High Intensity Interval Training: Investigating the impact of different running intensities on anaerobic speed reserve in club level Gaelic football players.

by

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10th May 2020

# INTRODUCTION

**Gaelic Football Overview**

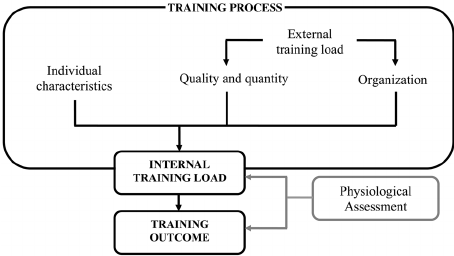
Gaelic football (GF) is an intermittent high-intensity team sport that combines short duration, high intensity bouts of anaerobic efforts (sprinting, accelerating, decelerating. change of direction) with sustained periods of light to moderate aerobic activity (walking and jogging) (Reilly & Doran, 2001). During training and match play, players are required to execute key performance decisions and apply their individual skills (kicking, hand passing, catching, tackling and blocking) under highly fatiguing and chaotic game driven environments, while simultaneously moving at high velocities and avoiding physical contact with their competitors (Beasley, 2015). GF is played on a rectangular grass surface (130-145 m 80-90 m) by two teams consisting of 15 players per team (Gaelic Athletic Association, 2013: Beasley, 2015; Reilly and Doran, 2001). Each team consists of one goalkeeper, six defenders, two midfielders and six forwards. The level of participation is characterised by sub-elite players representing local townland clubs and elite inter-county players representing their inter-county constituency (Reilly & Collins, 2008). Match-play consists of two 30 minute halves at sub-elite level and 35 minute halves at the elite intercounty level, separated by a 15 minute interval (Brown & Waller, 2014; Roe, Murphy, Gissane, & Blake, 2018).

Time motion analysis of elite GF match-play, suggest average total running distances (TD) range between 8,160 ± 1,482 m and 8,889 ± 1,448 m, combined with demanding levels of high speed running (HSRD ≥17 km/h), 1569 ± 594 m and 1,731 ± 659 m (Malone et al., 2017; Malone, Solan, Collins, & Doran, 2016; McGahan et al., 2018). The sprint distance accumulated (>22 km/h) was recorded at 445 ± 169 m, while peak sprint velocity was observed to reach 30.3 ± 1.8 km/h (Malone et al., 2016; Ryan, Malone, & Collins, 2018). Maximum aerobic speed (MAS) was calculated at (4.68 m/s) for GF players, Stephens, (2004), marginally lower that what is seen in Australian rules football (5.03 m/s), Lorenzen, Williams, Turk, Meehan, and Kolsky, (2009), and soccer (4.91 m/s) Rampinini, Impellizzeri, Castagna, Coutts, and Wisløff, (2009). but higher than rugby 7s (4.26 m/s) (Higham, Pyne, Anson, & Eddy, 2013). Research suggests that the three middle positions, midfielders, half forwards, and half backs exhibit higher values of TD, HSRD (>17 km/h), and sprinting (>20 km/h), respectively compared to full backs and full forwards (Malone et al., 2017, 2016). Meanwhile, the TD covered during match-play tends to vary across participation levels based on age group (Cullen et al., 2013) as well as position and competition level (Jennings, Cormack, Coutts, & Aughey, 2012).

Due to the aforementioned reasons, the intensive nature of these movements in GF warrants the utilisation, and hence constant training, of all three energy systems, adenosine triphosphate (ATP) creatine phosphate (CP), the glycolytic, and the aerobic systems. Many significant match-play events include single or repetitive activity efforts involving high running velocities and muscle power (Cregg, Kelly, O’Connor, Daly, & Moyna, 2013). The duration of these high-intensity activities is largely unpredictable because it is determined by the pattern of play and can vary greatly from player to player and from one game to another (Cregg et al., 2013). High intensity activity predominantly, depends on the anaerobic phosphagen and glycolysis systems, and the relative contribution of each system is highly dependent on the intensity and duration of high-intensity activity and recovery intervals (Cregg et al., 2013). However, despite the intermittent nature of sports such as GF that require increased anaerobic energy contribution (Buchheit, 2008), high intensity aerobic power and conditioning are instrumental to successful performance in field sports (Baker, 2011).

