechanical load (e.g., standing, walking, and jogging), the intermittent nature of football comprises several actions at near-maximal or maximal effort with high metabolic and mechanical load, including high-intensity runs, sprints, cuts, etc. [9, 14, 51, 52]. Depending on playing position, players cover around 2.5 km at high speeds ($>$ 19.8 km $\times$ h^{-1}) along with 40–60 sprints totaling 0.3–0.6 km and accounting for 4–12% and 5–18% of the total distance covered, respectively [4–6, 51, 53, 54]. High-intensity actions are typically followed by 60- to 70-s recovery before another intense action with a work-to-rest ratio of around 1:12, but can be as short as 1:2 during intense periods of a match [55, 56]. This is particularly true for central midfielders whose recovery periods between consecutive high-intensity actions often are $<$ 20 s [56]. Thus, players should possess a high capacity for both aerobic and anaerobic energy production to cope with the distances covered and to aid recovery between intense actions, as well as a high ability to perform repetitive high-intensity work and sprinting.

It is estimated that aerobic energy systems account for 70–90% of total energy consumption, while anaerobic energy systems account for the remainder [57–59]. This is reflected by mean and peak heart rates of 85%-max and 98%-max, respectively, and blood lactate$^-$ levels occasionally exceeding 12 mM during a match [60]. Hence, players should possess a high maximal aerobic power (i.e., $\dot{V}O_{2\,max}$) and ability to utilize a high fraction of $\dot{V}O_{2\,max}$ in order to endure the distances covered and recover between activities. In accordance, top-level players have a $\dot{V}O_{2\,max}$ of 60–75 mL $\times$ kg^{-1} $\times$ min^{-1} depending on seasonal phase and playing position [61].

Although the contribution from aerobic processes dominates during a match, the metabolic demands of intense actions vastly exceed the capacity of aerobic energy systems [57, 62]. Thus, anaerobic processes become important when players perform intense actions (e.g., sprinting or shooting), in transition between activities (e.g., backward running followed by a header), and during shifts to higher intensities (e.g., jogging to high-speed running). Anaerobic energy systems contribute substantially during various periods of a match. For example, after an intense period during the second half, muscle lactate$^-$ content rose from 4 to 17 mmol $\times$ kg$_{d.w.}{}^{-1}$ and muscle pH declined from 7.2 to values as low as 6.8 [63]. Therefore, players also need to develop a high capacity to perform intense actions taxing anaerobic energy systems.

2.2 Development of Fatigue

Performance declines transiently and progressively during a match, which is independent of playing position [64, 65]. Although highly conditioned players are more fatigue resilient than unfit players [16–18, 66], the number of high-intensity runs plunges toward half-time and during the final 30 min of the second half, as well as during intense periods—irrespective of training level [14, 16, 66]. The latter phenomenon is, for example, demonstrated in top-tier players, for which a period with many high-intensity actions precedes a period with few [14]. Match fatigue also manifests as a decline in peak sprint and repeated sprint performance during the second half [63] and a decline in maximal force, rate of force development, and electrically evoked force of the quadriceps muscle [66–68]. Thus, fatigue occurs transiently during intense periods and manifests more severely as the match progresses.

A multitude of factors contribute to muscle fatigue [27, 69], which include transient fluctuations of multiple ions (e.g. K^+ and Na^+) and metabolic perturbations (H^+ and inorganic phosphate accumulation, as well as a decline in adenosine nucleotides) in contracting muscle fibers [27]. Other factors likely also contribute, but more so towards the end of a match, including glycogen depletion [70, 71], reactive oxygen species [72], and muscle damage, such as microtears or disruption of myofibrils and the inter-fiber matrix [65, 73]. The latter factors may be responsible for the prolonged muscle force depression up to 72 h following a match [65, 68, 70]. Hence, match fatigue mainly occurs at the muscular level [66, 68, 70], while central fatigue is modest or negligible at normal ambient temperatures but contributes more in warm environments [74].

Muscle fatigue develops slowly at intensities below the capacity of aerobic energy systems and rapidly at higher intensities that engage anaerobic processes [27]. This is because ionic and metabolic perturbations are most severe at intensities taxing anaerobic energy systems [27]. Therefore, when the purpose is to enhance players' ability to perform repeated high-intensity exercise, the training needs to push the threshold for when ionic and metabolic perturbations occur and enhance the capacity of systems that counter these perturbations [27]. This can be achieved by prescribing various forms of HIIT during periods of intensified training, as described next.

3 Characteristics of Intensified Training

A period of intensified training is characterized by introducing or increasing the amount of HIIT, typically for a few weeks (Fig. 1). Depending on the desired outcome, it is necessary to manipulate the exercise intensity, duration, work-to-recovery ratio, and repetitions – not only to ensure the required intensity can be sustained throughout the training session, but also to target the relevant energy systems. When conducted at intensities where the metabolic demands for most parts can be matched by aerobic energy systems, the training is sub-classified as aerobic high-intensity training [23, 25, 26, 75–77]. At intensities exceeding the capacity of aerobic energy systems, and for which anaerobic energy systems dominate, the training is sub-classified as anaerobic training [26, 78–82]. We use the terms aerobic and anaerobic training because they reflect the energy systems that dominate during the training session and provide a clear physiologic focus of the training. In a running-dominated sport, such as football, this often represents intensities below and above those eliciting $\dot{V}O_{2\,max}$ ($v\dot{V}O_{2\,max}$/maximal aerobic speed) for aerobic and anaerobic training, respectively, which is typically around 50% of maximal running speed. Top-class players clock top speeds at 32.5–34.5 $km \times h^{-1}$ during a match [5, 6] with an estimated $v\dot{V}O_{2\,max}$ around 16–18 $km \times h^{-1}$ based on incremental treadmill running tests [83, 84]. The characteristics of the different training modalities are shown in Table 1.

3.1 Aerobic Training

Aerobic training aims at augmenting the power and capacity of aerobic energy systems and is divided into low-, moderate- and high-intensity aerobic training based on heart rate. Aerobic high-intensity training comprises intervals at > 90%-max heart rate. When the training aims at enhancing a player's ability to cover long distances of high-intensity running and recover from intense actions, we consider aerobic high-intensity training as the lowest intensity zone one should apply when conducting periods of intensified training. The typical interval duration is 1–4 min with < 1 times the recovery, such as 2-min work followed by 1-min recovery (Table 1), as this generally enables players to attain and sustain a heart rate of > 90%-max during each interval [20, 22]. The aerobic load is assessed with heart rate monitors [79] and is easily conducted in organized settings or technical drills, where the appropriate intensity can be controlled.

