Strength and Conditioning for Football: "From Science to Practice"

Chapter title: Analytical and Ecological Approaches to Aerobic and Anaerobic Conditioning in Football

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Introduction

Research in professional football has shown that the physical demands of competitive match-play have substantially increased over the last few decades (Carling et al., 2016) as well as the training demands (Oliveira et al., 2022). As such, the role of support staff has developed to provide theoretical, scientific, and practical support to the manager in a variety of areas. These include performance analysis, strength and conditioning, and the integration of technical and tactical elements. The role of fitness and conditioning staff is to have knowledge of scientific literature and analyze performance data to condition and recover players appropriately to deal with the ever-evolving demands of elite football competition.

Various football actions stress the different physiological energy systems (Malone et al., 2015). Football is characterized by intermittent bouts of low- and high-intensity activities

(Drust et al., 2007) in which aerobic metabolism is predominant from 80-90% of a full match (Stolen et al., 2005), while high-intensity anaerobic activity accounts for the remaining 10-20% (Rienzi et al., 2000). Professional players cover approximately 10-13 km during a football match (Di Salvo et al., 2007), in which central midfielders typically cover the most and central defenders the least (Bradley et al., 2009; Di Salvo et al., 2007). Therefore, the need to perform intense, repeated actions requires enhanced physical capabilities (e.g., speed, muscle strength, anaerobic power, agility, and maximal aerobic power) (Clemente et al., 2014; Rampinini et al., 2009).

Regarding the analytical and ecological high-intensity interval training (HIIT) approaches to aerobic and anaerobic conditioning, arguably both traditional HIIT, small-sided games (SSG), and circuit-type drills produce comparable effects on enhancing endurance performance and maximal oxygen uptake in soccer players (Clemente et al., 2023). Thus, this chapter highlights relevant insights on both analytical and ecological approaches to HIIT programming, for aerobic and anaerobic conditioning in football.

Aerobic and anaerobic contributions in football

Football has specific characteristics related to both anaerobic and aerobic profiles, as it is played at a minimum of 75% of maximum heart rate. Moreover, it encompasses extended durations of aerobic activities interspersed with brief high-intensity actions, necessitating elevated levels of both aerobic and anaerobic fitness. Additionally, neuromuscular-oriented activities such as changes of direction (COD), high-speed running (HSR), and sprints are pivotal factors that must be considered when programming aerobic/anaerobic conditioning (Buchheit & Laursen, 2013a).

To repeat high-intensity actions, drills should feature explosive, short duration work bouts followed by short recovery periods. This type of action has been referred to as "repeated sprint ability" (RSA) (Clemente et al., 2021). To develop this ability, it is relevant to know which aerobic or anaerobic determinants are related to performance, and to what extent. Some research showed negative associations between relative maximal oxygen uptake (VO_{2max}) and RSA mean and total [$r = -0.591$ to -0.655, $p < 0.001$] (Jones et al., 2013). For instance, a higher VO_{2max} may contribute to a better RSA by allowing the replenishment of phosphocreatine stores during recovery between sprints, and consequently helping to maintain higher performance through several high-intensity actions (Bogdanis et al., 1996). However, in another study, VO_{2max} appears to be moderately related to RSA (in terms of total work [kJ]; $r = 0.79$, $p < 0.05$) (Bishop et al., 2003). This suggests that factors other than VO_{2max} contribute to RSA performance, including anaerobic fitness.

High-intensity interval training (HIIT) methods for aerobic and anaerobic conditioning

HIIT comprises of six types, each meticulously crafted to elicit diverse demands on the aerobic, anaerobic, or neuromuscular systems. The existing body of literature categorizes these six HIIT variants, as depicted in Figure 1. This classification serves as a valuable tool for coaches and athletes, offering a spectrum of options to cater to specific training needs and goals when utilizing HIIT interventions (Buchheit & Laursen, 2013a).

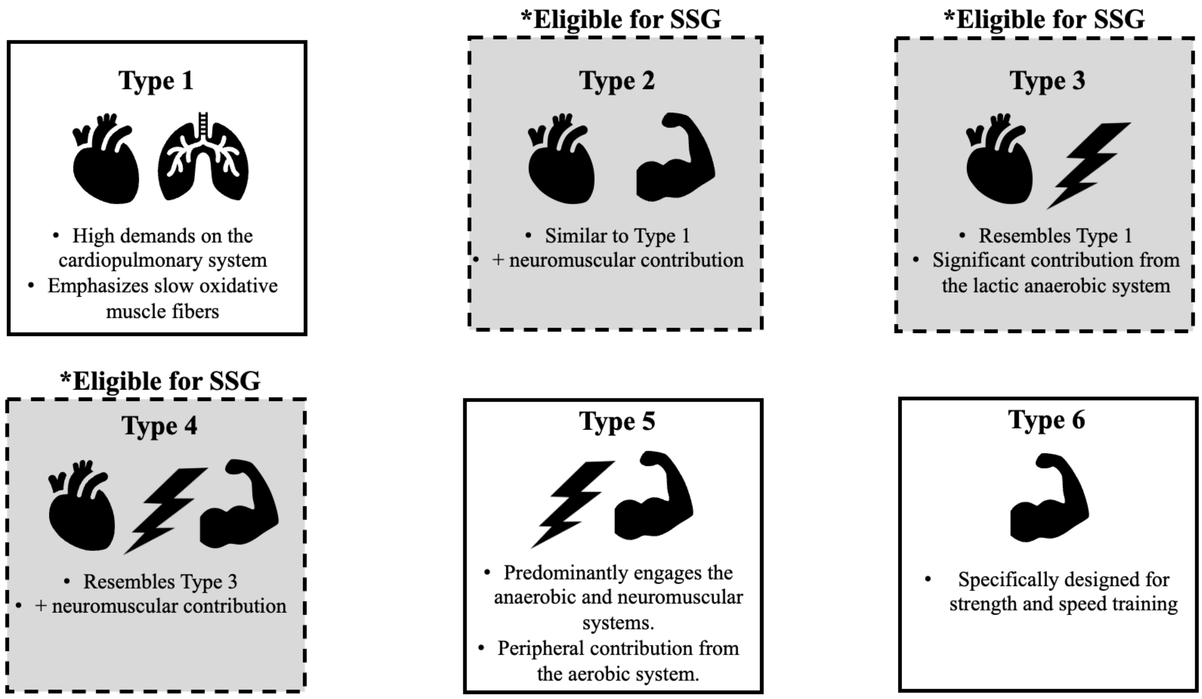

Figure 1. Categorization of high-intensity interval training types. *SSG: small-sided games.