**Physical Preparation of Team Sports – Process v Outcome**

There is no doubt that the athletic development for team sports is a unique obstacle to strength and conditioning coaches, due to the fact aerobic, anaerobic and neuromuscular physiology are closely related (Sandford, Allen, Kilding, Ross & Laursen, 2018). A fundamental understanding of the process and outcomes of the physical training undertaken is important (James & Scott, 2017). The outcomes of specific training include anatomical, physiological, and functional adaptations specific to the sport, whilst the process is characterised by the progressive overload of physical training (Figure 1) (Impellizzeri, Rampinini, & Marcora, 2005; Viru & Viru, 2000).



**Figure**  - The conceptual model of the training process (Impellizzeri et al., 2005). The training outcome is the result of the internal training load. This internal training load is the product of; (a) Individual characteristics (training status and genetic makeup), and (b) The quality, quantity and organisation of the external training load.

Whilst the prescription of external loads (the training process) can be manipulated to maximize physiological adaptations, it is the internal load that is central to the training outcomes (fatigue and adaptation) (Impellizzeri et al., 2005; Viru & Viru, 2000). Through physiological evaluation (assessment of the training outcome), appropriate prescription of the training stimulus and systematic monitoring of the does-response relationship and individual physiological adaptations can be optimised (James & Scott, 2017; Buchheit & Laursen, 2013b; Reilly, Morris, & Whyte, 2009).Therefore, training outcomes should be intended to improve the individual capacity for physical match-play performance (James & Scott, 2017).

Ultimately, physical preparation in team sports must achieve two main objectives. First, to improve the physical performance of athletes to tolerate the time needed to complete the tasks required to master sports skills (Joyce & Lewindon, 2014). Second, the potential of athletes to produce energy must be increased by developing the physical capacity needed to express certain sports skills faster and for longer (Stone & Kilding, 2009). It is the responsibility of the strength and conditioning coach to prescribe and employ appropriate training methodologies that have been carefully developed to achieve the desired physiological response, which in turn leads to increased physical performance (Berg, 2006). Subsequently, to be able to perform skills faster, the athlete’s energy production levels must be increased: to maintain high levels of expression and limit the accumulation of fatigue over time, their energy production capacity must be increased. In team sports, this requires a thorough understanding of the development of energy systems and recognition that the team sports landscape is often complex and interchangeable, while at the same time having a particular focus on different physiological qualities (Thomas Reilly, Morris & Whyte, 2009).

**High Intensity Interval Training – The Solution**

One of the most potent, and time efficient strategies for developing cardiorespiratory and metabolic functions in team sports, and thus the physical performance of athletes is high intensity interval training (HIIT), with such adaptations dependent on the intensity and duration of the work to rest periods (Billat, 2001;Buchheit & Laursen, 2013b, 2013c;Laursen & Jenkins, 2002; Sloth, Sloth, Overgaard, & Dalgas, 2013). HIIT has not been clearly defined but is characterised by short intermittent exercise performed at a maximal or near maximal effort at an intensity greater than 90% of V02peak (Gibala & McGee, 2008). In reality any exercise training session will challenge, at different respective levels relative to the training content, both the metabolic and neuromuscular/musculoskeletal systems (Buchheit, Kuitunen, et al., 2012; Vourimaa, Vasankari, & Rusko, 2000). However, for optimal development of parameters such as supramaximal, high-speed running, the intensity of the training must be adjusted to accommodate the abilities of each individual athlete, in addition, accounting for the athletes current training state, training history and physiological demands of the sport. Generic training prescription, in which individual work intensity is too low or too high, may not lead to the appropriate physiological adaptation or could increase the probability of overtraining (Kuipers, & Keizer, 1988).

