PERCEIVED FITNESS IS A STRONGER PREDICTOR OF MAXIMAL AEROBIC SPEED THAN SUBMAXIMAL FITNESS IN RUGBY UNION PLAYERS

KIERAN SMITH

ABSTRACT

Background: Monitoring athlete training effects in team sports requires a systematic approach, adopting frequently implementable methods and sensitive proxy outcome measures able to detect acute and chronic training effects. Consequently, the use of submaximal fitness tests (SMFT) in team sport settings has increased, likely given their time-efficient nature, ease of administration in-season, and strong physiological rationale in observing athlete responses to a standardised exercise stimulus. However, this process has primarily favoured objective measures over subjective athlete responses, and both approaches are yet to be assessed for their respective associations and predictive qualities with maximal test outcomes. **Aim:** The study evaluated the relationships and predictive qualities between field-based measures of perceived, submaximal and maximal aerobic fitness in a sample of rugby union players. **Methods:** Using an observational, cross-sectional approach, 47 high-performance British university rugby union players (21.1 ± 1.2 years; 184.86 ± 7.28 cm; 97.82 ± 14.31 kg) rated their aerobic capacity using a newly modified rating of perceived fitness (RPF) scale, before completing a SMFT (shuttle based, continuous-fixed, 4 min running at 12 $km \cdot h^{-1}$), and a 1.2 km shuttle run test (1.2SRT) to assess maximal aerobic speed (MAS). Data were analysed using magnitude-based inferences (MBI). **Results:** An almost certainly [large] positive association between RPF and MAS ($r = 0.58$; ±0.19) was revealed, with backs reporting a higher RPF (almost certainly [small] increase) and achieving a higher MAS (possibly [small] increase) during the 1.2SRT in comparison to forwards. A likely [small] negative association between SMFT exercise heart rate (HRex) and MAS ($r = -0.25$; ±0.23) and a possibly [small] negative relationship between

RPF and HRex (*r* = -0.19; ±0.27) was also identified. Regression analysis revealed RPF as the strongest predictor of MAS (R^2 = 0.33; SEE: 0.28) compared to SMFT HRex (R^2 = 0.06; SEE: 0.35), and both variables combined (Adj. R^2 = 0.29; SEE: 0.28), and RPF was shown to be a poor predictor of SMFT HRex as a measure of submaximal aerobic fitness (R^2 = 0.04; SEE: 8.48). **Conclusions:** Athlete RPF show promising levels of content, face and construct domains of validity in the prediction of MAS measured using the 1.2SRT; however, further work is needed to assess other domains of validity, reliability and sensitivity. Whilst SMFT HRex shows good convergent validity with some field measures of aerobic capacity, HRex is poorly related to or predictive of MAS measured using the 1.2SRT. RPF in its form derived from this study is not well related to or predictive of proxy measures of submaximal cardiovascular/aerobic fitness such as SMFT HRex. The RPF scale used in this study could be a useful monitoring tool in team sports.

Keywords: subjective performance evaluation; perceived fitness; submaximal fitness test; maximal aerobic speed; aerobic capacity; athlete monitoring; physical performance; rugby union; team sports; applied sport science

PERCEIVED FITNESS IS A STRONGER PREDICTOR OF MAXIMAL AEROBIC SPEED THAN SUBMAXIMAL FITNESS IN RUGBY UNION PLAYERS.

KIERAN SMITH

A thesis submitted in fulfilment of the requirements for the degree of MASTER OF SCIENCE (BY RESEARCH).

Department of Sport and Exercise Sciences

Durham University

2023

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HRex; *Exercise Heart Rate* ....

1, 8, 20, 21, 22, 54, 55, 61, 62, 66, 69, 71, 75, 76, 77, 78, 79, 80, 81, 83, 84, 87, 88, 89, 90, 91, 95, 96, 97, 98, 136, 137, 139, 140, 141, 142, 145, 146, 147, 148

HRmax; *Maximum Heart Rate* ....

.... 21, 39, 40, 52, 68, 69, 75, 76, 77, 86, 87, 92, 139, 141, 142, 143

HRpeak; *Peak Heart Rate* 39, 75, 77, 86

HRR; *Heart Rate Recovery* 54, 56, 70, 75, 76, 77, 87, 98, 136, 137, 139, 140, 141, 142

HRV; *Heart Rate Variability* 54, 56

HSR; *High-speed Running* 30, 31, 32, 33, 36

ICC; *Intraclass Correlation Coefficient* 20

IDE; *Integrated Development Environment* 74

IMU; *Inertial Measurement Unit(s)* 29

IQR; *Interquartile Range* 31

KPI; *Key Performance Indicators* 30

LS; *Linear Speed* 44

MAS; *Maximal Aerobic Speed* ....