As depicted in Figure 1, HIIT type 1 is characterized by aerobic metabolic processes that heavily rely on oxygen transport and utilization mechanisms, notably involving the cardiopulmonary system and oxidative muscle fibers. HIIT type 2, shares the metabolic characteristics with type 1 but exhibits a heightened level of neuromuscular strain. HIIT type 3, displays metabolic traits akin to type 1 but with a substantial contribution from anaerobic glycolysis and limited neuromuscular strain. HIIT type 4, mirrors the metabolic profile of type 3 but features elevated neuromuscular strain. HIIT type 5 is characterized by limited aerobic response yet significant anaerobic glycolytic energy contribution and neuromuscular strain. Finally, HIIT type 6, distinct from traditional HIIT, involves exclusively high neuromuscular strain, typically associated with speed and strength training. The selection of HIIT types to elicit specific HIIT-targeted responses encompasses short intervals, long intervals, repeated sprint training, sprint interval training (SIT), and game-based HIIT sessions (Laursen & Buchheit, 2019).

Furthermore, it is important to note that four primary HIIT formats can be employed to correspond with each of the six principal HIIT types. These formats are defined as short intervals (lasting less than 60-seconds), long intervals (above 60-seconds), SIT, and repeated-sprint training (Buchheit & Laursen, 2013a). It is noteworthy that short intervals can be effectively applied to accommodate the requirements of the first to the fourth HIIT types, whereas long intervals are best suited for the third and fourth types. Repeated-sprint training is particularly well-suited to match the fourth and fifth types, while SIT primarily aligns with the sixth type (Buchheit & Laursen, 2013a).

Long and Short Intervals

Distinguishing between short intervals and long intervals of HIIT highlights the disparate physiological effects during exercise. In the case of long intervals, exercising continuously at intensities surpassing the lactate threshold results in incremental disturbances to homeostasis, leading to a gradual onset of muscular fatigue and diminishing the body's capacity for effective muscular contraction (Poole et al., 2021). On the other hand, short intervals include briefer but more frequent recovery intervals, allowing for rapid restoration of homeostasis during these breaks (Gunnarsson et al., 2013).

The differential impact stems from the role of myoglobin within muscle cells. In short intervals, myoglobin functions as an oxygen reservoir, accumulating oxygen at the commencement of each brief exercise interval (Atakan et al., 2021). These recovery periods then facilitate the reloading of myoglobin with oxygen, minimizing the build-up of anaerobic by-products, such as lactate, during subsequent exercise intervals. This pattern in short intervals enables improved oxygen utilization, extraction, and swift re-establishment of homeostasis, resulting in a heightened average oxygen uptake and power output (Laursen & Jenkins, 2002).

This contrasts with long intervals, where the progressive disturbance of homeostasis leads to a prolonged and gradual onset of fatigue (Buchheit & Laursen, 2013a).

The long intervals represent protracted work segments focusing on a more extended phase of the intensity-time spectrum, typically within the range of 95% to 105% of the individual maximal aerobic speed (MAS) or 80% to 90% of the final velocity reached during the 30-15 intermittent fitness test (30-15IFT), known as V_{IFT} (Buchheit, 2010). To effectively execute long intervals of >2-minutes at 80-85% of V_{IFT}, brief recovery intervals of 1-2-minutes of passive rest should be interspersed or more extended periods of active recovery reaching up to 45% of V_{IFT} from 2-4-minutes (Figure 2).