Research suggests that the use of individual running velocity, by utilising training methods such as maximum aerobic speed (MAS) and sprint interval training (SIT) for the development of aerobic and anaerobic fitness can be both accurate and effective and lead to the desired physiological outcome (Baker, 2011; Blondel, Berthoin, Billat, & Lensel, 2001; Buchheit, 2008; Laursen & Jenkins, 2002). MAS or the velocity associated with V02max (vV02max) can be defined as the lowest running speed at which maximum oxygen uptake (V02max) is attained has been used ubiquitously as a reference intensity to individualise HIIT (Billat, 2001; Billat & Koralsztein, 1996; Baker, 2011; Hill & Rowell, 1996; Laursen & Jenkins, 2002; Laursen, Rhodes, Langill, McKenzie, & Taunton, 2002). MAS can be conceptualised as the maximum sustainable intensity, in contrast to maximal sprinting speed (MSS), that is, maximal attainable intensity. The attraction of MAS is that it represents an integrated measure of both V02max and the energy cost of running into a single factor, and might represent an athletes peak locomotor ability (Billat & Koralsztein, 1996). Since vV02max is theoretically the lowest speed needed to elicit V02max, it makes intuitive sense for this marker to represent an ideal reference for HIIT (Billat & Koralsztein, 1996; Laursen et al., 2002; Midgley, McNaughton, & Wilkinson, 2006).

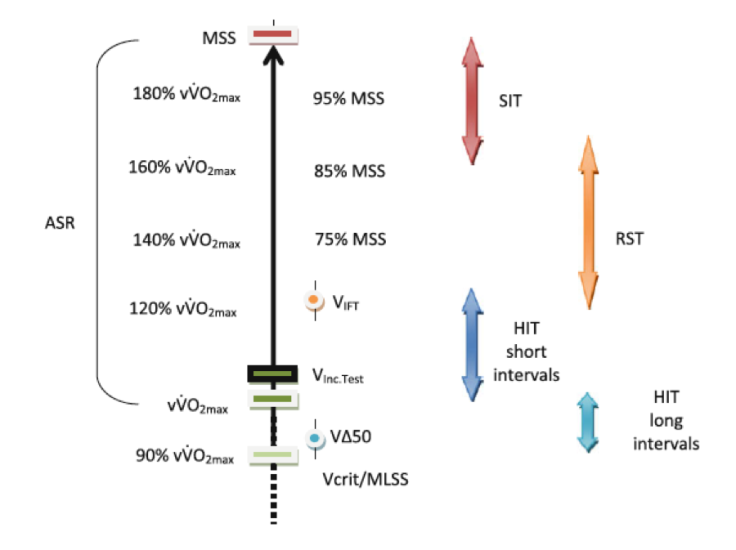


Figure - Buchheit and Laursen, "High Intensity Interval Training, Solutions to the Programming Puzzle: Part 1: Cardiopulmonary Emphasis," Sports Medicine 43 no. 5 (2013): 313-338.

Another popular method for developing aerobic and anaerobic characteristics of team sport athletes is SIT, which is defined by short repeated bursts (4-6 x <30 seconds) of intermittent supramaximal intensity (> 90% V02max), interspersed with active or passive recovery (Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005). Research has demonstrated SIT as a influential training stimulus prompting a multitude of advantages, prompting both central and peripheral physiological adaptations, marked by improvements in fitness and performance Laursen & Jenkins, (2002), this despite SIT involving a substantially lower total training volume than traditional continuous training (CT) (Burgomaster et al., 2005; Cocks et al., 2013). Indices of improved aerobic fitness (maximal oxygen uptake, muscle oxidative capacity, ventilatory and lactate thresholds, and time to exhaustion), and sprint performance (peak anaerobic power, mean power and peak aerobic power (w), have all been shown to significantly improve following 2 – 6 weeks of SIT (Burgomaster, Heigenhauser, & Gibala, 2006; Burgomaster et al., 2008, 2005; Gibala et al., 2006). Such research is of particular interest for GF, since HIIT and SIT represent a time efficient and alternative approach to improving aerobic and anaerobic capacity, and thus overall GF performance, while simultaneously minimising the additional training load, which may be beneficial to athletes who participate in a non-professional sport.

