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REVIEW ARTICLE

Development of Aerobic Fitness in Young Team Sport Athletes

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Abstract The importance of a high level of aerobic fitness for team sport players is well known. Previous research suggests that aerobic fitness can be effectively increased in adults using traditional aerobic conditioning methods, including high-intensity interval and moderate-intensity continuous training, or more recent game-based conditioning that involves movement and skill-specific tasks, e.g. small-sided games. However, aerobic fitness training for youth team sport players has received limited attention and is likely to differ from that for adults due to changes in maturation. Given young athletes experience different rates of maturation and technical skill development, the most appropriate aerobic fitness training modes and loading parameters are likely to be specific to the developmental stage of a player. Therefore, we analysed studies that investigated exercise protocols to enhance aerobic fitness in young athletes, relative to growth and maturation, to determine current best practice and limitations. Findings were subsequently used to guide an evidence-based model for aerobic fitness development. During the sampling stage (exploration of multiple sports), regular participation in moderate-intensity aerobic fitness training, integrated into sport-specific drills, activities and skill-based games, is recommended. During the specialisation stage (increased commitment to a chosen sport), high-intensity small-sided games should be prioritised to provide the simultaneous development of aerobic fitness and technical skills. Once players enter the investment stage (pursuit of proficiency in a chosen sport), a combination of small-sided games and high-intensity interval training is recommended.

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Key Points

- Aerobic fitness should be actively developed in team sport players throughout their development, rather than aligning exercise to specific periods of maturation.
- Sport-specific training programmes should be prioritised throughout development to increase the opportunity for concurrent physical and technical development.
- Training must be accurately prescribed using specific game variables to ensure the desired aerobic fitness adaptations are achieved.

1 Introduction

An important component contributing to successful performance in many invasion team sports is a player's physical ability to repeatedly produce high-intensity intermittent bouts of exercise during games that typically last 60–120 min [1–3]. The aerobic fitness status of an individual largely determines this ability due to its substantial role during recovery, which assists with delaying the onset of fatigue, allowing for high-intensity exercise to be sustained during play [4]. Furthermore, the aerobic energy systems are increasingly taxed as high-intensity exercise is repeated [5]. In addition, an increased aerobic capacity influences a player's technical and tactical performance during a game by allowing them to make better choices under fatigue [6]. Therefore, approaches to develop aerobic fitness in athletes require specific consideration.

In young athletes, fluctuations in the rate of anatomical, neurological, muscular, metabolic and hormonal development occur [7, 8]. These parameters likely play an important role in the ability to adapt to a specific training stimulus. To date, the most well-known model to include such physiological considerations is the long-term athlete development (LTAD) model [9]. The model attempts to balance training load and competition throughout childhood and adolescence. It suggests that through objective physiological assessment, e.g. peak height velocity (PHV), coaches can account for maturation rates for each athlete, and relevant individual training programmes can be prescribed accordingly. Furthermore, based on physiological parameters linked to natural growth and maturation, the model indicates specific periods of accelerated and enhanced physical development, termed 'windows of trainability'. However, recently, an absence of empirical evidence to support the LTAD model has resulted in much conjecture and debate surrounding its use [10]. Specifically, controversy exists in the literature around the timing of the accelerated and decelerated periods of peak oxygen uptake relative to maturity status, or in fact whether or not they even exist [8, 11]. Therefore, at present, the application of 'windows of trainability' by practitioners for the development of aerobic fitness is questionable.

Given the limitations of the LTAD model, the Youth Physical Development (YPD) model was introduced more recently [12]. It encompasses athletic development from early childhood (2 years of age) to adulthood (≥21 years of age) and aims to provide an overview of total physical development while identifying when and why the training of each fitness component should be emphasised. The YPD model proposes that more attention is given to aerobic fitness development as the athlete approaches adulthood, and at no stage is it the main focus of an individual's training. The rationale is based on the assumption that an individual will be exposed to aerobic fitness development during training and competition in their sport to a level that is adequate to participate successfully. However, as a result, this model does not provide any recommendations for how sport-specific activities that inherently develop aerobic fitness should be prescribed for team sport athletes.

More general descriptions of athlete development have also been proposed [13, 14]. The developmental model of sports participation (DMSP) was proposed by Côté et al. [14] based on retrospective studies of team sports [15–18]. The DMSP characterises development as a three-stage approach, with 'sampling', 'specialisation' and 'investment' broadly describing the process through which an athlete transitions. The different stages within the development process from beginner to elite level are based on changes in the type and amount of participation in sport activities, such as deliberate play, deliberate practice, and general and specific strength and conditioning, that are involved with training and competition [19]. Although such a model may present an oversimplified representation of athlete development and transition [20], it is based on recent evidence describing the types of activities in which young athletes engage throughout their progression to an elite level. Therefore, the DMSP model provides a practicable framework within which specific physiological components, such as aerobic fitness, can be incorporated and expanded.

With this in mind, the purpose of this paper is to review the development of aerobic fitness in team sport athletes throughout male youth, defined as players between the ages of 9 and 17 years. The focus on males only is due to differences in timing and tempo of maturation between sexes, and subsequent differences in physical and physiological characteristics from the onset of puberty [21, 22]. First, a brief review is provided on the natural development and generic trainability of aerobic fitness in youth, which is important to understand when considering young athletes. Second, training programmes specifically aimed at developing aerobic fitness in team sport players are reviewed to determine the most appropriate and effective training stimulus for a given development stage.

2 Determining Maturity Status of Young Athletes

Between the ages of 9 and 17 years, the biological development of an individual can vary considerably, in terms of timing and duration, compared with another athlete of the same chronological age [23–26]. Consequently, it is important to account for maturity status when investigating the development of young athletes to allow for classifications as 'on time', 'late' or 'early' in maturation [27]. Moreover, monitoring physical and physiological changes due to maturation and training allow the responsiveness to various training stimuli to be determined. The most common clinical method to determine biological maturity uses plain X-ray of the left hand, wrist or knee [27], and this has been used extensively to classify athletes according to their skeletal age [28–30]. However, the expense and ethical issues of invasive measures need to be carefully considered in non-clinical situations. Alternatively, sexual maturity revealed by secondary sex characteristics, such as pubic hair development, has been used to determine maturation (i.e. Tanner staging) and found to be consistent with skeletal maturity [31]. Nevertheless, this method requires physical examinations of participants by an experienced investigator, which is also invasive and can be an expensive and time-consuming process.