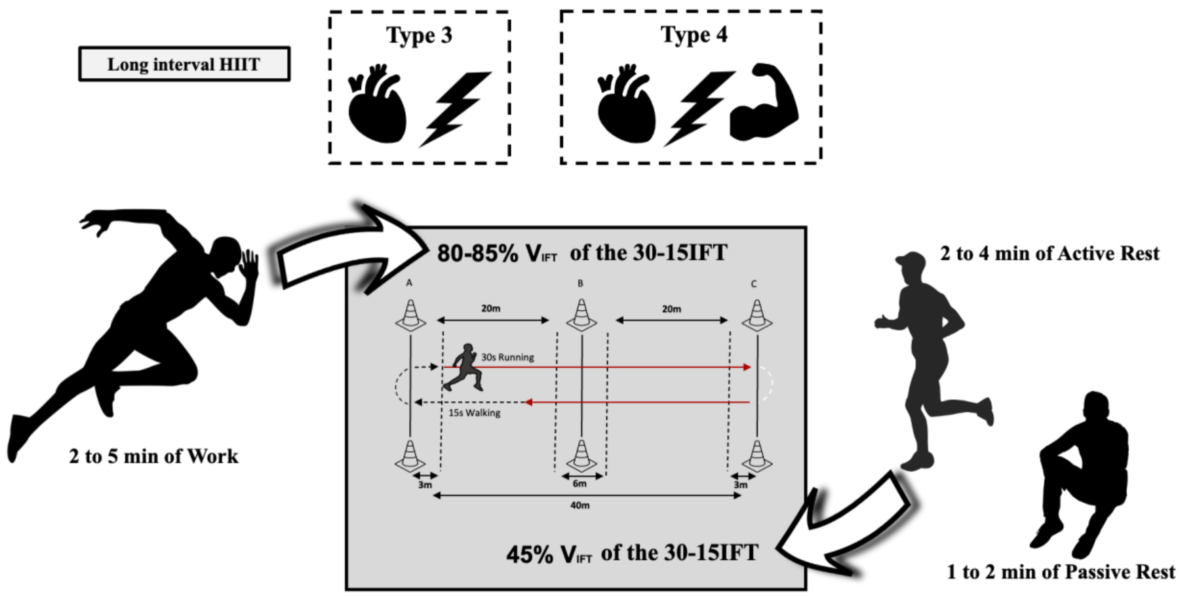

Figure 2. Intensity and duration of work and rest during long intervals (2-5-minutes).

While short intervals encompass set periods of less than 60-seconds, recurring within a comparably brief time span. To ensure short intervals achieve objectives, they should be executed repeatedly at intensities ranging between 90% and 105% of V_{IFT}, lasting 10-60-seconds and interspersed with less than 1-minute of recovery which may be passive or active up to 45% of V_{IFT} (Figure 3).

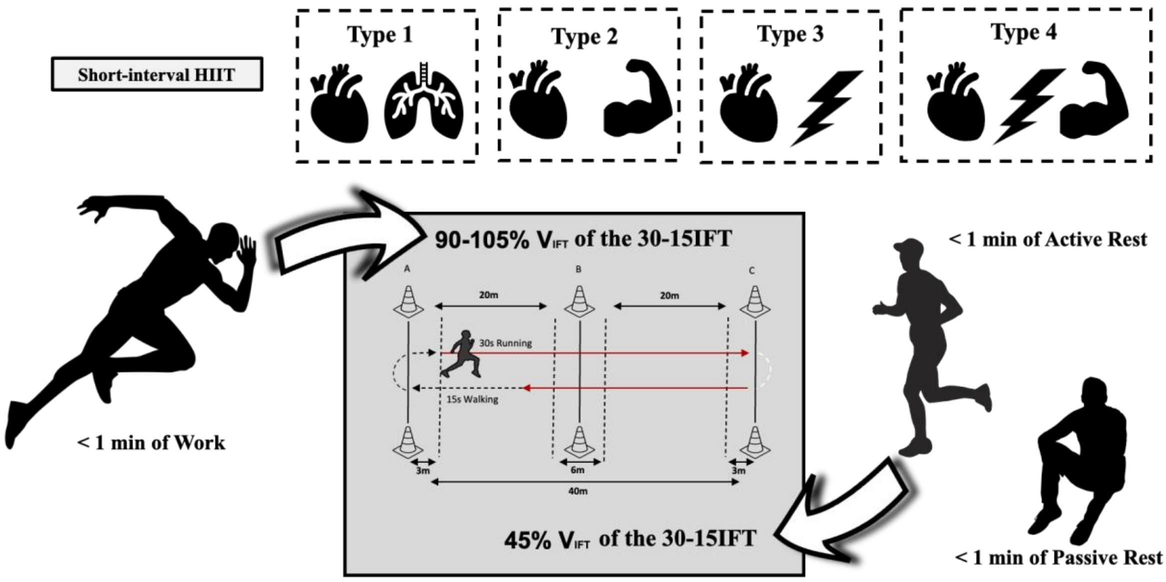

Figure 3. Intensity and duration of work and rest during short intervals (< 60-seconds).

Repeated-sprint training is characterized by the repetition of more than two brief (≤ 10-seconds) maximum-effort sprints, interspersed with a brief recovery interval lasting less than 1-minute (Buchheit & Laursen, 2013a) (Figure 4). The high-intensity nature of the repeated-sprint training naturally triggers substantial stress on the acute neuromuscular response, allowing for the pursuit of HIIT types 4 and 5 objectives. In repeated-sprint training, the decline in running speed demonstrates an escalating overall stress on the locomotor system, evidenced by diminished force production, altered stride patterns, decreased musculoskeletal stiffness, and a combination of neuromuscular adjustments and metabolic disruptions at the muscular level (Haugen et al., 2014).

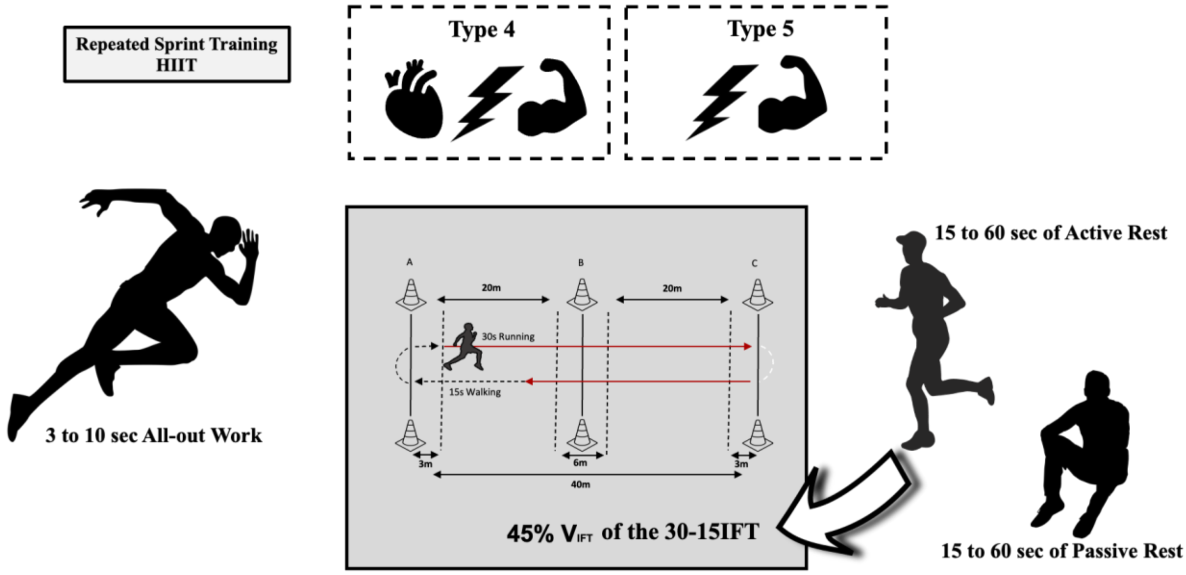

Figure 4. Intensity and duration of work and rest during repeated-sprint training (3-10-seconds maximum effort).