Depending on the format and rules, aerobic high-intensity training can be implemented in small-sided games [26], while still reaching heart rate responses > 90%-max. But because the nature of the game imposes a large degree of variability in player actions and speed, small-sided games are a form of HIIT that significantly taxes both aerobic and anaerobic energy systems [26, 85]. If the scope is to only tax and push the capacity of aerobic energy systems as much as possible, then small-sided games have inherent limitations as compared to more controlled generic drills. Although the rules and format of small-sided games can be

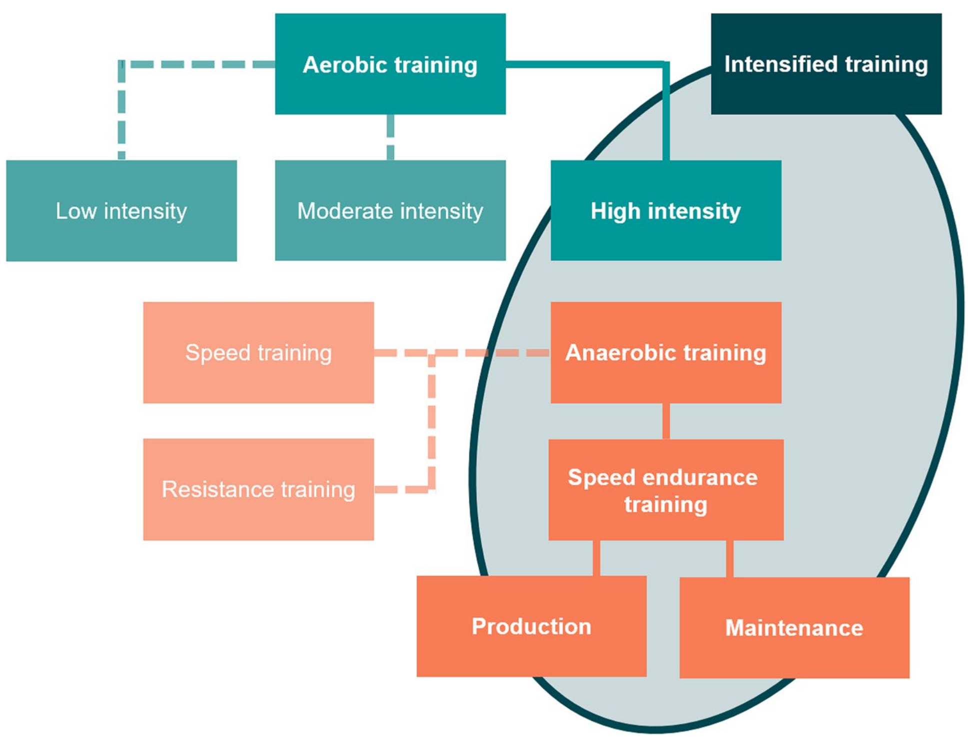

Fig. 1 Training modalities during periods with intensified training in football. The figure is based on Bangsbo [48, 80], Iaia et al. [76, 113], and Ade et al. [29]

adjusted so that the number of intense and impactful situations (such as sprints and 1*v*1) is minimized by regulating pitch dimensions, adding supporting players, or manipulating the number of touches by the player in possession, the overall internal and external load cannot be standardized. This is reflected by highly variable blood lactate⁻ and heart rate responses, as well as amount of high-intensity running during small-sided games [85–88]. As discussed by Buchheit et al. [22], the shifts in activities with alternating work and recovery periods during small-sided games may limit the ability to reach and maintain the cardiac strain necessary to achieve beneficial long-term adaptations in cardiac function as generic aerobic high-intensity training drills.

3.2 Anaerobic Training

Anaerobic training aims at enhancing the ability to perform repeated high-intensity exercise and is divided into speed training and speed endurance training (SET)—the former of which is sprint/agility training [48, 79, 80]. SET is further divided into production (SET-P) and maintenance (SET-M) training depending on intensity, duration, and recovery (Table 1). SET-P aims at enhancing the ability to perform repeated high-intensity exercise, whereas SET-M aims at enhancing the ability to tolerate and sustain fatigue during high-intensity exercise [57, 79, 80, 89]. In SET-P, the work duration is shorter than 40 s at or close to maximal speed with > 5 times recovery, while in SET-M, the work duration is normally 15–90 s at near-maximal speed with 1–3 times recovery, but can be conducted with shorter work intervals (Table 1). Sprint interval training (15–30 s all out with 2–4 min recovery) and repeated sprint training (3–7 s sprints with < 60 s recovery) are hence forms of SET-P with long and short durations, respectively. The long recovery with SET-P and SET-M ensures that players retain high speeds through each bout. But given the longer recovery between bouts with SET-P than SET-M, this allows for higher intensity and utilization of anaerobic energy systems. For example, elite youth players run faster and produce more lactate⁻ during a session of SET-P than SET-M, while the latter induces a greater heart rate response and imposes more prolonged neuromuscular fatigue (24 h post session) [29]. The major metabolic and ionic perturbations associated with sessions of SET [27, 30], together with the high external load from multiple bursts at maximal effort, can inflict substantial neuromuscular fatigue and muscle damage—especially in unaccustomed players [28]. Therefore, SET should be dosed prudently.

Like aerobic high-intensity training, SET can be implemented in technical drills and small-sided games, such as 1*v*1 or 2*v*2 [79]. Because the intensity is based on speed, the appropriate intensity cannot be assessed using heart rate when conducting SET. Often the coach qualitatively assesses players' effort and encourages them to put in the highest possible effort during each bout, but can also be assessed objectively using photo sensors (for controlled settings often not involving ball or other technical elements), accelerometers, and GPS trackers to measure running speeds. The latter systems can have some limitations in terms of accurately measuring intermittent and rapid shifts in velocities [53, 90, 91], such as those occurring during intense small-sided games with SET focus.