In a sporting context, cheaper and less invasive assessments of maturation, while still being accurate, are more appropriate. Accordingly, maturational status based on Tanner staging can be estimated via self-assessment questionnaires [32, 33], though this still requires administration by a qualified examiner and willingness by participants to engage in the process. More recently, two non-invasive, practical methods of predicting maturity status have been introduced in studies with young athletes. The first determines maturation using maturity-based cumulative height velocity curves that predict mature height [34]. Second, a measure that predicts years from PHV (a maturity offset value) using simple objective anthropometric measures has been developed [26] and widely adopted [22, 27, 35, 36]. PHV describes the point during maturation when the rate of growth in stature is at its maximum [26]. Rather than chronological age, years from PHV is used to characterise changes in body size, body composition and performance relative to changes in height [22, 27]. Maturity status can be expressed as pre-PHV (>1 year prior to PHV), mid-PHV (±1 year from PHV) and post-PHV (>1 year post-PHV) and comparisons of any changes in physical capacity or performance made accordingly. Such an approach is an excellent method for classification of young team sport players when interpretation of physical tests is being conducted. However, limitations exist, as the accuracy of PHV usually requires serial measurements for a numbers of years surrounding the occurrence of PHV and can only be used retrospectively. Furthermore, given that the protocols for prediction of PHV are based on populations with European ancestry, further research is required with athletes of diverse ethnic backgrounds [37].

3 Natural Development of Aerobic Fitness in Youth

The status and functioning of the respiratory, cardiovascular and metabolic systems combine to determine an individual's aerobic fitness. In exercise science, a number of measures can be determined to characterise an individual's aerobic ability, including work economy, lactate threshold (LT), oxygen uptake ($\dot{V}O_2$) kinetics and peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) [38], with the latter being the most commonly used measure by which aerobic fitness is assessed [7].

The natural development of $\dot{V}O_{2peak}$ during growth and maturation has been investigated with both cross-sectional [22, 39, 40] and longitudinal [21, 41–45] research designs. Absolute $\dot{V}O_{2peak}$ increases approximately 200 ml·min^{-1} per year prior to puberty [46] and continues to increase until ~16 years of age in males and ~13 years of age in females [27, 47]. The presence of a growth spurt in $\dot{V}O_2$ (i.e. a non-linear increase) similar to that for height has been indicated, with the estimated maximum rate of development in $\dot{V}O_2$ (ml·min^{-1} per year) occurring near the time of PHV [21, 22]. Following PHV, $\dot{V}O_{2peak}$ continues to increase in both sexes, with males having higher values than females at all ages [21]. These increases are predominantly attributed to changes in central mechanisms that occur with growth, including an increase in the size of the heart, lungs and muscles, and in blood volume [46]. Size-independent mechanisms, such as the activation of cellular aerobic enzymes [21, 48] and increases in circulating hormones (e.g. testosterone) [46], have also been suggested to contribute to the increase in $\dot{V}O_{2peak}$ during growth. However, further research is needed to investigate how these mechanisms contribute to the natural development of aerobic fitness in youth specifically.

4 Development of Aerobic Fitness with Training

Physical training of 3–4 sessions per week for 8–12 weeks has been shown to increase $\dot{V}O_{2peak}$ over and above the normal increase attributable to age and maturation by around 8–10 % [11]. However, the response to aerobic training is conflicting, especially in pre-PHV children. In support of the proposed 'window' for aerobic fitness development (i.e. after PHV onset) [9], longitudinal studies have reported that $\dot{V}O_{2peak}$ increases only slightly prior to PHV, despite 3–4 years of prior training, and thus specific aerobic fitness training at prepubescent ages may not appreciably improve this component [49, 50]. The reasons for this are not clear, but stroke volume is reported to be similar in trained and untrained prepubescent boys, suggesting that a potential limitation is cardiac development prior to puberty [51]. In contrast, more recent studies have reported significant improvements in $\dot{V}O_{2peak}$ pre-PHV following training [52–54]. Differences in the activity history of participants, or in exercise protocol (i.e. intensity and duration), may have contributed to the discrepancies in findings between the studies. Therefore, it appears that aerobic performance can still be enhanced during the pre-PHV stage of development. Studies utilising participants at mid-PHV are limited but indicate increases in $\dot{V}O_{2peak}$ in males following training [55, 56]. Improvements in aerobic performance during this stage of development have been related to changes in hormone secretion during maturation [7].

The discrepancy in the literature in terms of whether a 'window' does in fact exist is likely due to a lack of well-monitored training protocols that are similar in their exercise type, duration, intensity and recovery period. Furthermore, much of the evidence for the development of aerobic fitness in young individuals is based on cross-sectional studies, which restricts inferences due to a lack of causality. To assess changes in aerobic fitness during growth and the influence of training concurrently, further research involving training studies at specific PHVs and across different maturity levels, together with well-planned longitudinal studies, are required. In the meantime, aerobic fitness should be actively developed throughout childhood and adolescence rather than aligning exercise prescription to any specific 'windows of opportunity' [10, 57].

5 Analysis of Methods to Increase Aerobic Fitness in Young Team Sport Athletes

The aim of this review was to depict the current practices used by young team sport players to enhance aerobic performance. Subsequently, findings were used to guide an evidence-based model for aerobic fitness development. This analysis is relevant to the context of team sport athlete development and relative to growth and maturation. All young athletes in reviewed studies were categorised into sampling (∼6–12 years), specialisation (∼13–15 years) and investment years (∼>16 years). This classification, which has been used in a previous review [58], corresponds approximately to the years prior to PHV, around PHV and post-PHV for males, respectively [27]. Despite the practical usefulness of classifying athletes according to chronological age, limitations exist due to differences in the stage of maturation (i.e. early, on time, and late maturation) across athletes within the same development stage.

5.1 Search Strategies and Inclusion Criteria

The electronic databases PubMed, Google Scholar, SPORTDiscus, and MEDLINE were searched multiple times between 1 September 2012 and 31 October 2012 for articles published between the years 1950 and 2013. The following keywords were used in various combinations during the electronic searches: 'team sport', 'athletes', 'youth', 'child', 'aerobic', 'fitness', 'aerobic power', 'high-intensity', 'small-sided games', 'interval', 'running'. References were also identified from textbooks of sports science and aerobic and anaerobic training. The identified articles, manuscripts and thesis reference sections were also scanned to identify further studies. The studies were required to be written in English. Final selections were based on team sport populations under the age of 18 years ($n = 14$).