Sprint interval training involves maximal effort sprints, but the duration is extended, typically ranging from 20-45-seconds. These efforts are highly demanding, and the recovery period is passive and prolonged, usually spanning between 1-4-minutes (Figure 5). The SIT method is another variant of HIIT that involves more extended efforts and recovery periods, for instance, repeated 30-second sprints with 2-4-minutes of passive recovery. Sprint interval training demands a maximum performance, allowing it to be prescribed without individual pre-testing (i.e., MAS is not specifically required to determine the intensity). Therefore, SIT targets specific acute responses, particularly in type 5 responses, requiring primarily anaerobic glycolytic and neuromuscular reactions (Hoffmann et al., 2014).

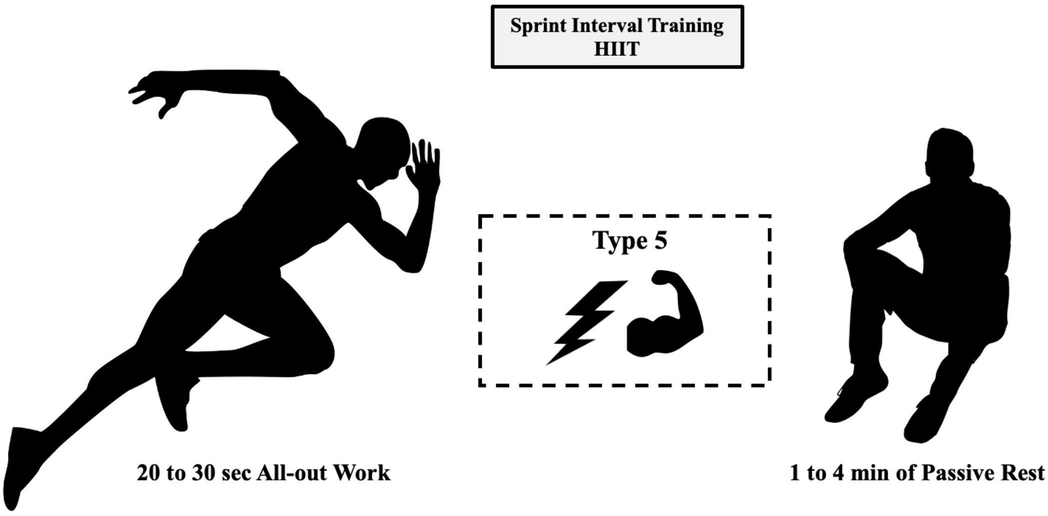

Figure 5. Intensity and duration of work and rest during sprint interval training (20-30 s all-out).

The Maximal Aerobic Speed and Anaerobic Speed Reserve for HIIT programming

Given the profoundly aerobic nature of various field sports, necessitating athletes to sustain high-intensity performance levels throughout the game's duration, the significance of elevated aerobic power in overall performance becomes apparent. For this reason, MAS is commonly utilzed for running-based HIIT prescription (Bok et al., 2023). However, using only MAS for running-based HIIT prescription raises an important issue, as it does not consider the athletes' individual maximal sprinting speed (Sandford et al., 2021). Specifically, MAS can be considered as the "lowest" speed when reaching VO_{2max} (Bentley et al., 2002; Rampinini et al., 2009). However, during a VO_{2max} assessment, it is still possible to increase speed without increasing oxygen consumption. The differences between the lowest and the maximum speed when reaching VO_{2max} is known as anaerobic speed reserve (ASR). Thus, other speeds of ASR can also be used for training prescription as a better tool to estimate time to exhaustion (Buchheit, 2010). Even so, there is scarce research employing this approach (Julio et al., 2019) while most studies use MAS (Mallol et al., 2015; Munoz et al., 2015; Paquette et al., 2017; Silva et al., 2011).

An example of how HIIT prescription based on MAS can be particularly misleading is illustrated in Figure 6. Two different athletes (athletes A and B), both of whom have exactly the same MAS (16 km/h), but different maximal sprinting speed (athlete A = 28 km/h; Athlete B = 35 km/h). Considering that ASR is calculated as the difference between MAS and maximal sprinting speed, athlete A has an ASR of 12 km/h, while athlete B has an ASR of 19 km/h.

Consequently, if a coach prescribes the same HIIT exercise (e.g., 10-second run at 120% of MAS, representing a running speed of 19.2 km/h) for both athletes A and B, athlete A will be running closer to his maximal sprinting speed (28 km/h), athlete B will be running further from his maximal sprinting speed (35 km/h). In this scenario, athlete A may be exerting a lot of effort, while athlete B may be 'cruising'.