Table 1 Characteristics of aerobic and anaerobic training during a period of intensified training

Aerobic training	Intensity (%-max heart rate)	Duration (s)	Work:rest (ratio)	Reps	Example	Desired outcome
AHT—long intervals	> 90	60–240	3:1–1:1	2–8	4 × 4 min at > 90%-max heart rate (work:rest 2:1)	↑ Aerobic capacity
AHT—short intervals	> 90	10–60	2:1–1:1	8–30	12 × 30 s at > 90%-max heart rate (work:rest 2:1)	↑ Aerobic capacity
Anaerobic training	**Intensity (%-max speed)**	**Duration (s)**	**Work:rest (ratio)**	**Reps**	**Example**	**Desired outcome**
SET-M—long intervals	50–80	15–90	1:1–1:3	6–12	5 × 60 s at 70%-max speed (work:rest 1:2)	↑ Repeated high-intensity exercise, fatigue tolerance
SET-M—short intervals	60–100	5–15	1:2–1:5	10–25	3 sets 6 × 5 s at near-to-max speed (work:rest 1:3)	↑ Repeated high-intensity exercise and sprinting
SET-P	70–100	15–40	1:5–1:8	4–12	6 × 30 s at near max speed (work:rest 1:6)	↑↑ Repeated high-intensity exercise

AHT aerobic high-intensity training, *SET-M* speed endurance maintenance training, *SET-P* speed endurance production training

During intensified training periods aiming to enhance players' ability to tolerate the distances covered and aid recovery between intense actions, the amount of aerobic high-intensity training is increased. But when the aim is to enhance the ability to perform repeated intense exercise, the amount of SET is typically increased. The respective amount of aerobic low- and moderate-intensity training is decreased so that the overall weekly training load imposed is balanced.

4 Aerobic High-Intensity Training

4.1 Performance Adaptations

When introduced in the early pre-season to players returning from intermission, 8–10 weeks aerobic high-intensity training augments $\dot{V}O_{2\,max}$ 8–11% [23, 75]. This is not surprising. What is more relevant is whether aerobic high-intensity training can be utilized to intensify the training in the late preparation phase and competitive season. In a study by Jensen et al., an additional 30-min aerobic high-intensity training (2–4 min interval-play separated by 1–2 min recovery) once weekly for 12 weeks in the competitive season augmented $\dot{V}O_{2\,max}$ 5% in elite players [92]. Similarly, aerobic high-intensity training, comprising 4 × 4 min intervals with 3 min active recovery, increased $\dot{V}O_{2\,max}$ 7% in elite youth and first team senior players when performed twice weekly for 7 weeks in the competitive season [93]. Thus, aerobic high-intensity training can be introduced in the competitive season to augment $\dot{V}O_{2\,max}$, but the effect depends on the volume of aerobic high-intensity training, and how accustomed players are to the training, as not all studies show similar in-season effects [94].

The question then arises whether the augmented $\dot{V}O_{2\,max}$ translates into an enhanced ability to perform high-intensity exercise. A few studies have shown that $\dot{V}O_{2\,max}$ differs between successful and unsuccessful teams within the same league [95, 96], but no such pattern is apparent across top national leagues or between amateur and professional players [97, 98]. Nor does $\dot{V}O_{2\,max}$ correlate well with high-intensity exercise during match-play [99] and appears to be a poor indicator of training status in professional players [100]. And although 4–8 weeks of twice-weekly aerobic high-intensity training (4 × 4 min intervals at 90–95%-max heart rate with 3 min active recovery) increases the number of sprints performed during match-play in players returning from intermission in the early pre-season [23, 24], this possibly reflects the common changes in conditioning during this phase. In young elite players, changes in match running performance do not necessarily match changes in aerobic speed and appear position-dependent [101].

This is not to say that aerobic high-intensity training is not beneficial for football players. Studies show that a period of aerobic high-intensity training is associated with enhanced intermittent running performance, such as during a Yo-Yo intermittent recovery (IR) test [92, 93]—the latter of which correlates with the amount of high-intensity runs during match-play [99, 102]. For example, in the aforementioned study by Jensen et al., Yo-Yo IR level 2 performance increased 15% during the training period [92]. Likewise, in professional players, 4 weeks of aerobic high-intensity training in the competitive season, comprising 5–11 sets 3 min > 90%-max heart rate with 2 min recovery in a small-sided game, enhanced performance 2% during a repeated sprint test (6 × 20 m with 25 s active recovery) [103]. This underlines the utility of aerobic high-intensity training to enhance performance during a period of intensified training in otherwise unaccustomed players in the late preparation phase or competitive season (Table 2).

4.2 Physiological Adaptations

Aside from augmenting $\dot{V}O_{2\,max}$, a period of aerobic high-intensity training induces numerous beneficial adaptations, which include peripheral adaptations in the microvasculature and oxidative capacity of skeletal muscle [104–108]. While not extensively examined in elite football players, aerobic high-intensity training increases capillary density and expands mitochondrial volume in skeletal muscle fibers [104–108]. In semi-professional players returning from intermission, 4 weeks of high-intensity training enhanced the capacity for oxidative metabolism of the trained muscle as reflected by an increased capillary density and in vitro maximal activity of citrate synthase and hydroxyacyl-CoA dehydrogenase (HAD) in muscle homogenates [109]. Such adaptations favor the exchange of substrates and metabolites due to a greater capacity for microvascular diffusion and oxidative metabolism, and allow the muscle to engage in oxidative energy-generating processes faster [110]. This, in turn, lowers the reliance on anaerobic metabolism and pushes the threshold for when ionic and metabolic perturbations occur [27]. Indeed, muscle biomarkers of oxidative capacity and capillarization correlate with distances covered by football players during match-play [102]. Furthermore, the capacity of aerobic energy systems is a determinant of the ability to re-synthesize muscle phosphocreatine between intense actions [111] and is associated with the rate of elimination and restoration of $lactate^-$ and H^+ homeostasis [27]. Together, these adaptations allow the working muscles to recover faster after intense actions.