5.2 Data Analysis

To evaluate the magnitude of the training effects, percent change [(post mean (X) − pre X) ÷ pre $X \times 100$] was calculated for each dependent variable. To account for the variance of the change within and between groups, effect size (ES) calculations [(post X − pre X) ÷ pre-standard deviation (SD)] were also included. The standardised effects were classified as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), very large (2.0–4.0) and extremely large (>4.0) [59]. The main training variable of interest was $\dot{V}O_{2peak}$, but other aerobic fitness variables and performance outcomes were included when reported in the studies. The results of the analysis were discussed according to different factors thought to influence training adaptations in youth team sport players, such as development stage/maturity, training duration, training sessions and training modes.

5.3 Athlete Characteristics

A total of 361 team sport athletes were investigated, including 326 as part of intervention groups in 13 separate studies and 35 athletes acting as controls in three studies (Table 1). Chronological age ranged from 11 to 17 years, with an estimated mean age of 15.5 ± 1.6 years. Maturation was directly (Tanner stages) assessed in five studies ($n = 141$) and indirectly (PHV) assessed in two studies ($n = 39$). The non-inclusion of maturity assessment in many of the studies made it impossible to differentiate between participants across studies based on biological development. Instead, as outlined in the DMSP, athletes were categorised by chronological age into development stages of sport participation [14]. Accordingly, 20 athletes were in their sampling years [60], 171 in their specialisation years [6, 32, 61–66] and 135 in their investment years [35, 61, 67–70]. A high proportion of the athletes investigated were playing their chosen sport at the junior elite level (80 %), whereas the remaining athletes played at junior club level (14 %) or were recreational players (6 %). Weekly training and playing time was 7.5 h per week for sampling aged athletes, and ranged from 3.3 to 10 h (mean 5 h) per week for specialisation athletes and from 3.3 to 14 h (mean 8 h) per week for investment athletes. Considerable variation existed in weekly training and playing time between studies and, in contrast to previous research, demonstrated no obvious increase with development stage [14].

Table 1 Review of effects of generic training on aerobic fitness variables in young team sport players

Study	Sport/level	Age, years[a] (no. of participants)	Development phase (maturity marker)	Baseline $\dot{V}O_{2peak}$ (ml·kg·min^{-1})[a]	Study duration (week)	S/wk	Intervention	Training phase	Performance test (s)	% Change	ES
Sperlich et al. [65]	Soccer/junior elite	13.5 ± 0.4 (9)	Specialisation (no)	55.1 ± 4.9	5	3–4	HIIT 4–12 (30–240 s at 90–95 % HR_{peak}/30–180 s at 50–60 % HR_{peak} PR)	Mid-season	$\dot{V}O_{2peak}$	↑ 7.0	0.77
Sperlich et al. [65]	Soccer/junior elite	13.5 ± 0.4 (9)	Specialisation (no)	55.3 ± 4.3	5	3–4	MXD 2–6 (6–30 min at 50–70 % HR_{peak}/0–5 min PR)	Mid-season	$\dot{V}O_{2peak}$	↑ 2.0	0.26
Gabbett et al. [71]	Rugby League/ junior elite	14.1 ± 0.2 (14)	Specialisation (no)	43.3 ± 1.3 (predicted)	10	3	MXD 6 weeks CONT + 4 weeks RS and HI – various (10–40 m/15–30 s PR) + various (45–90 s 'hard'/45–180 s PR)	Pre-season	p$\dot{V}O_{2peak}$	↑ 12.7	4.2**
Hill-Haas et al. [62]	Soccer/junior elite	14.6 ± 0.9 (10)	Specialisation (PHV)	60.2 ± 4.6	7	2	MXD = AP, HIIT, RS, COD, and SL	Pre-season	$\dot{V}O_{2peak}$ (ml·kg·min^{-1}) $\dot{V}O_{2peak}$ (ml·kg$^{0.75}$·min^{-1}) MSFT YYIRT1	↑ 2.0 ↑ 2.4 ↑ 3.1 ↑ 21.9	0.26 0.29 0.53 1.51**
Buchheit et al. [32]	Handball/ junior club	15.7 ± 0.9 (17) (Tanner III–V)	Specialisation (Tanner)	NR	10	2	HIIT (6–12 min of 15 s at 95 % V_{IFT}/15 s PR)	Pre-season	V_{IFT} $Tlim_{100\% V_{IFT}}$ $Tlim_{95\% V_{IFT}}$ $Tlim_{90\% V_{IFT}}$	↑ 5.6 ↑ 36.1 ↑ 11.6 ↑ 17.1	0.56* 0.68* 0.30 0.54
Safania et al. [64]	Soccer/ recreational	15.7 ± 0.7 (10)	Specialisation (no)	34.0 ± 1.4 (predicted)	6	3	HIIT 4 (4 min at 70–95 % HR_{peak}/3 min at 60–70 % HR_{peak}) and 30 min 'competitive play'	Pre-season	p$\dot{V}O_{2peak}$	↑ 28.0	6.9***
Manna et al. [63]	Hockey/ junior elite	14–15.9 (30)	Specialisation (no)	54.6 ± 2.8	12	5	MXD = HIT + CONT + TECH	Pre-season and in-season	$\dot{V}O_{2peak}$ (week 8) $\dot{V}O_{2peak}$ (week 12)	↑ 3.1 ↓ 0.4	0.61* 0.07
Tonnessen et al. [35]	Soccer/junior elite	16.4 ± 0.9 (10)	Investment (PHV)	NR	10	1	RS 2–5 (4–5 × 40 m at 95–100 %/1.5–2 min: 10 min)	Pre-season	MSFT 10 × 40 m RSA (s)	↑ 5.0 ↓ 2.2	0.5 –0.70**
Tonnessen et al. [35]	Soccer/junior elite	16.4 ± 0.9 (control = 10)	Investment (PHV)	NR			Regular soccer training	Pre-season	MSFT 10 × 40 m RSA (s)	↔ ↓ 1.1	–0.32*
Gabbett et al. [71]	Rugby League/ junior elite	16.9 ± 0.3 (21)	Investment (no)	43.4 ± 1.1 est	10	3	MXD 6 weeks CONT + 4 weeks RS and HI – various (10–40 m/15–30 s PR) + various (45–90 s 'hard'/45–180 s PR)	Pre-season	e$\dot{V}O_{2peak}$	↑ 4.1	1.6