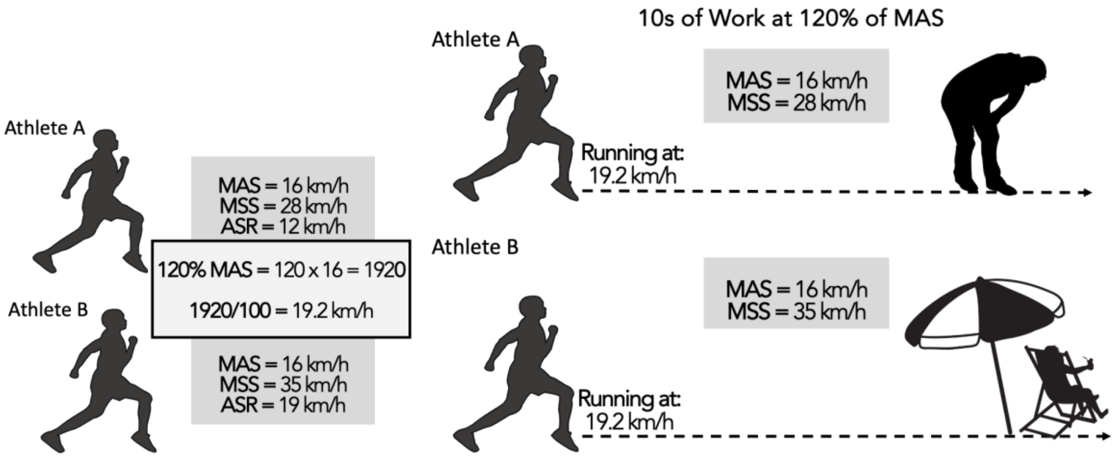

Figure 6. Running-based HIIT bout using only maximal aerobic speed for different athletes.

However, it is possible to individualize the HIIT bout by using percentages of each athlete's ASR. The potential lies in modifying interval prescription based on a proportion of the ASR as opposed to solely depending on MAS percentages. For instance, rather than executing a 10-second run at 120% MAS, the sane run could be performed at 20% of the ASR. An athlete with a greater reserve is likely to engage in a more strenuous run at a higher speed compared to another athlete possessing an equivalent MAS but with a lower ASR (Sandford et al., 2021). As depicted in Figure 7, by considering the ASR percentage HIIT prescription method, athlete A avoids excessive strain during his conditioning session.

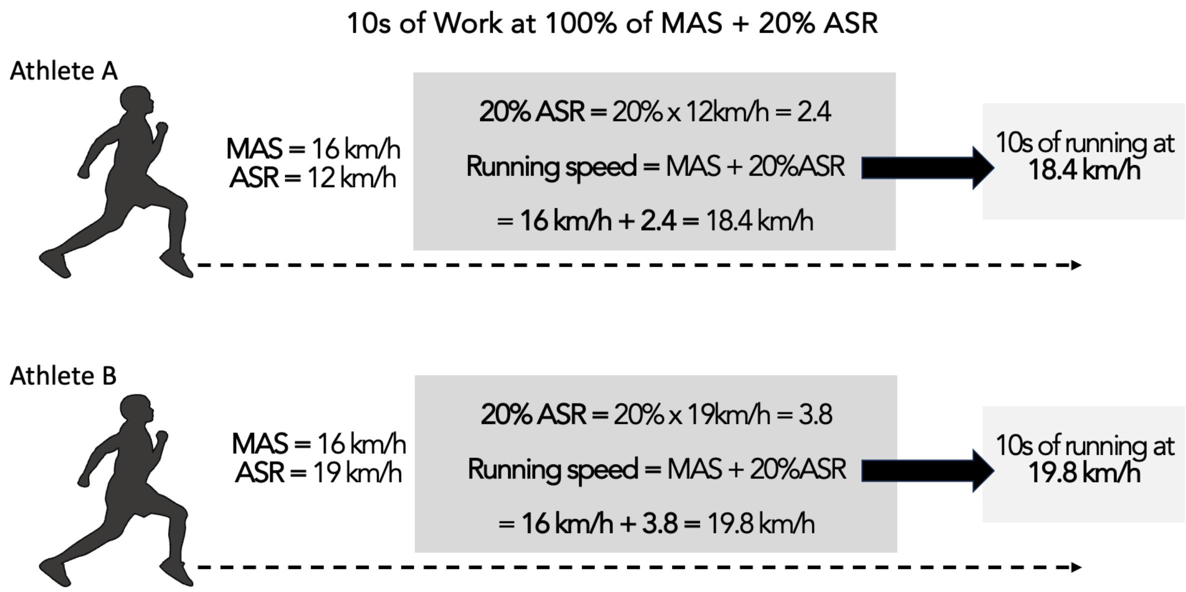

Figure 7. Running-based HIIT bout using the anaerobic speed reserve (ASR) percentage.

Focusing on ASR is crucial for HIIT programming to optimize athletes' preparedness, for instance, a previous study investigated the factors that influence the time an athlete can continue running at high intensities, specifically in the range of 90-140% of MAS (Blondel et al., 2001). The authors found that the athlete's ASR was a better predictor of endurance at these high intensities compared to MAS alone. Put simply, if an athlete was running at, 120% of MAS, what determined how long they could keep going at that intensity was not just the percentage above MAS, but also how effectively ASR was utilized at that level of effort. A significant portion of the variation in the time an athlete could sustain exercise at 120% and 140% of MAS could be explained by how much of the ASR was utilized (Blondel et al., 2001). This, in turn, suggests that ASR becomes particularly important when exercising at very high intensities, even more so than MAS.

SSG-based HIIT types

It is noteworthy that SSG is primarily associated with types 2, 3, and 4 of HIIT. Consequently, coaches may opt to design SSG with the intention of promoting cardiorespiratory adaptations, with variable emphasis on the neuromuscular system. The convergence of HIIT types 2, 3, and 4 with SSG highlights the complexity of targeting distinct physical attributes in isolation within the context of SSG (Clemente, 2020). Small-Sided-Games can be strategically designed to highlight the emphasis on HIIT types 2, 3, or 4, according to the coaches' aims. However, it is of paramount importance to consider the influencing factors that affect the imposed intensity during SSGs (Clemente, 2020).