However, coaches automatically assume that by individualising the training prescription using (%MAS), the training stimuli are also normalised as is the training adaptation. Nevertheless, the acute internal reaction to the external training prescription will depend on individual characteristics (Jovanović, Thome, & Mann, 2018). Using (%MAS) in isolation may inadvertently lead to contrasting physiological stress, fatigue, and adaptation. An alternative approach, publicised by Buchheit and Mendez-Villanueva, (2013) used a technique which assessed field-based testing data to estimate a players aerobic (MAS) and speed capabilities (MSS). This technique allows for an estimation of a players anaerobic speed reserve (ASR) and has been used to establish the transition into speed development (>30 ASR) (Bundle, Hoyt, Weyand, & Weyand, 2003). ASR, defined as the difference between an athlete’s absolute maximal sprinting speed (MSS) and their vV02max (MAS), thus being underpinned by both metabolic power and musculoskeletal function, is suggested to be more conducive to higher velocity training prescription (Blondel et al., 2001; Jovanović et al., 2018). Furthermore, Hunter et al. (2014) stated that utilising multiple field based measures, for instance, MAS, MSS and ASR poses a more ecological, valid, economical and practical technique for individualising thresholds.

**Anaerobic Speed Reserve – ASR**

ASR has only recently been considered in relation to high intensity intermittent runningBuchheit, Hader, & Mendez-Villanueva, 2012; Buchheit & Mendez-Villanueva, (2013),and repeated sprint performance (Buchheit, Abbiss, Peiffer, & Laursen, 2012; Buchheit & Mendez-Villanueva, 2014; Alberto Mendez-Villanueva, Hamer, & Bishop, 2008; Ufland, Ahmaidi, & Buchheit, 2013). The administration ofASR has been found to overcome interindividual variations in supramaximal running performance (Figure 3). Nevertheless, running velocity profiles and physiological responses to supramaximal training of this magnitude must be closely monitored, reasons being, athletes with similar MSS but dissimilar MAS can experience inconsistencies in exercise tolerance during supramaximal intensity training (Blondel et al., 2001; Buchheit, & Laursen, 2013a; Buchheit & Mendez-Villanueva, 2014). In contrast, athletes presenting similar MAS but contrasting MSS can also exhibit similar inconsistencies in exercise tolerance; in such cases, higher MSS is suggested to improve the athlete’s economy during supramaximal running speeds (Figure 3) (Buchheit & Mendez-Villanueva, 2013, Alberto Mendez-Villanueva et al., 2008). If the intensity of a short-term HIIT session is based exclusively on aerobic markers (percentage of MAS), athletes with higher MSS will be conditioned at a substandard portion than their maximum athletic capacity (Buchheit et al., 2012; Buchheit, & Laursen, 2013b). MAS usually leads to athletes participating in HIIT with contrasting physiological demands and exercise tolerance than predicted (Buchheit & Laursen, 2013a).

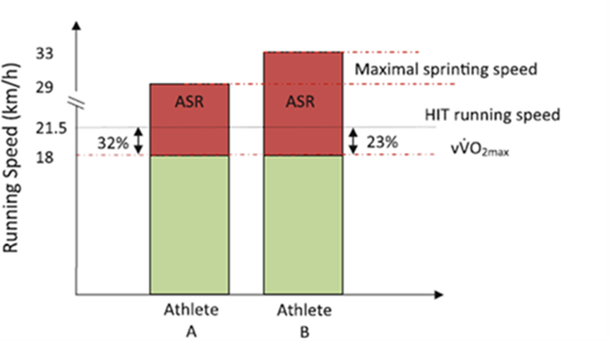


Figure - Buchheit and Laursen, "High-Intensity Interval Training, Solutions to the programming puzzle: Part 1: Cardiopulmonary Emphasis," Sports Medicine 43 no. 5 (2013): 313-338