Table 1 continued

Study	Sport/level	Age, years[a] (no. of participants)	Development phase (maturity marker)	Baseline $\dot{V}O_{2peak}$ (ml·kg·min^{-1})[a]	Study duration (week)	S/wk	Intervention	Training phase	Performance test (s)	% Change	ES
Gabbett [68]	Rugby League/ junior elite	16.9 (16.7–17.1) (36)	Investment (no)	46.3 (45.0–47.7)	14	2	MXD = various (10–40 m/15–30 s PR) + various (45–90 s 'hard'/45–180 s PR) + skill-based conditioning games	Pre-season	e$\dot{V}O_{2peak}$	↑ 8.6*	No SD
Impellizzeri et al. [69]	Soccer/junior elite	17.2 ± 0.8 (15)	Investment (Tanner)	57.7 ± 4.2	12	2	HIIT 4 (4 min at 90–95 % HR_{peak}/3 min at 60–70 % HR_{peak})	Pre-season and in-season	$\dot{V}O_{2peak}$ (week 4) $\dot{V}O_{2peak}$ (week 12) $\dot{V}O_2$ at LT (week 4) $\dot{V}O_2$ at LT (week 12)	↑ 7.4 ↑ 8.3 ↑ 8.0 ↑ 12.9	1.21 1.35 0.95 1.53
Bravo et al. [67]	Soccer/junior elite	17.3 ± 0.6 (13)	Investment (no)	52.8 ± 3.2	12	2	HIIT 4 (4 min at 90–95 % HR_{peak}/3 min AR)	In-season	$\dot{V}O_{2peak}$ YYIRT1 RSA	↑ 6.6 ↑ 12.5 ↔	1.1** –
Bravo et al. [67]	Soccer/junior elite	17.3 ± 0.6 (13)	Investment (no)	55.7 ± 2.3	12	2	RS 3 (6 × 40 m sprints/20 s PR (4 min PR))	In-season	$\dot{V}O_{2peak}$ YYIRT1 RSA	↑ 5.0 ↑ 28.1 ↑ 2.1	1.2* – 0.76*
Impellizzeri et al. [70]	Soccer/junior club	17.8 ± 0.6 (13)	Investment (Tanner)	NR	4	2–3	HIIT 4 (4 min at 90–95 % HR_{peak}/3 min active jog)	Post-season	$\dot{V}O_{2peak}$ YYIRT1	↑ 4.0 ↑ 12.0	0.23** 0.75***

AP aerobic power training (intensity >90 % HR_{max}), *AR* active recovery, *COD* change of direction sprint training, *CONT* continuous training, *ES* effect size, $e\dot{V}O_{2peak}$ estimated peak volume of oxygen uptake, *HI* high intensity, *HIIT* high-intensity interval training, HR_{peak} peak heart rate, *LT* lactate threshold, *MSFT* multi-stage fitness test, *MXD* mixed training, *NR* not reported, *PHV* peak height velocity, *PR* passive recovery, $p\dot{V}O_{2peak}$ predicted peak volume of oxygen uptake, *RS* repeated sprint, *RSA* repeated sprint ability, *SD* standard deviation, *SL* speed ladder drills, *S/wk* intervention sessions per week, *Tanner* Tanner Staging System of Sexual Maturity, *TECH* technical, *Tlim* time to exhaustion, V_{IFT} final running velocity during the 30–15 intermittent fitness test, $\dot{V}O_{2peak}$ peak volume of oxygen uptake, *YYIRT1* Yo-Yo intermittent recovery test level 1, ↓ indicates decrease, ↑ indicates increase, ↔ indicates no change

* $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$ change following training

[a] Data are presented as mean ± SD or mean (range) unless otherwise indicated

Table 2 Review of effects of sport-specific training on aerobic fitness variables in young team sport players

Study	Sport	Age, years[a] (no. of participants)	Development phase (maturity marker)	BL $\dot{V}O_{2peak}$ (ml·kg·min^{-1})[a]	Study duration (weeks)	S/wk	Intervention	Training phase	Performance test(s)	% Change	ES
Vamvakoudis et al. [60]	Basketball/ junior elite	11.5 (20)	Sampling (Tanner)	51.4 ± 3.9	78	6	MXD 90 min (drills 8–10 min at 75–85 % HR_{peak} + 40–45 min at 50–60 % HR_{peak}, instructional games, and jumping and sprinting)	All	$\dot{V}O_{2peak}$ (week 52) (ml·kg·min^{-1}) $\dot{V}O_{2peak}$ (week 78) (ml·kg·min^{-1})	↑ 3.6** ↑ 11.1**	
Vamvakoudis et al. [60]	Basketball/ junior elite	11.5 (controls = 18)	Sampling (Tanner)	NR	78	2–3	MXD 40 min (soccer, basketball and volleyball games in PE class at 40–50 % HR_{peak})	All	$\dot{V}O_{2peak}$ (week 52) (ml·kg·min^{-1}) $\dot{V}O_{2peak}$ (week 78) (ml·kg·min^{-1})	↓ 0.7 ↑ 0.9	
Chamari et al. [6]	Soccer/junior elite	14.0 ± 0.4 (18)	Specialisation (no)	65.3 ± 5.0	8	2	Dribbling track 4 (4 min at 90–95 % HR_{peak}/3 min at 60–70 % HR_{peak}) and SSGs 4 (4 min 4 vs. 4 at 90–95 % HR_{peak}/3 min at 60–70 % HR_{peak} AR)	Mid-season	$\dot{V}O_{2peak}$ (ml·kg·min^{-1}) $\dot{V}O_{2peak}$ (ml·kg$^{0.75}$·min^{-1}) Hoft test	↑ 7.5 ↑ 12.0 ↑ 9.6	1.0 1.0 1.2**
Hill-Haas et al. [62]	Soccer/junior elite	14.6 ± 0.9 (9)	Specialisation (PHV)	59.3 ± 4.5	7	2	SSGs 3–6 (7–13 min 2 vs. 2 to 6 vs. 6 various rules)	Pre-season	$\dot{V}O_{2peak}$ (ml·kg·min^{-1}) $\dot{V}O_{2peak}$ (ml·kg$^{0.75}$·min^{-1}) MSFT YYIRT1	↓ 0.67 ↓ 0.60 ↓ 0.7 ↑ 17.1	–0.09 –0.11 –0.07 0.74**
Bogdanis et al. [66]	Basketball/ junior elite	14.7 ± 0.5 (10)	Specialisation (Tanner)	52.3 ± 1.4	4	5	MXD 120 min (drills, exercises, 5 vs. 5 full-and half-court games)		$\dot{V}O_{2peak}$ (ml·kg·min^{-1})	↑ 4.9	0.22*
Bogdanis et al. [66]	Basketball/ junior elite	14.7 ± 0.5 (10)	Specialisation (Tanner)	52.5 ± 1.3	4	5	MXD 120 min (drills, exercises, 5 vs. 5 full- and half-court games and circuits)		$\dot{V}O_{2peak}$ (ml·kg·min^{-1})	↑ 4.9	0.22*
Bogdanis et al. [66]	Basketball/ junior elite	14.7 ± 0.5 (control = 7)	Specialisation (Tanner)	NR			No training		$\dot{V}O_{2peak}$ (ml·kg·min^{-1})	↔	
Buchheit et al. [32]	Handball/ junior club	15.7 ± 0.9 (15) (Tanner III–V)	Specialisation (Tanner)	NR	10	2	SSGs 2–4 (150–240 s 4 vs. 4)	Pre-season	V_{IFT} $Tlim_{100\%V_{IFT}}$ $Tlim_{95\%V_{IFT}}$ $Tlim_{90\%V_{IFT}}$	↑ 6.5 ↑ 26.5 ↑ 5.5 ↑ 39.4	0.8* 0.62* 0.14 0.93*
Safania et al. [64]	Soccer/ recreational	15.7 ± 0.7 (10)	Specialisation (no)	34.2 ± 1.6 est	6	3	SSGs 4 (4 min various 2 vs. 2–4 vs.4/3 min PR) + 30 min 'competitive play'	Pre-season	e$\dot{V}O_{2peak}$	↑ 25.4	5.4***