5 Speed Endurance Training

5.1 Performance Adaptations

Several studies highlight the effectiveness of SET to enhance performance across a range of sports [21]. Football is no

Table 2 Effect of aerobic high-intensity training in the late preparation phase or competitive season on selected outcomes in elite football players

Study	Players	Training regimen					Adaptations	
		Dose	Intensity	Period	When	Mode	Physiological	Performance
Chamari et al. (2005) [144]	18 Elite Youth	4 × 4 min 3 min rest 2/wk	90–95% HR_{max}	8 wks	In-season	Drills/SSG	+ 8% VO_{2max} + 10% RE 7 km × h^{-1}	+ 10% distance covered during technical drill
McMillan et al. (2005) [145]	11 Elite Youth	4 × 4 min, 3 min rest 2/wk	90–95% HR_{max}	10 wks	Late season	Drills	+ 9% VO_{2max}	↔ 10 m sprint
Impellizzeri et al. (2006) [24]	15 Elite Youth	4 × 4 min, 3 min rest 2/wk	90–95% HR_{max}	4 + 8 wks	Late preparation & in-season	Runs	+ 8% VO_{2max} + 3% RE at lactate threshold	+ 6% match distance + 20% match runs (> 14 km × h^{-1})
Impellizzeri et al. (2006) [24]	14 Elite Youth	4 × 4 min, 3 min rest 2/wk	90–95% HR_{max}	4 + 8 wks	Late preparation & in-season	SSG	+ 7% VO_{2max} + 3% RE at lactate threshold	+ 4% match distance + 26% match runs (> 14 km × h^{-1})
Jensen et al. (2007) [92]	16 Elite Youth	5–6 × 2–4 min, 1–2 min rest 1/wk	Not specified	12 wks	In-season	SSG	+ 5% VO_{2max}	+ 15% Yo-Yo IR2 + 21% RSA fatigue index
Ferrari Bravo et al. (2008) [93]	13 Elite Youth and first team	4 × 4 min, 3 min rest 2/wk	90–95% HR_{max}	7 wks	In-season	Runs	+ 7% VO_{2max}	+ 12% Yo-Yo IR1 ↔ RSA ↔ 10 m sprint
Sporis et al. (2008) [146]	24 Elite Youth	3 × 20 m; 3 × 40 m; 3 × 60 m; 2 min rest 3/wk	90–95% HR_{max}	13 wks	Late preparation & in-season	Drills	+ 5% VO_{2max}	+ 6% 200 m time + 4% 400 m time + 8% 800 m time + 7% 1200 m time + 7% 2400 m time
Owen et al. (2012) [103]	15 Elite	5–11 × 3 min, 2 min rest 1–2/wk	> 90% HR_{max}	4 wks	In-season	SSG	+ 4% RE 14 km × h^{-1}	+ 1% RSA best sprint + 2% RSA total sprint
Jastrezebski et al. (2013) [94]	11 Youth	7 sets 6 × 15 s/15 s, 1.5 min rest 2/wk	85–90% HR_{max}	8 wks	In-season	Runs	↔ VO_{2max} ↔ Anaerobic power	↔ 5 and 30-m sprint
Belegisanin (2017) [147]	23 Professional	6–12 min 15–30 s, 15 s rest 1–2/wk	≈100% vVO_{2max}	8 wks	In-season	Runs	+ 6% VO_{2max}	-

HR_{max} maximum heart rate, *RE* running economy, *RSA* repeated sprint ability, *SSG* small-sided games, *VO_{2max}* maximal oxygen consumption, *vVO_{2max}* velocity eliciting VO_{2max}, *Yo-Yo IR1/2* Yo-Yo intermittent recovery test level 1 or 2, + denotes a beneficial effect

exemption. A period of intensified training with SET-P or SET-M conducted in the late preparation phase or the competitive season enhances the ability to perform high-intensity exercise in elite players [46, 112–116] (Table 3). The addition of only a small volume SET appears sufficient to enhance high-intensity performance. Adding one weekly 30-min SET-P session (6–9 × 30 s at 90–95%-max speed with 3 min recovery) for 5 weeks in the competitive season enhanced Yo-Yo IR level 2 performance 11% in semi-professional players [115]. And in first division players, 13 SET-M sessions during 9 weeks in the final part of the half-season, comprising 2–3 sets 8–10 × 30-m sprints with 10 s recovery, enhanced Yo-Yo IR level 1 by 12% [114]. In the latter study, the team gained more points during the intervention period (13 points in seven matches) than in the preceding period (4 points in ten matches). Similar beneficial effects of SET are seen in elite youth players during periods of intensified training in the competitive season [112, 113].

Although performance adaptations to SET-P and SET-M overlap to some extent, dissimilarities can occur [21, 117]. In professional youth players, 3 weeks SET (6–8 × 20-s sprints three times weekly) conducted in the competitive season enhanced Yo-Yo IR level 2 performance 10% with 120 s recovery between sprints (i.e., SET-P) but only 4%

with 40 s recovery (i.e., SET-M) [113]. The same applied to repeated sprint ability [113]. Likewise, SET-P enhanced Yo-Yo IR level 2 performance more than SET-M in amateur youth players when added twice weekly for 4 weeks in the competitive season [81]. While these studies tend to favor SET-P over SET-M, cross-study analyses reveal no clear differences between SET-P and SET-M on intermittent running performance in elite players (Fig. 2 and Table 3). But given the greater heart rate response and presumably cardiovascular load with SET-M compared to SET-P [29, 118], it may well be that SET-M is superior in terms of maintaining or increasing the aerobic capacity, whereas SET-P possibly induces greater anaerobic stimuli and external load [29]. Notwithstanding, studies demonstrate that both forms of SET effectively enhance the ability to perform high-intensity exercise in elite football players during a period of intensified training (Table 3).

5.2 Physiological Adaptations

SET induces numerous adaptations of importance for performance during high-intensity exercise [21, 27]. But unlike aerobic training, performance enhancements in athletes exposed to a period of SET seldom reflect adaptations in $\dot{V}O_{2\,max}$, capillarization, and muscle oxidative capacity as these factors remain unaltered or even lowered [21, 114, 119–124]. Instead, studies show that SET augments the capacity of ion transport systems in the trained muscle [21, 125–127].

A period of intensified training with SET upregulates subunits of the Na^+/K^+-ATPase in skeletal muscle [21]. Such adaptation counters exercise-related K^+ and Na^+ shifts and accelerates restoration of K^+ and Na^+ balance in recovery between intense actions [21]. Indeed, the muscle content of Na^+/K^+-ATPase subunits correlates with the amount of high-intensity runs during match-play [102]. Furthermore, SET increases the capacity for H^+ and lactate$^-$ removal, as well as enhances H^+ buffer capacity in skeletal muscle [21]. This allows the contracting muscle fibers to counter the decline in myoplasmic pH and preserve glycolytic flux during intense exercise [27]. For example, in a study by Gunnarsson et al., semi-professional players subjected to once-weekly SET-P for 5 weeks exhibited a 9% higher muscle content of the key lactate$^-$/H^+ co-transporter (MCT1), which was associated with 11% better performance during a Yo-Yo IR level 2 test [115]. Some studies also show that SET enhances the running economy of semi-professional players [114, 115], which aside from neuromuscular and tendon adaptations, may involve a reduction of sarcoplasmic reticulum Ca^{2+}-ATPase isoform 1 (SERCA1) in the trained muscle [27, 128]. Together, these adaptations enhance the ability to counter exercise-related ionic shifts and metabolic perturbations, and explain much of the improved ability to perform repeated high-intensity exercise with a period of SET.