This is due to the fact that the same absolute running intensities (%MAS) may involve a different proportion of one’s ASR (Figure 3), resulting in differing physiological demands and in turn, a different exercise tolerance (Buchheit, 2010). Recommendations have proposed a two pronged approach whereby training is targeted towards improving maximal sprinting speed alongside the inclusion of HIIT to improve the ability to recover between bouts (Bishop, Girard, & Mendez-Villanueva, 2011). In support of this, both MSS and MAS were significant predictors of repeat sprint ability (RSA) in a cohort of 61 team sport players (Buchheit, 2012). Thus, an understanding of both the metabolic and biomechanical specificity is required if repeated supramaximal running ability is to be enhanced. It is therefore imperative for the prescription of running based conditioning to include a velocity that comprises duel sensitivity to both the aerobic and anaerobic capabilities of the athlete.

For this reason, the concept of ASR, requires a fundamental understanding of the physiological differences between MAS and MSS, whereby, MAS represents the fastest mechanical speed that can be maintained aerobically, while MSS is generated by the horizontal ground reaction impulse (Rabita et al., 2015; Weyand et al., 2006). MSS, classified as the velocity an athlete can no longer accelerate when performing all out sprint efforts, Buchheit and Laursen, (2013b); Moir, Brimmer, Snyder, Connaboy, and Lamont, (2018); Sandford, Kilding, Ross, and Laursen, (2019), closely pertains to mechanical or neuromuscular limitations instead of metabolic power accessibility in the non-sustainable range above the critical speed, thereby increasing neuromuscular demand for maintaining external force output throughout the short duration performance (Bundle & Weyand, 2012; Burnley, Vanhatalo, & Jones, 2012). Alternatively, a considerable increase in neuromuscular activity was not observed when the workload was predominantly supported by aerobic systems listed below the critical speed parameters (Bundle & Weyand, 2012; Burnley et al., 2012). If an athlete exhibits a decreased ASR, their ability to preserve or enhance impulse may be restricted. As a result, the application of ASR is considered complex due to these two poignant parts, the former principally limited by metabolism (vV02max) and the latter restricted primarily by mechanical force and not energy supply (Bundle & Weyand, 2012; Rabita et al., 2015; Weyand, Sternlight, Bellizzi, & Wright, 2000).

Research has suggested that ASR in isolation cannot predict improvements in mean repeated sprint time (Buchheit & Mendez-Villanueva, 2014). This is due to the independent changes within MAS and MSS and their impact on ASR calculations. From a practical viewpoint, ASR modifications hinge on both MSS and MAS, as a result. the function of ASR as a component of performance, will be drawn by adjustments to the relevant MSS and MAS profile of the athlete (Sandford et al., 2018; Sandford et al., 2019). Although training individualised by ASR may be beneficial for supramaximal running development, ASR scores should not be compared between individuals or considered in terms of performance without MAS and MSS being independently analysed. Subsequently, team sports athletes’ running prescription provides a unique degree of complexity, whereby contrasting physiological and mechanical profiles can achieve similar performances (Sandford & Stellingwerff, 2019). By extension, an important application of ASR is the simultaneous investigation of the metabolic and mechanical limitations of the athlete’s profile in relation to various other components that should be developed, specifically, aerobic, anaerobic, neuromuscular, and mechanical properties (Sandford et al., 2018; Sandford, Kilding, et al., 2019). For coaches, the diversity of athletes presents significant challenges to curating the daily training prescription according to the athlete profiles for maximising individualisation to a given stimulus and avoiding a non-responder outcome (Sandford & Stellingwerff, 2019).