Small-Sided-Games consist of a reduction in the dynamic structure of the conventional football game. Consequently, these games may assume a more tactical and/or physical character, depending on the type of modifications and constraints of the task implemented by the coach (Clemente, 2016; Davids et al., 2013). Small-Sided-Games have increased theoretical and operational popularity in football, as perception and learning of players regarding important technical-tactical determinants is achieved, as well as allowing a relevant variation of physiological stimuli (Clemente et al., 2014; Clemente et al., 2021).

Moreover, SSG have the advantage of producing greater motivation, motor efficiency, tactical concentration, and technical ability of football players (Arslan et al., 2020; Sarmento et al., 2018). However, it is also necessary to highlight the greater variability that SSG presents in terms of exercise intensity when compared to traditional methods such as non-football-specific running. Thus, despite the SSG demonstrating significant value, the coach must supplement these games with some tasks of an analytical nature, as these present greater control regarding the intensity of the exercise (Clemente et al., 2021).

Generally, SSG present differentiated forms of HIIT (Buchheit & Laursen, 2013b, 2013a). In turn, these produce biological adaptations, also differentiated, in the medium to long term (Moran et al., 2019). The format of SSG is related to different types of task constraints (Clemente, 2016; Davids et al., 2013) which include (Morgans et al., 2014; Sarmento et al., 2018):

- Changes in the number of players involved;
- Field configuration (individual area per player, width/length ratio and field size);
- Presence or not of scoring a goal (goal scoring in mini goals or conventional goals);
- The presence or not of goalkeepers;
- Type of actions allowed (limitation of touches on the ball or movements);
- Number of sets, repetitions, effort/recovery ratio.

All these types of constraints promote different physiological adaptations, especially in the cardiorespiratory system (internal load responses) (Gonçalves et al., 2017; Hammami et al., 2018). However, there are other factors that can affect adaptations at the cardiorespiratory level, such as age, competitive level, sex, physical fitness level, and/or psychological/mental aspects (Clemente et al., 2021; Kunrath et al., 2020). In the next subchapters, different conditioning/constraints that the coach can implement in SSG will be presented, as well as the physiological impact on the players, especially at the cardiorespiratory level.

Number of players and pitch size

The general finding in the literature is that as player numbers increase, exercise intensity decreases (Morgans et al., 2014; Iacono et al., 2023). This relationship is, however, partly dependent on whether the pitch size also increases. Nevertheless, it is important to consider that the relationship between heart rate (HR) and blood lactate (La-) presents notable inter-individual variability. Generally, the lactate threshold is approximately 50–60% of HRmax in untrained individuals and 80% of HRmax in trained individuals (Janssen, 2001). The anaerobic threshold occurs on average with an La- of approximately 4 mmol/L, although it may be higher than this value (Ghosh, 2004; Jamnick et al., 2020; Heck and Wackerhage, 2024). In this way, when the coach's objective is to develop a SSG with greater aerobic emphasis, it is important to consider the pitch size, number of players, sets and repetitions (Morgans et al., 2014) to avoid higher HRmax and La- values, also reducing a level of exacerbated fatigue, which will not meet the training objectives of the coach (Clemente et al., 2014).

On the other hand, previous studies have not clearly shown the same RPE response during exercise (e.g., 2 *vs.* 2 = 7.6 arbitrary units [AU], while 4 *vs.* 4 = 7.9 AU) (Aroso et al., 2004; Dellal et al., 2012; Hill-Haas et al., 2009; Köklü, 2012; Rampinini et al., 2007; Randes et al., 2012). However, this variable cannot be considered in isolation, as the size of the field may also influence the intended stimulus. In this sense, it is noteworthy that games reduced to 4 *vs.* 4 seem to be more adjusted to a high-intensity level, probably to work the glycolytic system (Clemente, 2016).

Some studies show that the larger the field, the greater the physiological stimulus, regardless of the number of players, showing that this variable can be decisive in the type of training and stimulus that is intended to be imposed. Likewise, the larger field size allows for exploring longitudinal and lateral areas, which allows the development of important technical-tactical issues (Aroso et al., 2004; Casamichana & Castellano, 2010; Kelly & Drust, 2009; Owen et al., 2011; Rampinini et al., 2007). Figure 8 presents an example of SSG acute responses in terms of HR and La- concentrations for different SSG formats.