Table 2 continued

Study	Sport	Age, years[a] (no. of participants)	Development phase (maturity marker)	BL $\dot{V}O_{2peak}$ (ml·kg·min^{-1})[a]	Study duration (weeks)	S/wk	Intervention	Training phase	Performance test(s)	% Change	ES
Impellizzeri et al. [69]	Soccer/junior elite	17.2 ± 0.8 (14)	Investment (Tanner)	55.6 ± 3.4	12	2	SSGs = 3 vs. 3–5 vs. 5 (various rules)	Pre-season and in-season	$\dot{V}O_{2peak}$ (week 4) $\dot{V}O_{2peak}$ (week 12) $\dot{V}O_2$ at Tlac (week 4) $\dot{V}O_2$ at Tlac (week 12)	↑ 6.4 ↑ 7.1 ↑ 7.1 ↑ 10.8	0.88 0.98 0.69 1.04

AP aerobic power training (intensity: >90 % HR_{max}), *AR* active recovery, *BL* baseline, *COD* change of direction sprint training, *CONT* continuous training, *ES* effect size, $e\dot{V}O_{2peak}$ estimated peak volume of oxygen uptake, *HI* high-intensity, *HIIT* high-intensity interval training, HR_{peak} peak heart rate, *LT* lactate threshold, *MSFT* multi-stage fitness test, *MXD* mixed training, *NR* not reported, *PHV* peak height velocity, *PR* passive recovery, $p\dot{V}O_{2peak}$ predicted peak volume of oxygen uptake, *RS* repeated sprint, *RSA* repeated sprint ability, *SD* standard deviation, *SL* speed ladder drills, *S/wk* intervention sessions per week, *Tanner* Tanner Staging System of Sexual Maturity, *TECH* technical, *Tlim* time to exhaustion, $\dot{V}_{IFT}$ final running velocity during the 30–15 intermittent fitness test, $\dot{V}O_{2peak}$ peak volume of oxygen uptake, *YYIRT1* Yo-Yo intermittent recovery test level 1, *% Change* percent change, ↓ indicates decrease, ↑ indicates increase, ↔ indicates no change

* $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$ change following training

[a] Data are presented as mean ± SD or mean (range) unless otherwise indicated

5.4 Training Mode

The specific details of training mode for each study are presented in Tables 1 and 2. Two main training modes were implemented to improve aerobic fitness in young players: generic training and sport-specific training. Generic training (Table 1) involved non-sport-specific exercise and included either high-intensity interval training (HIIT), repeated sprint training, continuous moderate intensity exercise, or a combination of the three (mixed training). Briefly, HIIT was the most popular training mode (six interventions), followed by repeated sprints (two interventions) and continuous running (one intervention). Four studies investigated the effects of mixed training modes on aerobic performance [61–63, 68]. Mixed exercise protocols included the performance of drills and activities involving technical skills [63] and skill-based games [68]. Alternatively, sport-specific training (Table 2) involved the implementation of purposely designed exercise tasks involving a ball. These included small-sided games (SSGs; five interventions), exercise drills and activities (four interventions) and a game-specific circuit (one intervention).

With respect to developmental stage, HIIT interventions were implemented more often with athletes while in their investment years compared with athletes in their specialisation years (40 vs. 20 %, respectively). Mixed exercise training regimes and SSGs were more frequently implemented with specialisation-aged athletes than with investment athletes (35 vs. 20 and 28 vs. 10 %, respectively), and repeated sprint training was only used with athletes in their investment years. The sole study that investigated players in their sampling years implemented a sport-specific mixed training intervention.

5.5 Effects of Generic Training on Aerobic Fitness and Performance

The effect of generic training on aerobic performance in young team sports players was considered in ten studies (Table 1). Generic training is defined as exercise modes not involving the technical skills of the sport towards which training is focused. In a series of six studies investigating HIIT, players undertook 5–12 weeks of exercise 2–4 times per week. Interventions lasted between 15 s and 4 min, with 4–24 repetitions at work intensities corresponding to 90–95 % of peak heart rate (HR_{peak}), separated by 15 s to 3 min of active or passive recovery. Four of the seven studies implemented 4 × 4 min of running at 90–95 % of HR_{peak} separated by 3 min of active recovery at 60–70 % of HR_{peak}, which has previously been shown as an effective regime to increase aerobic fitness and soccer specific performance in adults [1]. Although the magnitude of the changes varied considerably, all training interventions that controlled for intensity were effective at improving $\dot{V}O_{2peak}$ by 4–28 % [32, 64, 65, 67, 69, 70]. When analysis was restricted to studies involving high-level players (junior elite), the variability reduced considerably to 4–7.4 %. Impellizzeri et al. [69] reported the largest improvement in $\dot{V}O_{2peak}$ (7.4 %) after a 4-week pre-season training regime, when players may have been deconditioned, especially since no further increase in $\dot{V}O_{2peak}$ was reported following an additional 8 weeks of training during the competitive season. In contrast, $\dot{V}O_2$ at lactate threshold was improved following both the pre-season and competitive season training (8 and 4.9 %, respectively), suggesting a lack of sensitivity of $\dot{V}O_{2peak}$ to HIIT training in this cohort. Importantly, three of the six studies that implemented HIIT protocols also examined the influence of HIIT on intermittent shuttle running performance. In this regard, total running distance increased by 12–32.5 % in the Yo-Yo intermittent recovery test (YYIRT) level 1 [67, 70], and final running velocity was increased by 5.6 % in the 30–15 intermittent fitness test [32], suggesting that multiple physiological variables are associated with intermittent shuttle running.