It is without question the physical preparation of team sport athletes is complex, whereby athletes who possess diverse physiological profiles routinely compete against one another during competitions; for instance, positional adjustments frequently occur to eliminate the tactical dominance of the opposing team (Buchheit, 2008). Although the precise positioning of each player can vary depending on the tactical settings of each team, continuous interaction provides players with similar technical skills but a greater ASR profile, regardless of their position, an advantage over opponents with lower ASR and similar MAS. (Buchheit & Laursen, 2013a; Alberto Mendez-Villanueva et al., 2011). Presenting physical attributes similar to professional soccer, high-speed running classification can be utilised to acknowledge positional dissimilarities in GF that have been shown to be useful for determining the type of profile required to perform optimally in a specific playing position (Sporis, Jukic, Ostojic, & Milanovic, 2009). From a practical standpoint, developing superior MSS characteristics may reduce the proportion of ASR utilised by athletes, which is significantly related to the tolerance level of athletes for high-intensity activity during game performance (Buchheit, Hader, & Mendez-Villanueva, 2012). Possessing a higher ASR enables a reduction of the relative intensity (percentage of ASR) of exercise above vV02max, thereby reducing the contribution of the anaerobic energy system and minimising peripheral fatigue (Bundle et al., 2003; Weyand, & Bundle, 2005). Furthermore, the assessment of MAS, MSS and ASR can enable the identification of two dominant markers (biomechanical and physiological), which can improve accuracy in identifying the strengths and limitations of individual athletes, while at the same time, determining the tolerance levels of athletes for high intensity training. In addition, recognising athletes' physical strengths and weaknesses improves the coach’s decision-making abilities, when players with the same technical characteristics are compared between game positions.

Coaches, therefore, may have to opt for a more sophisticated approach to training prescription to improve athletic performance due to the rapidly changing landscape of modern-day GF (Malone et al., 2017). One-dimensional approaches should be revised based on significant individual responses to a given stimulus (Sandford & Stellingwerff, 2019). Therefore, the utilisation of three fundamental assessments, MAS (characterised as an indicator of aerobic power), MSS (highlighting the athletes’ biomechanical and mechanical abilities), and ASR (defined as the velocity zone between vV02max and MSS) calculation can provide a valuable insight into athletic potential (Sandford & Stellingwerff, 2019). Subsequently, this assessment methodology will enable more targeted interventions through the utilisation of athlete subgrouping to improve the understanding of training responses, ultimately supporting the coach’s ability to efficiently prescribe individual training.

**METHODS**

**Experimental Approach to the Problem**

The current longitudinal study investigated the impact that different supramaximal high intensity interval training (HIIT) and sprint interval training (SIT) intensities had on the ASR profile of sub-elite Gaelic football players. Using a fully controlled study design, participants were divided into one of three training groups, which were conducted alongside the standard training sessions MAS-120 (n = 12), ASR-40 (n = 12) or 30-s SIT (n = 11) (Buchheit, Mendez-Villanueva, Quod, Quesnel & Ahmaidi, 2010; Burgomaster et al., 2005; Gibala et al., 2006). The current research design also provided a non-intervention period of three weeks (control group), prior to the six-week training intervention. The players in each training group were matched according to their ASR performance profile, ensuring that all three groups had the same mean values before conducting the six-week training intervention.

Therefore, the current study involved multiple objectives. (1) Evaluate the running speed performance (MAS-MSS) of sub-elite club level GF players to calculate the anaerobic speed reserve (MSS-MAS). (2) Determine the impact of the six-week training intervention using different HIIT intensities (MAS-120%, ASR-40% and SIT) and their impact on ASR. (3) Compare running speed performance (MAS, MSS and ASR) between playing positions, which may aid coaches in tactical decision making and team selection in GF. (4) Quantify, the training load of three competitive games with reference to TD, (HSRD ≥17 km/h), and sprint distance (>22 km/h), to investigate if the additional volume impacted ASR, between starters and non-starters (5) Evaluate the impact that different training intensities had on participants who displayed, MAS-H, MAS-L, MSS-H and MSS-L.