6 Combined or Mixed Interval Training

6.1 Performance Adaptations

Given the beneficial effects of aerobic high-intensity training and SET, one is tempted to ask whether it is relevant to combine or mix weekly sessions of both aerobic and anaerobic training during periods of intensified training. The general idea is to retain or increase the capacity of aerobic energy systems while concomitantly gaining the adaptations of SET. Dupont et al. [129] examined this in professional players training 8–10 times weekly. In the study, players underwent a 10-week intensified period of aerobic high-intensity training and SET incorporated into the usual training twice weekly during the competitive season. The training enhanced maximal aerobic speed ≈8% and mean performance during a repeated 40-m sprint test 3.5% (5.56 to 5.35 s) [129]. The aerobic high-intensity training comprised two sets 12–15 × 15-s at 120%-max aerobic speed with 15 s recovery once weekly, while the SET comprised 12–15 × 40-m sprints (≈ 5.5 s) with 30 s recovery once weekly. Notably, during the intensified training period, the team won 78% of matches, which was considerably better than the 33% win rate during the 10 weeks preceding the training period [129].

Similar effects have been observed in semi-professional players during 2 weeks of intensified training with ten sessions of aerobic high-intensity training (8 × 2 min with 1 min recovery) and SET-P (10–12 × 25- to 30-s sprints with 3 min recovery) concomitant with a 30% reduction in weekly training time at the end of the competitive season [124, 126]. Though the training did not significantly increase Yo-Yo IR level 2 performance (937 m before vs. 994 m after the training), it enhanced mean repeated sprint time 2.6% and running economy at 75% maximal aerobic speed (from 198 to 193 $mL \times kg^{-1} \times km^{-1}$) [124].

From these concurrent training studies (Table 4), it is not possible to decipher the contribution of each training form for the performance adaptations. But combined training comprising aerobic high-intensity training and SET has been shown to elicit beneficial performance effects across a range of sports—especially in endurance sports where aerobic high-intensity training often is added during intensified training periods to maintain or enhance the capacity of aerobic energy systems despite significant reductions in overall training volume of low-to-moderate intensity aerobic training (sometimes up to 70% reduction), while achieving the beneficial effects of SET on the ability to tolerate and counter metabolic and ionic disturbances [119, 125, 127, 128, 130].

Fewer studies have investigated the effect of mixed interval training forms. 10–20–30 training performed 2–3

Table 3 Effect of speed endurance training (SET) in the late preparation phase or competitive season on selected outcomes in elite football players

Study	Players	Training regimen					Adaptations	
		Dose	Intensity	Period	When	Mode	Physiological	Performance
SET—production training								
Gunnarsson et al. (2012) [115]	18 Semi-professional	5–9 × 30 s, 3 min rest 1/wk	All out	5 wks	In-season	Drills	↔ VO_{2max} + 6% RE at 10 km × h^{-1} (+ 3%) RE at 14 km × h^{-1}	+ 11% Yo-Yo IR2 ↔ Agility ↔ 10 & 30 m sprint
Iaia et al. (2015) [113]	6 Elite Youth	6–8 × 20 s, 2 min rest 3/wk	All out	3 wks	End of season	Runs	–	+ 10% Yo-Yo IR2 + 3% RSA ↔ 200 m run ↔ 20 & 40 m sprint
Macpherson and Weston (2015) [116]	14 Semi-professional	4–6 × 30 s, 4 min rest 3/wks	All out	2 wks	In-season	Runs	+ 3% VO_{2max}	+ 18% Yo-Yo IR1
Iaia et al. (2017) [112]	10 Elite Youth	1–3 sets 6 × 5 s/30 s recovery, 2 min rest 1–2/wk	All out	5 wks	In-season	Runs	–	(+ 6.5%) Yo-Yo IR2 + 3.6% RSA (+ 1.3%) 200 m run + 2.7% 20 m sprint
SET—maintenance training								
Ferrari Bravo et al. (2008) [93]	13 Elite Youth & first team	3 sets 6 × 40 -m sprints/20 s recovery, 4 min rest 2/wk	All out	7 wks	In-season	Runs	+ 5% VO_{2max}	+ 28% Yo-Yo IR1 + 2.1% RSA ↔ 10 m sprint
Wells et al. (2014) [46]	8 Elite	2 sets 2–4 × 60 s, 2 min rest 2 sets 3–5 × 35 s, 2 min rest 2 sets 5–7 × 10 s, 2 min rest 3/wk	All out	6 wks	In-season	Runs	↔ VO_{2max} ↔ VO_2-kinetics + 9% Anaerobic power	+ 13% Yo-Yo IR2
Iaia et al. (2015) [113]	7 Elite Youth	6–8 × 20 s, 40 s rest 3/wk	All out	3 wks	End of season	Runs	–	+ 4% Yo-Yo IR2 ↔ RSA + 2% 200 m run ↔ 20 & 40 m sprint
Nyberg et al. (2016) [114]	16 Semi-professional	2–3 sets 8–10 × 5 s/10 s recovery, 3 min rest 1–2/wk	All out	9 wks	In-season	Runs	+ 2% RE at 10 km × h^{-1} ↔ RE at 16 km × h^{-1} + 11% VO_2-kinetics	+ 12% Yo-Yo IR1
Iaia et al. (2017) [112]	9 Elite Youth	1–3 sets 6 × 5 s/15 s recovery, 2 min rest 1–2/wk	All out	5 wks	In-season	Runs	–	+ 11% Yo-Yo IR2 + 2.6% RSA + 2.0% 200 m run (+ 1.5%) 20 m sprint

HR_{max} maximum heart rate, *RE* running economy, *RSA* repeated sprint ability, *SSG* small-sided games, *VO_{2max}* maximal oxygen consumption, *vVO_{2max}* velocity eliciting VO_{2max}, *Yo-Yo IR1/2* Yo-Yo intermittent recovery test level 1 or 2