Other generic training studies have adopted alternative approaches including repeated sprint protocols between 95 and 100 % intensity [35, 67]. Ferrari-Bravo et al. [67] reported a significant improvement in the $\dot{V}O_{2peak}$ of junior elite soccer players following three sets of 6 × 40 m maximal sprints, twice a week for 12 weeks. Using a similar protocol involving 2–5 repetitions of 4–5 × 40 m sprints at 95–100 % intensity, but of different frequency and duration (i.e. once per week for 10 weeks), Tønnessen et al. [35] showed an increase (5 %; ES 0.5) in the distance covered during the multi-stage fitness test (MSFT or Beep Test) and predicted $\dot{V}O_{2peak}$ accordingly, in junior elite soccer players. A control group that participated in regular soccer training showed no change in MSFT performance [35], suggesting that game play alone is insufficient to enhance aerobic fitness measures.

Four studies implemented mixed training regimes. Mixed training is defined as training that involves various combinations of continuous moderate-intensity running, HIIT, repeated sprinting, and technical drills and activities within the same session. Three of the four studies reviewed reported moderate to large increases in $\dot{V}O_{2peak}$ of 3.1–12.7 % [61, 63, 68]. The remaining study only showed a small increase (2 %; ES 0.26) in $\dot{V}O_{2peak}$ [62]. Specifically, Hill-Haas et al. [62] implemented a combination of coach-prescribed HIIT, repeated sprinting and change of direction drills without stipulating specific exercise intensity. As a result, minimal exercise was performed above 90 % HR_{peak}, which was given as a reason for the limited improvement in $\dot{V}O_{2peak}$ observed. Finally, with 2–6 repetitions of 6–30 min of moderate-intensity running (50–70 % of HR_{peak}), Sperlich et al. [65] reported a small increase in $\dot{V}O_{2peak}$ (2.0 %; ES 0.26) in junior elite soccer players. Unfortunately, the individual impact of each exercise mode during mixed training regimes is impossible to determine, making it difficult to derive specific implications for practice.

The importance of aerobic capacity and the ability to repeat high-intensity exercise for successful team sport performance is well accepted [72, 73]. Small to very large improvements in $\dot{V}O_{2peak}$ following generic training interventions have been reported independently of training frequency, duration and length of intervention. Periods of high-intensity effort appear to be a key factor in training design to obtain a substantial increase in $\dot{V}O_{2peak}$. Performance during intermittent shuttle running can be improved by various generic training methods and without a concomitant increase in $\dot{V}O_{2peak}$.

5.6 Effects of Sport-Specific Training on Aerobic Fitness and Performance

Sport-specific training is defined as exercise regimes that involve technical and/or tactical tasks similar to those of the athletes' chosen sport. To date, eight studies (Table 2) have investigated sport-specific training in young team sports players, with SSGs and ball-based drills and activities. Study duration and session frequency ranged from 4 to 78 weeks and from 2 to 6 sessions per week, respectively. Moderate to very large increases in $\dot{V}O_{2peak}$ were reported following SSG training regimes in junior elite [6, 32, 69] and recreational players [64]. Buchheit et al. [32] also reported a moderate increase in the final running velocity on the 30–15 intermittent fitness test in junior club handball players. Large variation in game methodology existed across studies (e.g. duration and player numbers ranged from 2.5 to 13 min and 2 vs. 2 to 6 vs. 6, respectively), but SSGs were selected based on previous descriptive research indicating that exercise intensity responses would be high when lower playing numbers and larger pitch sizes were implemented, and therefore sufficient stimulus for aerobic adaptation would be achieved [74, 75]. In contrast, when Hill-Haas et al. [62] implemented SSG training that was prescribed by a soccer coach to increase the external validity of their study, no change in $\dot{V}O_{2peak}$ was reported. However, despite no change in $\dot{V}O_{2peak}$, an increase in the YYIRT level 1 (17 %) was reported [62], suggesting that intermittent shuttle running performance is determined by multiple physiological characteristics.

Sport-specific, mixed training protocols have been implemented in two previous studies [60, 66]. Increases in $\dot{V}O_{2peak}$ were reported following exercise regimes consisting of 78 weeks of drills and instructional games (11.1 %) [60] and 4 weeks of exercise drills and SSGs (4.9 %; ES 0.22) [66] in junior elite basketball players. A control group that performed 'normal' basketball training during the same intervention period showed no change in $\dot{V}O_{2peak}$ [60]. Additionally, a sport-specific training circuit in combination with SSGs was examined [6]. Junior elite soccer players completed one 4 versus 4 SSG session and one circuit session of equal intensity (4 × 4 min at 90–95 % HR_{peak}, separated by 3 min running at 60–70 % HR_{peak}) each week for 8 weeks. Increases were reported in $\dot{V}O_{2peak}$ relative to bodyweight (7.5 %; ES 1.0), allometrically scaled $\dot{V}O_{2peak}$ (12 %; ES 1.0), and in the distance covered during the Hoff Dribbling Track Test (9.6 %; ES 1.2) [6].

In summary, improvements in peak $\dot{V}O_2$ and intermittent shuttle running performance were reported following various sport-specific aerobic fitness training protocols. SSGs were the most beneficial method of training implemented, but limited variation in this type of training has been investigated to date. Additional studies are warranted to further explore the use of SSGs to develop aerobic fitness across a wide range of team sports that may require different game constraints to achieve adequate stimulus for adaptation, particularly for athletes in the sampling stage.

6 An Evidence-Based Model of Aerobic Fitness Development in Young Team Sport Players

Based on the available literature, a proposed model for the development of aerobic fitness in young team sport players is presented (Fig. 1). It is intended to provide coaches with a strategic approach to develop aerobic fitness in their players. Specifically, the model is designed to provide clear and simple prescriptive guidelines based on scientific theory and evidence, while at the same time allowing room for situational and sport-specific needs. The model proposes the most beneficial types of aerobic exercise based on developmental stage. However, it is by no means exclusive, and coaches should use these guidelines with individual and situational variability in mind.