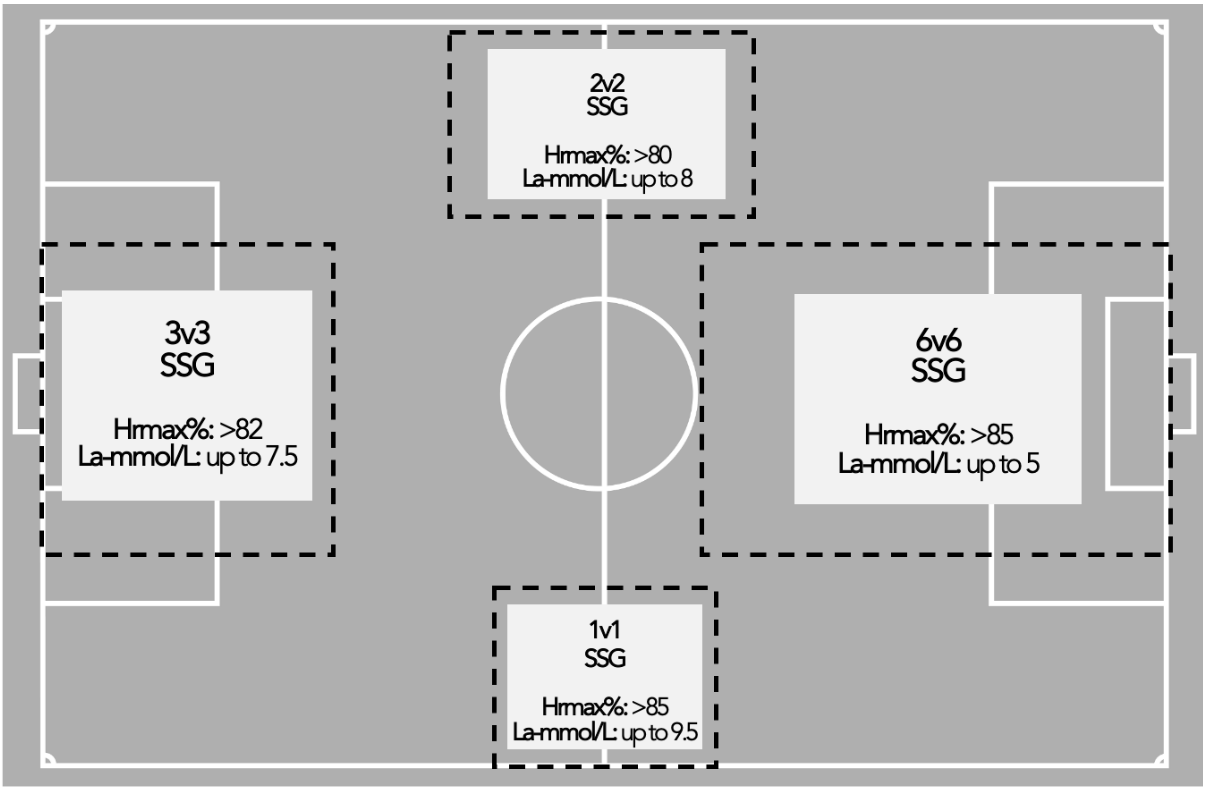

Figure 8. Effects of number of players and field size in small-sided games

Task constraints of SSG

As mentioned previously, there are other types of constraints such as rules related to ball possession, whether or not to score a goal, whether or not to use goalkeepers, whether or not to use additional players, often referred to as neutral players or floaters that play for the team in possession, who play with the team in possession of the ball), goal size, number of goals, restrictions on the number of touches on the ball, goal line, or even the use or not of coach's encouragement. The literature suggests that the use of small goals and different types of scoring (goal scoring, use of goalkeepers, ball possession, goal size, etc.) can significantly increase the physiological impact when compared to traditional goal formats or the use of goalkeepers. However, there are few studies that have compared these issues (Casamichana et al., 2013; Clemente et al., 2014; Halouani et al., 2014; Mallo & Navarro, 2008). As for the existence or absence of goals during SSG, the physiological stimulus increases in the absence of goals (for example, in an SSG where the objective will be to maintain ball possession). Regarding the number of touches on the ball, the more limited the number of touches, the greater the physiological stimulus. This specific rule modification was tested with data suggesting that limiting the number of consecutive touches compared to free play significantly enhances acute physiological responses, by increasing HR, La- and RPE values blood lactate concentrations, and subjective perceived exertion (Casamichana et al., 2014; Dellal et al., 2011). Please see Figure 2 and Table 3 (Casamichana et al., 2014; Dellal et al., 2011).

The type of marking (i.e., man-to-man, double marking, zonal) has also an influence on physiological responses. In a study carried out with amateur players in the 3 *vs.* 3, 6 *vs.* 6, and 9 *vs.* 9 formats, the mean (HRmean) and HRmax increased in the 3 *vs.* 3 when the marking was made man-to-man from 163 to 169 (HRmean) and 180 to 183 (HRmax) (Casamichana et al., 2015). Also in young players, comparisons between free marking and man-to-man marking or even 2 *vs.* 1 marking revealed a greater heart rate effort (167 vs 178 vs 185 bpm), RPE (2.0 vs 4.3 vs 7.2 arbitrary units) and distances covered (e.g., total distance, 1612 vs 1751 vs 1783 m and distance > 18 km/h, 48 vs 74 vs 125 m) (Cihan, 2015). Therefore, man-to-man marking seems to promote a greater physiological stimulus. While, not using goalkeepers, the use of mini-goals, and limiting the number of touches and man-to-man marking increase the intensity of the reduced game. On the other hand, the use of goalkeepers, conventional goals, unlimited touches on the ball, and zone marking, decreases the intensity.

Another variable to consider is the verbal encouragement given by coaches, which also has a physiological impact on reduced games. Higher values of HR, La- and RPE (Figure 9), were found in SSG with verbal coach encouragement when compared to games without encouragement (Rampinini et al., 2007; Sampaio et al., 2007). To summarize the contents related to the topic of this subsection, Figure 9 illustrates the athletes' internal responses to the presence or absence of verbal encouragement by the coach.