+ denotes a beneficial effect, and if in parentheses, then the effect was not clear (i.e., $p > 0.05$)

times weekly for 10 weeks in the competitive season was shown to enhance Yo-Yo IR level 1 performance 18% in sub-elite players and to a greater extent than a matched group performing speed training (2–3 sets of 6 × 6-s sprints with 54 s passive recovery and 4 min rest between sets) [131]. The 10–20–30 training comprised 2–3 sets of 10-s maximal

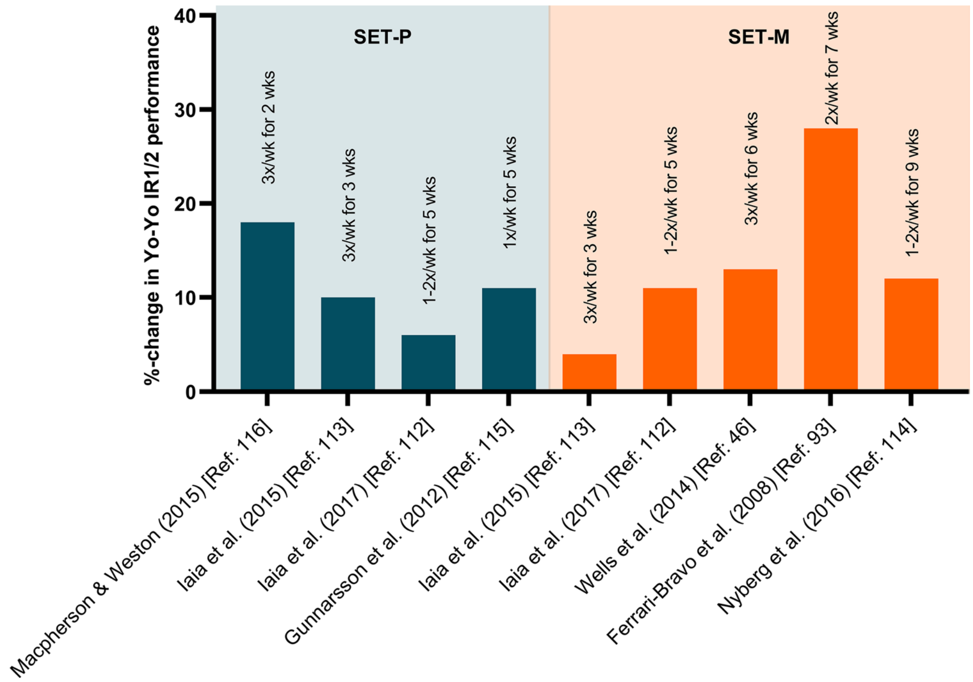

Fig. 2 The effect of speed endurance production (SET-P) and maintenance (SET-M) training on Yo-Yo intermittent recovery (IR) level 1 or 2 performance during a period of intensified training conducted in the late preparation phase or the competitive season in elite football players

bursts, 20 s at moderate speed, and 30 s jogging repeated five times, and elicits a high aerobic and anaerobic load as reflected by ≈45% time spent at > 90%-max heart rate and 10–23 mM blood lactate^{-} levels [132].

Thus, combined aerobic high-intensity training and SET can be used to intensify the training and enhance performance in the late-preparation phase and competitive season in both semi-professional and professional players.

6.2 Physiological Adaptations

In one of the studies combining aerobic high-intensity training with SET, performance adaptations were associated with a 15% greater muscle content of the catalytic α_2-subunit of the Na^+/K^+-ATPase and 27% higher activation of its regulatory FXYD1 (phospholemman) subunit [126]—the latter of which predicted 36% of the change in repeated sprint time (Fig. 3A). In addition, muscle pyruvate dehydrogenase (PDH) content increased 17%, while MCT1 tended

Table 4 Effect of combined aerobic and anaerobic training in the late preparation phase or competitive season on selected outcomes in elite football players

Study	Players	Training regimen					Adaptations	
		Dose	Intensity	Period	When	Mode	Physiological	Performance
Dupont et al. (2004) [129]	22 Professional	12–15 × 15 s, 15 s rest 1/wk 12–15 × 40 m, 30 s rest 1/wk	120% vVO_{2max} All out	10 wks	In-season	Runs	8% maximal aerobic speed	+ 3.5% 40-m sprint
Thomassen et al. (2010) [126] and Christensen et al. (2011) [124]	7 Semi-professional	8 × 2 min, 1 min rest 2.5/wk 10–12 × 25–30 s, 3 min rest 2.5/wk	88% HR_{max} All out	2 wks	End of season	SSG/Drills	+ 2.6% RE at 75% maximal aerobic speed ↔ VO_2-kinetics	↔ Yo-Yo IR2 + %1.8 RSA

HR_{max} maximum heart rate, *RE* running economy, *RSA* repeated sprint ability, *SSG* small-sided games, *VO_{2max}* maximal oxygen consumption, *vVO_{2max}* velocity eliciting VO_{2max}, *Yo-Yo IR1/2* Yo-Yo intermittent recovery test level 1 or 2

+ denotes a beneficial effect, and if in parentheses, then the effect was not clear (i.e., $p > 0.05$)

to increase 13%, which suggests that the players achieved a greater capacity for pyruvate to be directed towards the citric acid cycle and ability to extrude lactate⁻ and H^+ [27]. Because the training did not change $\dot{V}O_2$-kinetics or oxidative enzymes, fiber-type composition, and fiber cross-sectional area of the trained muscle [124, 126], the performance enhancements appear to be attributed to a greater ability of the trained muscle to counter ionic shifts, as well as an improvement of running economy.

In the 10–20-30 training study, the players increased muscle content of proteins involved in oxidative metabolism and ion transport, including a 51% increase in complex I-V of the electron transport chain and 27–33% increase in Na^+/K^+-ATPase subunits α_2 and β_1 [131]. Therefore, the enhanced Yo-Yo performance likely related to a greater ability to counter ionic and metabolic perturbations. Indeed, change in Na^+/K^+-ATPase β_1 subunit content predicted 46% of the change in Yo-Yo IR level 1 performance with the training (Fig. 3B, unpublished data) [131]. Hence, it appears that a period of combined or mixed training forms with both aerobic and anaerobic components not only upregulates Na^+/K^+-ATPase subunits in skeletal muscle of football players but also accentuates its activation via FXYD1. This likely aids players' ability to counter K^+ and Na^+ disturbances during intense actions [27].