**Subjects**

The maximal aerobic and anaerobic running performance were collected from thirty-eight Gaelic footballers (Senior Club Division 1) players: 15 defenders, 6 midfielders, and 17 forwards (age: 21.6 ± 4.2; height: 1.74 ± 5.8 cm; body mass: 75.6 ± 1.5 kg). All participants were told that they could withdraw from the study at any time, in addition participants would receive detailed individual feedback on the conclusion of the study.

According to the inclusion criteria, all participants must complete the anthropometric and physical performance assessments, have two years of GF experience at the sub-elite club level (Division 1), be over 18 years of age, not on medication contraindicative to exercise performance and considered injury-free and fit to participate by the team physiotherapist. Furthermore, participants were not eligible for inclusion if satisfying any of the following: (i) current illness or history of illness; (ii) currently participating in elite level intercounty training (iii) travel-based players unable to meet (>90%) of allocated team training. These data were gathered from Health Screening forms completed prior to the study. In Table 1 is shown the anthropometrical data of the participants (n = 38).

During the eleven-week intervention, only one participant was excluded from the study, due to the failure in meeting the minimum number of training sessions needed for all groups which was set to eleven. Every participant who missed more than one session due to absenteeism, injury or did not take a performance test on the scheduled day was removed from the study. Injury reports were collected weekly. Injury was defined as an event that limits a participant's ability to participate in scheduled training due to pain or discomfort. Throughout the course of the study, one injury was reported during HIIT and SIT training. The participant who reported the injury was removed from the study due to minor lower extremity injury (Knee tendonitis). Compared with other HIIT and SIT studies with aerobic and aerobic running tests, it is not clear whether this attrition rate is unusual, since attrition was not reported in any of the research reviewed.

**Procedures**

The study consisted of participants who initially conducted MAS and MSS running performance assessment on the same day. All testing and data collection were directed by the lead researcher and were undertaken indoors (anthropometric) and outdoors (MAS-MSS) on an all-weather grass pitch between 9.00 am and 12.00 noon, to limit the influence of possible circadian rhythm variations on performance (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005). All participants were asked to refrain for intense physical exercise 24 hours prior to the initial testing session. To maximise performance, participants were instructed to consume adequate amounts of slow digesting carbohydrates, lean protein and water 24 hours prior to each scheduled testing (Holway & Spriet, 2011). After the completion of the anthropometric assessments, a standardised “RAMP” warm up, which consisted of jogging, bodyweight movements and running exercises were organised and directed by the lead researcher (Jeffreys, 2007). Testing were conducted in the stated sequence and each participant was assigned to a fixed time, and the testing assessments followed that sequence to ensure optimal recovery between trial attempts, thereby minimising the impact of cumulative fatigue impacting performance (Read & Cisar, 2001).Each player was assigned to a fixed time, and the testing assessments followed that sequence to ensure optimal recovery between trial attempts and to minimise cumulative fatigue impacting performance (Read & Cisar, 2001).

The initial testing session took place at the beginning pre-season training (November 30, 2019), pre-testing consisted of (1) Anthropometrical (2) MSS assessments; (3) 1,500m time trial (1,500TT). From week 2 to 4, participants commenced a three-week general preparation phase (GPP), whereby all individuals participated in the same training programs (*control group).* On completion of the three-week control period (December 21, 2019),MAS and MSS running performance were retested. On week five the implementation of a six-week training intervention commenced, participants were allocated to one of three training groups (*see training groups below*). The three training groups completed twelve HIIT and SIT sessions twice a week during the six-week study intervention. Completion of the study (February 8, 2020) included anthropometric, MSS and MAS retesting of the three training intervention groups.