6.1 The Sampling Stage

The main focus during the sampling stage is participation in a number of activities with an over-riding emphasis on enjoyment [14]. Generic aerobic fitness training regimes consisting of regular running, cycling or swimming, continuous or interval exercise, have been shown to increase $\dot{V}O_{2peak}$ by 8–10 % in this age bracket [11]. However, to maximise a player's development, the importance of early engagement and deliberate play in game-based activities has been reported [76]. Unfortunately, research investigating the trainability of aerobic fitness for young team sport players in their sampling years is limited to only a single study by Vamvakoudis et al. [60] (Table 2). Vamvakoudis et al. [60] reported a substantial improvement in the $\dot{V}O_{2peak}$ of junior elite basketball players by implementing drills and instructional games, six times per week for 52 weeks. Each session lasted for at least 60 min with 40–50 min of training time spent at 50–60 % HR_{peak}, but a short period of moderate-intensity exercise (i.e. 10 min between 75 and 85 % HR_{peak}) was included. Based on these findings and the overall objectives of the sampling years, regular participation in moderate-intensity, sport-specific mixed training is proposed (Fig. 1). However, further research is required to examine aerobic fitness trainability in team sport populations during this developmental stage.

Although only a single study has implemented aerobic fitness training specifically, a previous study showed improvements in the Yo-Yo intermittent endurance test of soccer players following combined strength and high-intensity training in the form of dynamic exercise (i.e. resistance exercise and sprints) [77]. Nevertheless, concurrent soccer training performed by the participants was proposed to play a role in eliciting this improvement. In addition, a relationship between a 15 m sprint time and Yo-Yo intermittent endurance test (r −0.77, $p < 0.05$) observed in this study suggested that speed plays a role in intermittent shuttle running performance [77].

In summary, activities implemented to improve aerobic fitness in this development stage should be playful and fun and focus on providing opportunities for technical skill acquisition. Experimental designs examining the best use of SSGs would therefore seem appropriate. Consideration of game characteristics and structure given the level of technical skill of the athletes involved is critical. Furthermore, training protocols that include strength and speed components may also benefit intermittent shuttle running performance development during this development stage.

6.2 The Specialisation Stage

The overall focus of the specialisation stage is mastery of individual, sport-specific skills and other sport-specific activities [14]. The majority of training time is dedicated to deliberate practice, with some time spent in deliberate play activities. With this in mind, aerobic fitness training that provides for the simultaneous development of technical

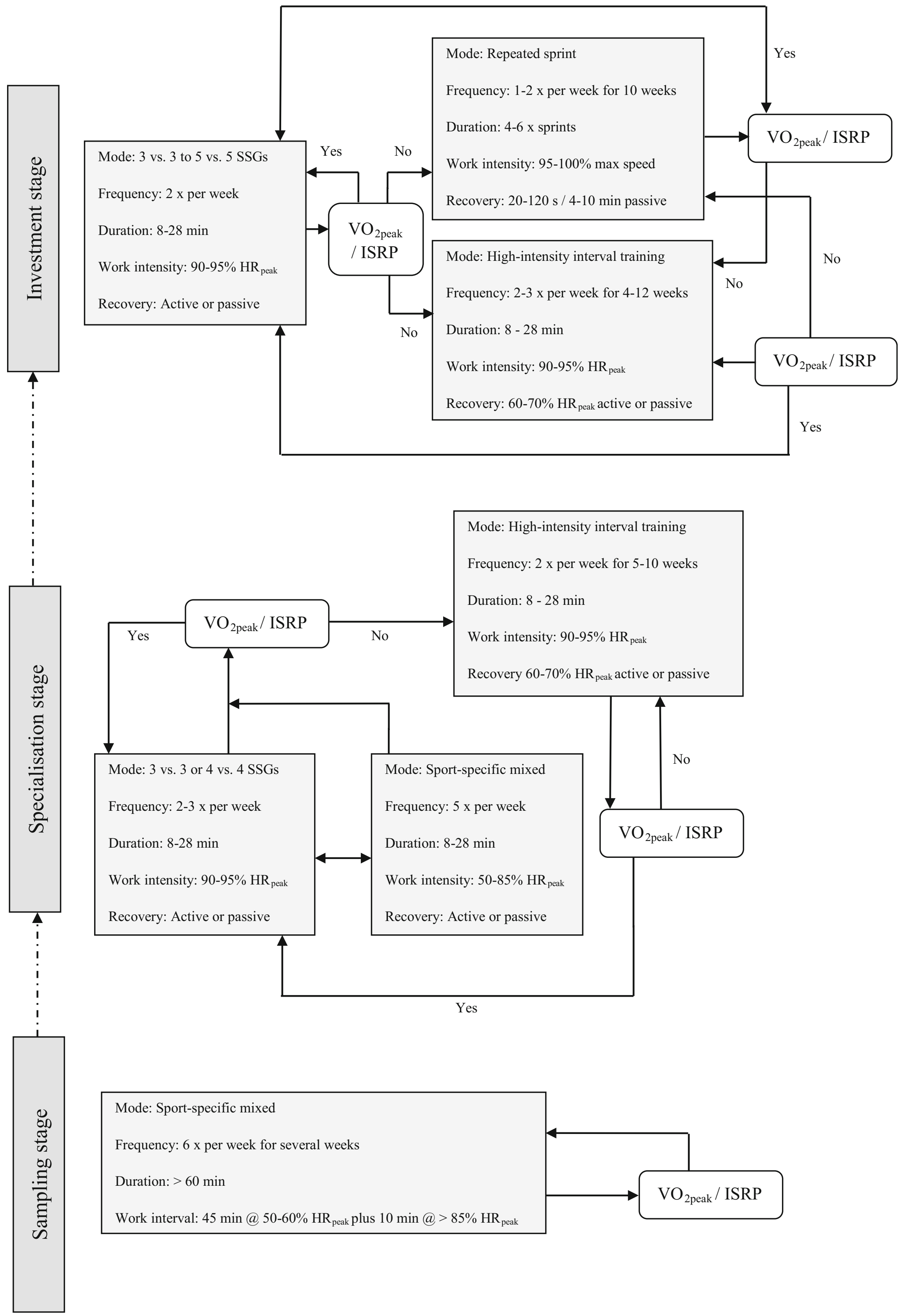

Fig. 1 A proposed evidence-based model for aerobic fitness development in young team sport players. *HR_{peak}* peak heart rate, *ISRP* intermittent shuttle running performance, *max* maximum, *min* minutes, *SSGs* small-sided games, $\dot{V}O_{2peak}$ peak volume of oxygen uptake