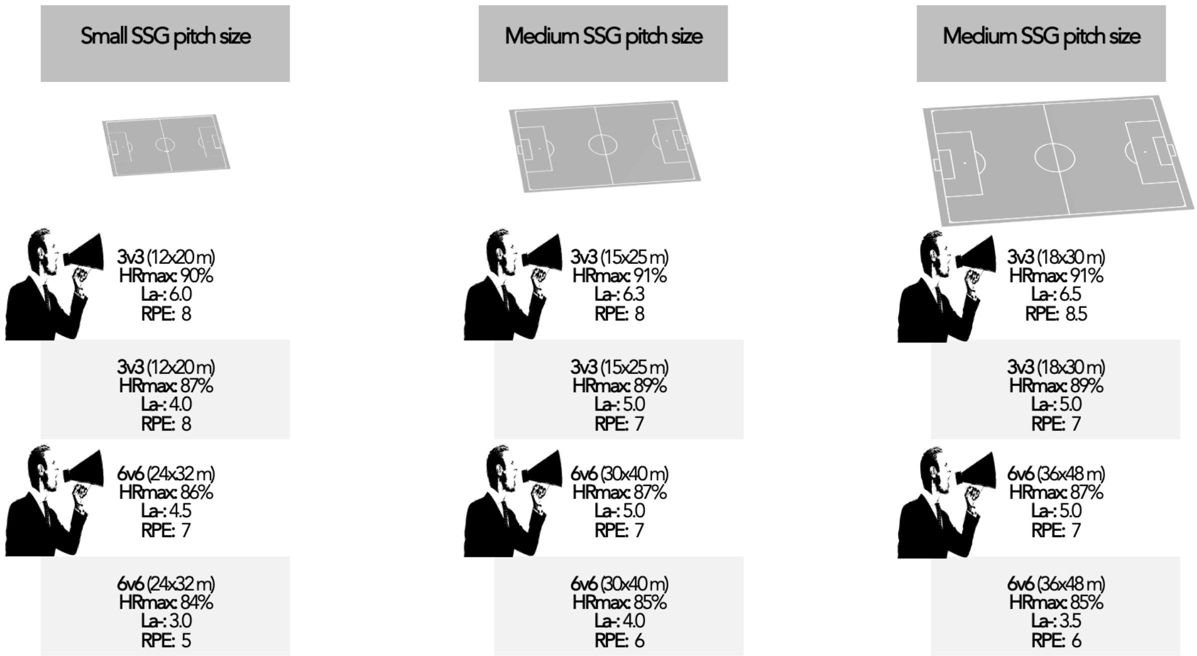

Figure 9. Impact of encouragement during small-sided games

Active or passive rest also influences the physiological impact produced by SSG. The results of another study (Arslan et al., 2017) demonstrated an increasing physiological response with passive rest when compared to active rest in terms of RPE and La-. Furthermore, 2 *vs.* 2 with passive rest induced significantly lower %HRmax and total distance covered than with active recovery. Additionally, the distance covered at high intensity was significantly greater in the 4 *vs.* 4 active recovery games than in the 4 *vs.* 4 passive recovery games (Arslan et al., 2017).

The use of neutral players or "jokers" is related to the support that is intended to be given to offensive or defensive positions, causing a numerical superiority. Normally, the neutral player only participates in offensive or defensive moments with the attacking or defensive team, respectively. In this situation, there are few studies available (Bekris et al., 2012a; Bekris et al., 2012b). Therefore, a clear trend of the physiological impact is not available. For example, in 1 *vs.* 1 and 4 *vs.* 4 games, the highest HR values were observed without a neutral player. In the 3 *vs.* 3 games, the highest HR values were achieved with a defensive neutral, and in the 2 *vs.* 2 games, the highest HR was observed with an offensive neutral player (Bekris et al., 2012a; Bekris et al., 2012b). Thus, more research is needed on this topic to expand the previous findings. Table 1 summarizes the main physiological stimuli depending on the type of SSG.

Table 1. Physiological responses of small-sided games

Condition Type	**Higher ↑ / Lower ↓ Using ✓/ Not Using X**	**Physiological Stimuli**
Number of players	↑	↓
4 vs 4 or ↓ number	↑ anaerobic	↑
5 vs 5 or ↑ number	↑ aerobic	↓
Field size	↑	↑
Goal scoring	X	↑
Number of ball touches	↓	↑
Marking type	man-to-man	↑
Marking type	free	↓
Goalkeeper utilization	Not clear	Not clear
Neutral player utilization	Not clear	not clear
Coach encouragement	✓	↑
Active recovery		↑ (HR%)
Passive recovery		↓ (RPE and La-)

Practical Applications

The knowledge derived from the preceding sections offers valuable insights for practitioners in designing and implementing training and conditioning sessions in football, catering for both aerobic and anaerobic fitness. The following practical applications provide tangible guidance for enhancing athletes' performance:

- **Analytical HIIT programming:** Coaches should employ HIIT methods that meet individual athlete profiles. To ensure effective HIIT programming, consider utilizing the ASR as a crucial parameter, concurrent with the use of MAS values. Individualize HIIT bouts by adjusting the percentage of the ASR, focusing on specific endurance, strength, or anaerobic power objectives.
- **Long and Short Intervals:** Distinguish between long and short intervals for HIIT programming. Long intervals are ideal for prolonged, high-intensity exercise phases and should be interspersed with short recovery periods. Short intervals with shorter but more frequent recovery intervals, help maintain oxygen utilization and improve power output. Coaches should select the interval type according to training objectives and individual athlete capabilities.
- **Understanding SSG-based HIIT:** SSG serve as an excellent method for implementing HIIT of various types. Coaches should strategically design SSG to align with specific physiological and technical/tactical goals, from HIIT types 2 to 4.
- **SSG task constraints:** Manipulate rules and task constraints in SSG to elicit desired physiological responses. The number of players, pitch and goal size, scoring rules, working and rest periods and ball touches can impact SSG intensity. Understanding how each constraint influences physiological stimuli is crucial for crafting tailored

training sessions. Hence, customization of SSG attributes is pivotal to achieving targeted training outcomes.

- **Verbal encouragement:** Coaches can employ verbal encouragement to elevate the physiological response during SSG-based HIIT. Providing feedback, motivation, and instructions during training can increase HR, La-, and RPE. Utilizing encouragement carefully aligns with specific training objectives.
- **Rest Types:** Active and passive rest intervals have differing effects on exercise intensity during both analytical and ecological HIIT approaches. The choice between active and passive rest depends on the desired physiological response. Passive rest can lead to higher HR and La- levels, while active rest may be more suitable for moderate-intensity training. Coaches should select the appropriate rest type according to the training objectives.

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