6.3 Practical Considerations

Before conducting periods with intensified training, one needs to consider several factors, which include seasonal phase, match schedule, and player load. Because professional players may participate in > 50 matches during the season, this hardens the planning of intensified training, and coaches should carefully consider the overall load imposed on the players [133]. The COVID-19 epidemic illustrates the challenges of a packed match schedule that constraints the time for training and recovery. For example, in the 2020/21 season, Chelsea FC played eight matches during 4 weeks in May of which two were finals—the FA Cup and UEFA Champions League. It is a matter of prudently dosing the training load when introducing periods with intensified training during the competitive season. Thus, we recommend conducting intensified training mainly during periods with one weekly match, or during shorter season breaks, and with a 15–30% reduction in training volume by reducing the time spent on low-to-moderate intensity exercise. Match program constraints often only allow for intensified training periods of 1–2 weeks. Despite the short duration and concomitant reduction in training volume, studies show beneficial performance effects of intensified training in football players for periods of only a few weeks [89, 113, 115, 124, 126].

Table 5 provides an overview of practical considerations of training forms utilized during intensified training periods conducted in the late preparation phase or competitive season in elite football players specifically related to training effects, performance outcomes, and individual/contextual factors using the framework described by Jeffries et al. [134]. Given that aerobic fitness is essential for recovery processes, we recommend aerobic high-intensity training as a fundamental part of the majority of microcycles both in and out of season but with different dosing strategies. Detraining off-season reduces physical fitness and likely increases the risk of injury during the subsequent pre-season phase when the training load increases [43]. For this reason, the off-season should be considered a transition period to

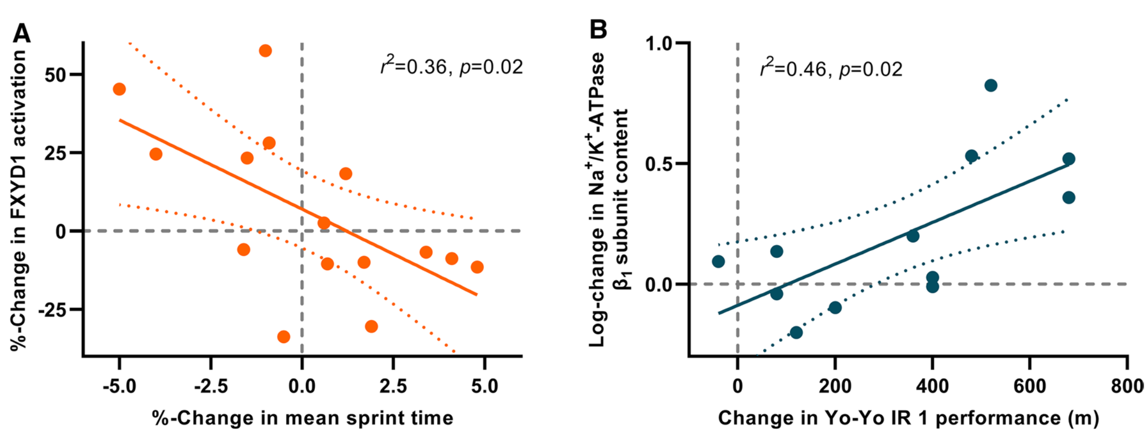

Fig. 3 **A** Correlation between change in muscle FXYD1 (phospholemman) activation, a regulatory subunit of the Na^+/K^+-ATPase, and change in mean sprint time during a repeated sprint test (10 × 20 m) over 2 weeks' combined speed endurance production training and aerobic high-intensity training in semi-professional football players. Adapted from Thomassen et al. [126]. **B** Correlation between change in muscle Na^+/K^+-ATPase β_1 subunit content and change in Yo-Yo intermittent recovery (IR) level 1 performance over 10 weeks 10–20–30 training in sub-elite football players. Unpublished data from Hostrup et al. [131]

prepare players for the loads imposed during the pre-season preparation phase. Even small doses of once-weekly aerobic high-intensity training off-season maintain or improve aerobic fitness in football players [135] and should be combined with progressive increments in the amount of resistance training [136, 137]. In the pre-season phase leading up to the start of the competition season, we recommend progressively increasing the dose of aerobic high-intensity training up until the late preparation phase (typically a few weeks before the season starts).

During the late preparation phase, the amount of SET and speed training is increased while lowering the amount of low-to-moderate intensity aerobic training. An advantage of SET-based training is that it is time-efficient, implements easily in drills with ball, and a small dose elicits beneficial effects [89, 115]. Only one to one and a half weekly sessions of SET for 5–9 weeks during the competition season were sufficient to enhance intermittent running performance of highly trained players [114, 115]. Thus, when the competitive season has started, SET can still be administered but should be dosed accordingly. The combination of aerobic high-intensity training and SET is relevant for substitute and rotation players throughout the competitive season. A busy match schedule seldom allows for both types of HIIT to be performed simultaneously in players playing > 60 min per match.

If constraints allow it, then the selection of training regimen can be based on the individual needs of players and incorporated in technical or tactical drills with balls to optimize specificity and translation. If the aim is to improve aerobic fitness and ability to recover, then aerobic high-intensity training should be prioritized. Although any player needs a basal level of aerobic fitness, aerobic high-intensity training is particularly relevant for central midfield players who often need to cover longer distances and have shorter recovery periods than other playing positions [56]. One can also consider periods with SET-M, as blocks with SET-M make the players able to tolerate fatigue and sustain the many runs at high speeds, while still imposing a high cardiovascular load in the training. Wingers and full-backs, who typically perform numerous high-intensity runs [138], likely benefit from SET-M because they need to tolerate the severe metabolic and ionic perturbations with less time to recover between the

Table 5 Practical considerations of training forms utilized during intensified training periods conducted in the late preparation phase or competitive season in elite football players