and tactical skills would seem advantageous. Accordingly, and given the clear effects presented in this review [6, 32] (Table 2), training built on a foundation of SSGs and complemented with mixed sport-specific training interventions would appear advantageous. SSGs consisting of 3 versus 3 or 4 versus 4 player formats, performed 2–3 times per week on playing areas 25 × 30 or 30 × 40 m, respectively, have been shown to provide sufficient intensities for successful aerobic adaptation, as well as improving intermittent shuttle running performance [6, 32, 62] (Fig. 1). Work phases during SSGs should be carefully monitored to achieve intensities of 90–95 % HR_{peak}, and should be separated by passive rest or active recovery at 60–70 % HR_{peak} [6, 32]. There is no clear influence of the length of programme, but training blocks of at least 8 weeks appear necessary for developing $\dot{V}O_{2peak}$. Alternatively, training interventions involving a mix of ball drills, activities and circuits have also been shown to be effective at improving aerobic fitness [6, 66] (Table 2) and therefore valuable for use during the specialisation stage if they can be practically incorporated into the team sport environment (Fig. 1).

Despite recent evidence depicting the advantages of SSGs compared with HIIT [32], limitations with this type of exercise have also been suggested [75]. Limited research delineating the effects of prescriptive variables on player's physiological and physical responses during various SSG formats and codes presents a clear need for more training studies in young athletes to determine the most effective stimulus for development of aerobic fitness. Furthermore, since SSGs require a combination of technical and tactical abilities, decision making and physical exertion, it seems that concurrent abilities may be required to achieve sufficient stimulus for subsequent aerobic adaptation [75]. Consequently, lower-skilled players and/or those with poor game intelligence and understanding may profit less from SSG training. Similarly, this is also the case for more experienced, highly skilled players, who through effective decision making may be capable of reducing the intensity at which they are required to work during SSGs [75]. Therefore, the relationship between aerobic fitness, technical skill, game intelligence and attainable exercise intensity should be investigated further in future research. More specifically, studies are required to determine whether or not differences in technical skill and game intelligence across players in the same team can be accounted for using SSGs to achieve similar aerobic fitness outcomes.

Because aerobic fitness may not always be improved to the desired level using SSGs or sport-specific mixed training regimes [62], and to account for individual variability in exercise intensity [75], utilisation of HIIT during the specialisation stage of player development is worthwhile. Indeed, less variability in exercise intensity has been shown with generic interval training compared with SSGs, presumably because individual player workloads can be accurately prescribed and maintained throughout training [78, 79]. High-intensity interval training is effective at increasing aerobic fitness and intermittent shuttle performance during this development stage [32, 65]. This form of training should be prescribed two times per week for blocks of 5–10 weeks. Work period can vary in duration from 30 s to 4 min, but intensity should be consistently high (90–95 % HR_{peak}). This can be accomplished by using the final running velocity of the 30–15 intermittent fitness test to set individual running distances [78] or controlled with HR monitoring technology [79]. Rest intervals should involve active (i.e. 60–70 % HR_{peak}) or passive recovery (see Table 1) [32, 64, 65]. Once players adapt to the training stimulus and aerobic fitness is increased, SSGs may again become the exercise mode that is prioritised (i.e. refer to arrows on Fig. 1). Importantly, the phase of training players are in should be considered before implementing this type of exercise. Overall training and competition load must be carefully monitored to avoid overtraining and injury due to the rapid changes in growth experienced by players during this stage of development.

6.3 The Investment Stage

The investment stage is characterised by the acquisition of expertise, during which deliberate practice as a team is the best use of the training hours [13, 80]. The main focus is on improving performance, with an emphasis on competitive activities. However, despite players entering young adulthood during this stage, they are still physically developing and therefore overall training volume should be considered. Impellizzeri et al. [69] reported a moderate improvement (6.4 %) in $\dot{V}O_{2peak}$ after SSG training in junior elite soccer players. Since both physical and technical outcomes can be gained concurrently during SSGs training, this method should be prioritised during the investment years (Fig. 1). However, to ensure desired outcomes are met, a high level of prescription should be of utmost importance. Team numbers can vary from 3 versus 3 to 5 versus 5, but games should be performed in large areas relative in size to the total number of players involved [69, 81]. Games consisting of four bouts of 4 min at high intensity (90–95 % HR_{peak}) separated by 3 min of active recovery (60–70 % HR_{peak}) have been shown to be effective [69]. However, further studies are required to elucidate other SSG variables and work:rest ratios effective at eliciting appropriate stimulus to improve aerobic fitness.

In the case of shortfalls in SSGs training to meet individual aerobic fitness targets, or to maintain aerobic fitness in-season, 'top-up' sessions involving HIIT and/or repeated sprint training are recommended. Performance of HIIT should be completed 2–3 times per week, for blocks of 4–12 weeks, at similar durations suggested for SSGs above. Work bouts should be performed at high intensity (90–95 % HR_{peak}) and separated by either active or passive recovery [67, 69, 70]. Alternatively, repeated sprint training blocks could be performed 1–2 times per week for 10–12 weeks. More specifically, four to six 40 m sprints should be completed at 95–100 % of maximum effort, separated by 20 s to 2 min of passive recovery. Sprint blocks should be repeated 2–5 times, interspersed with passive rest lasting 4–10 min in duration [35, 67].

7 Conclusions

Given current evidence on natural development of aerobic fitness and trainability, aerobic fitness should be actively developed in team sport players throughout their development, rather than aligning exercise to specific periods of maturation. However, based on a range of studies investigating aerobic fitness in young team sport players, the current review has highlighted particular training modes and loading parameters appropriate for implementation during the different developmental stages. In general, sport-specific training programmes should be prioritised throughout development to increase the opportunity for concurrent physical and technical development. However, training must be accurately prescribed using specific game variables to ensure the desired adaptations are achieved. Because of the longitudinal and dynamic nature of players' development over several years, aerobic fitness should be monitored carefully and short-term interventions prescribed with the long-term physiological, technical and tactical skill objectives in mind. There is an apparent need for more descriptive training studies, particularly involving SSGs, to further assist in optimising aerobic fitness development alongside useful technical and tactical attributes in young team sport athletes.

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