**Performance testing**

***Maximal aerobic speed.*** The gold standard method to estimate MAS would be to evaluate speed at maximum oxygen uptake (sV02max). Estimating, sV02max is, however, labour intensive and time consuming. An indirect alternative is mean running speed calculated from a time trial assessment (Lorenzen, Williams, Turk, Meehan, & Clclonl Kolsky, 2009; Sandford, Rogers, et al., 2019; Slattery, Wallace, Murphy, & Coutts, 2006) Estimation of MAS based on time trial performance is conceivable since time trials require maximal effort demanding a high contribution of aerobic power, which MAS is claimed to measure (Léger & Boucher, 1980). Previous research has indicated that distances between 1500 m and 3200 m can be used to accurately estimate MAS (Bellenger et al., 2015; Lorenzen, Williams, et al., 2009).

The measurement of MAS (km.h-1) is suggested to be closely related to the duration of the effort, regardless of the protocol adopted; 4m 58s is proposed to be the optimal timeframe for MAS calculation irrespective of the sport (Chamoux, Berthon, & Laubignat, 1996). Significant correlations are reported between vV02max, the average velocity during a v5TT, and the 1,500m time trial (Berthon et al., 1997; Lacour, Padilla-Magunacelaya, Chatard, Arsac, & Barthélémy, 1991). For the purpose of this study, participants’ MAS profiles were investigated using 1,500m time trial assessment, which has been illustrated to correlate significantly with the laboratory measure (r = - 0.791) (Lorenzen, Williams, et al., 2009). The rationale for this was to limit the volume of testing to fit around the players training and match schedule.

The maximal aerobic speed was calculated by dividing the total running distance (d) by the time taken to complete the assessment in seconds (s) e.g. (d - 1500/s - 380 = 3.95 m/sec), alternatively this can converted into kilometres per hour by the following formula (m/s x 3.6 = km/hr).

***Maximal sprinting speed*.** The flying 40-meter maximal sprint assessment was used to calculate MSS, with each participant completing three 40 m maximal sprints with approximately three minutes (passive recovery) between trial attempts. Distances were marked to the nearest centimetre using a standard measuring tape, and vertical poles were placed at the start and at 10m and 40m distances. Once the participant was prepared to partake in the assessment, an instruction of “on you” was provided, thereby permitting the participant to start and accelerate on their own mark and maximally to the end of the marked distance (Sandford et al., 2018).

The GPS units used during this study were from the manufacturers Playertek. The units were 10Hz (10 samples taken per second) and also included a 10 Hz Tri-Axial magnetometer, 400 Hz Tri-Axial Accelerometer and Gyroscope. The Playertek GPS units were worn in a neoprene bib, within a specially manufactured pouch, to ensure the unit is held secure between the shoulder blades. One of the main limitations of the Playertek device is that there is currently no function to allow you to observe how many satellites the unit is connected to at any one time. Having this function increases the reliability of the data produced as no measurements would be taken before the unit had connected to the desired number of satellites. However, Raizaday et al (2019) found that between 9am-12pm, Playertek displayed the highest number of connected satellites and the best HDOP values. In addition, Raizaday et al (2019) found that Playertek devices showed a high level of both validity and reliability with regards to straight line speed, in comparison to gold standard catapult systems. The primary variable of interest taken from the GPS for analysis will be the participants’ MSS, representing the ceiling value of the athletes’ ASR (Sandford et al., 2018).

***Anaerobic speed reserve.*** ASR will be calculated as the difference between MSS and MAS with the following equation:

ASR = MSS (km/h) – MAS (km/h) (Mendez-Villanueva et al., 2012)

**Match Day Collection**

TD, HSRD (> 17 km / hr) and sprint distances (> 22 km / hr) are collected using (Playertek GPS system) for three competitive games. The mean performance for TD, HSRD, and sprint distances in six competitive games were used to determine the effect of additional training load, if any, on ASR between starters and non-starters. Players were asked to wear individual GPS units, positioned between the shoulder blades, encased in an elastic compartment in the jersey. Devices were switched on fifteen minutes before the game commenced and switched off immediately afterwards. Data sets were then downloaded, where further analysis was performed through the system software provided by the manufacturer (Playertek). Each pod contains a 10 Hz Tri-Axial magnetometer, 400 Hz Tri-Axial Accelerometer and Gyroscope.