Training form	Parameters	Description
AHT	Prescription	Twice weekly for 2–4 weeks during the late preparation phase and once or twice weekly for 1–2 weeks in-season
	Internal load	High cardiovascular load, moderate muscle metabolic load, and some musculoskeletal load
	External load	Efforts at intensities near or slightly exceeding that corresponding to aerobic capacity
	Positive effects	Enhances the ability to cover long distances of high-speed running and recover from intense actions
	Negative effects	Induces neuromuscular fatigue
	Other factors & considerations	Can be performed early and later in the weekly microcycle (until 48 h pre-match) Relevant to central midfielders, wingers, and full-backs in-season
SET-M	Prescription	Once or twice weekly for 1–2 weeks during the late preparation phase or in-season
	Internal load	Imposes musculoskeletal strain, a high muscle metabolic, and a moderate cardiovascular load
	External load	Near all-out efforts at high speeds and intensities
	Positive effects	Enhances the ability to tolerate fatigue and sustain high-speed runs
	Negative effects	Depresses neuromuscular function and induces micro-damages in muscles taking days to recover from
	Other factors and considerations	Should be performed early in the weekly microcycle (until 72 h pre-match) Particularly relevant to central midfielders, wingers, and full-backs in-season
SET-P	Prescription	Once or twice weekly for 1–2 weeks during the late preparation phase or in-season
	Internal load	Imposes severe musculoskeletal strain and a high muscle metabolic load
	External load	All-out efforts at high speeds and intensities
	Positive effects	Enhances the ability to perform repeated high-speed runs and sprints
	Negative effects	Depresses neuromuscular function and induces micro-damages in muscles taking days to recover from
	Other factors and considerations	Should be performed early in the weekly microcycle (until 72 h pre-match) Particularly relevant to center-backs, strikers, wingers, and full-backs in-season

AHT aerobic high-intensity training, *SET-M* speed endurance maintenance training, *SET-P* speed endurance production training. The framework is based on Jeffries et al. [134]

intense actions than other playing positions. Attackers and center-backs usually have longer recovery periods but more intense actions [56, 76, 138]. For these players, SET-P may be particularly relevant, as it comprises all-out efforts with long recovery, and effectively enhances the ability to perform repeated high-speed running and sprinting [29].

Because SET, and SET-P in particular, induces high internal and external loads, often comprising repeated high-speed runs, sprints, and cuts, we recommend prescribing SET drills at least 72 h before a match (i.e. early in the weekly microcycle) and at the end of training sessions so that it does not impact the quality of other training focuses due to its acute negative effects (e.g., fatigue) [29]. While not extensively investigated in elite players, SET-P and SET-M induce severe acute neuromuscular fatigue in sub-elite players for which the early fatigue profile is severest for SET-P, while SET-M imposes a more prolonged depression of neuromuscular function for several days possibly due to the greater volume of high-intensity stretch–shortening cycle actions [29]. Therefore, the coach needs to be cautious when prescribing SET to unaccustomed players.

The planning of intensified training in the late preparation phase or the season also varies according to team level. In our experience, lower-division teams often down-prioritize physical training, which relates to the conception that physical training constraints time for technical and tactical training. However, blocks of HIIT implements easily with technical drills and small-sided games [79]. Table 6 illustrates how a typical week with intensified training can be structured for professional and semi-professional teams during periods of once-weekly matches in the season.

7 Conclusion

The evolution of football imposes greater demands on the players, especially in terms of their ability to cope with the increasing match intensity both with and without the ball [2, 7–9, 139]. In modern football, managers are ever more seeking fast and skillful players who have exceptional physical conditioning to perform repetitive high-intensity exercise and who can tolerate high weekly training and match loads [9–11, 139]. Constraints of a busy match schedule make it challenging for coaches to plan physical training in phases leading up to the start of the season and, in particular, during the competitive season. However, coaches can utilize periods of intensified training during these phases to enhance players' ability to perform intermittent exercise at high intensities with only small doses of HIIT strategies. The addition of aerobic high-intensity training once or twice weekly can improve the capacity of aerobic energy systems and pushes the threshold for when ionic and metabolic perturbations, and hence fatigue, occurs. Furthermore, the ability to perform repeated high-intensity exercise can be enhanced by introducing only a small-volume SET once or twice weekly, which relates to a greater capacity of muscle ion transport systems and improved running economy. Players can also achieve beneficial performance adaptations with combined or mixed aerobic high-intensity training and SET. With such an approach, the capacity of aerobic energy systems can be retained or increased while concomitantly gaining the beneficial adaptations of SET. But given the risk of overload and injuries, periods with intensified training should be carefully planned with consideration of the season plan, match schedule, and player load. Therefore, training volume spent at low-to-moderate intensity is often reduced dramatically during intensified training periods.

Table 6 Week plan during a period of intensified training with aerobic high-intensity training (AHT), speed endurance maintenance (SET-M) and production training (SET-P)

	Professional		Semi-professional	
	Morning	Afternoon	Morning	Afternoon
Sunday		Match		Match
Monday	Recovery activities *AHT (8 × 2 min)		Recovery activities *AHT (8 × 2 min)	
Tuesday	Technical/tactical training	SET-M (6–8 × 1 min)		SET-M (5–6 × 1 min)
Wednesday		Technical/tactical training		
Thursday	Technical/tactical training	SET-P (4–5 × 20-s)		SET-P (4–5 × 20-s)
Friday	Technical/tactical training Speed training			Technical/tactical training Speed training
Saturday	Technical/tactical training		Technical/tactical training	
Sunday		Match		Match

*Non-match loaded players

8 Directions for Future Research

A limitation of the state-of-the-art related to HIIT effects in football players is that most studies included non-elite players. The few studies performed with semi-professional and professional players typically utilized non-randomized single-group trials with no appropriate control group and small sample sizes [43, 140]. More randomized controlled studies in top-level players are warranted, especially with regards to the dose–response and playing-position specific effects of various forms of HIIT to intensify the training in-season, along with periodized and concurrent strategies during different phases in-season.

Another overlooked area is the effect of HIIT programs on the performance of professional female players. While the relative physical match demands are fairly similar in male and female professional players, some differences are apparent for a range of physiological variables. Among others, male players are vastly more explosive and have greater intermittent endurance capacities than female players [141, 142]. The gap between the sexes is particularly large for activities taxing anaerobic energy systems, while the gap narrows for activities mainly engaging aerobic energy systems [142]. Hence, there may be a potential for increasing the amount of anaerobic training in female players as also suggested by others [138].

It would also be relevant to assess how periods with SET affect the incidence of injuries. Given the high mechanical loads and neuromuscular activation associated with SET, it may be that this training form, if dosed properly, can enhance the ability to cope with the sudden changes in forces and stress inflicted during match play. Such adaptations are relevant considering, for example, the two to six times greater incidence of anterior cruciate ligament injuries in females than male team sport athletes [143], but also with respect to muscle injuries. In general, anaerobic high-intensity training, including sprints and specific actions with high impact on muscles and bone, leads to significant improvements in the player's bone health and muscle growth [89].

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Author contributions Both authors conceptualized and wrote the review, and approved the final version of the manuscript.

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