1, 8, 19, 20, 21, 22, 37, 46, 47, 48, 49, 50, 51, 62, 63, 64, 66, 73, 75, 77, 78, 79, 80, 81, 83, 84, 85, 86, 87, 88, 89, 90, 91, 95, 96, 97, 98, 143, 144, 145, 146, 147, 148, 150

MBI; *Magnitude-Based Inference(s)* 1, 74, 76, 77, 79

MD; *Mean Difference* 20

MEMS; *Micro-electrical Mechanical System* 29, 30, 31, 34, 36, 54

MSS; *Maximal Sprinting Speed* 48

QR code; *Quick Response Code* 69

r; *Correlation Coefficient* 1, 19, 20, 41, 42, 50, 58, 74, 79, 84, 85, 113, 148

R^2; *Coefficient of Determination* 2, 74, 80, 81

RAS; *Reactive Agility Speed* 44

RHIE; *Repeated High-intensity Effort(s)* 32, 46, 47, 114

RPE; *Ratings of Perceived Exertion* 19, 38, 41, 42, 54, 57, 58, 107

RPF; *Rating(s) of Perceived Fitness* ....
1, 8, 19, 21, 22, 61, 62, 68, 69, 74, 75, 76, 77, 78, 79, 80, 81, 83, 84, 85, 86, 87, 88, 89, 90, 93, 95, 96, 97, 98, 130, 131, 136, 137, 139, 140, 142, 144, 145, 146, 147, 148

RS^2; *Rugby-Specific Repeated-Speed Test* 46

SD; *Standard Deviation* 8, 74, 75, 150

SEE; *Standard Error of the Estimate* 2, 74, 80, 81, 148

SMFT; *Submaximal Fitness Test(s)* ....
1, 2, 8, 17, 18, 20, 21, 22, 51, 52, 54, 55, 61, 62, 64, 66, 69, 70, 75, 76, 77, 78, 79, 80, 81, 83, 84, 87, 88, 89, 90, 91, 95, 97, 98, 145, 146, 147

sRPE; *Session Rating(s) of Perceived Exertion* 41, 42

SRR; *Speed Reserve Ratio* 48

SSG; *Small-sided Games* 52

TD; *Total Distance* 30, 31, 32

TE; *Typical Error* 20

TEM; *Typical Error of Measurement* 29

TMA; *Time-motion Analysis* 28, 34

U16; *Under 16* 46

U18; *Under 18* 46

U20; *Under 20* 36, 51, 103

$\dot{V}CO_2$; *Carbon Dioxide Production* 47

VIF; *Variance Inflation Factor* 81, 89, 148

$\dot{V}O_{2max}$; *Maximal Oxygen Uptake* 18, 45, 47

STATEMENT OF COPYRIGHT

ACKNOWLEDGEMENTS

I would like to personally thank my supervisory team: Mr Rob Cramb; Dr Katie Di Sebastiano; and Dr Shaun McLaren, for generously providing their invaluable expertise, knowledge and guidance throughout the development of this study. Additionally, this study would not have been possible without the keen interest and support shared by the coaching staff and the players who participated. I am also grateful to my peers for their assistance during data collection. Finally, I would like to thank friends and family for their continuing support throughout my education to date and those who directly supported the creation of this thesis by providing valuable feedback and proofreading drafted chapters.

CHAPTER 1. INTRODUCTION

1.1 Background

Rugby union is a field-based contact team sport in which teams of 15 on-field players, comprising forwards and backs, attempt to outscore the opposing team through unlimited phases of play (Till et al., 2020; World Rugby, 2022a). The objective of the invasion sport is to physically carry the ball over an opponent's goal-line and force it to the ground to score a try, with further points also accumulated through conversions, penalties or drop goals (World Rugby, 2022a). The sport is believed to have originated in Rugby, England, in 1823. It is now considered one of the most popular sports in the world, encompassing 9.6 million players and 877 million people following the sport worldwide (World Rugby, 2022a; World Rugby, 2019; World Rugby, 2018). Given the increasing interest in the sport, and the increasingly formalised training and competition setting, the subsequent demand for optimal performance and competitive advantage over opposing teams has increased research into the monitoring and training processes underpinning rugby union performance and team sports more generally (Smart et al., 2014; Jeffries et al., 2021).

Like other field-based teams sports such as football and hockey, rugby union is characterised by short durations of high-intensity activity comprising high-speed running, sprinting, collisions and tackling, intermixed with longer phases of lower intensity activity (Cahill et al., 2013; McLaren et al., 2016). Consequently, for players to regularly sustain these intermittent demands of rugby competition, a wide array of well-developed physical performance qualities are required (Smart et al., 2014; Gabbett and Seibold, 2013; Ross et al., 2015). For example, measures of aerobic and anaerobic fitness, speed and acceleration and muscular strength and power have all been linked with match results, match actions and skill performance (ES = 0.74 ± 0.51) (Gabbett and Gahan, 2016), competition standard, recovery and fatigue status (ES = 0.71 ± 0.38) (Johnston, Gabbett and Jenkins, 2015) and injury probability (odds ratio: 1.39, 95% CI: 0.98 – 1.98) (Cross et al., 2016; Windt and Gabbett, 2017). Furthermore, unlike other team sports, rugby union matches involve high-intensity bouts comprising contact incidents (tackles and rucks), grappling actions such as mauls and scrummaging, and high-speed collisions (Tucker et al., 2021). Subsequently, demanding players possess robust cardiorespiratory fitness to enable recovery from the anaerobic nature of cumulative high-intensity bouts (Swaby, Jones and Comfort, 2016).

The assessment of aerobic fitness in team sports such as rugby union is largely inferred through maximal-effort, exhaustive, intermittent field tests such as the 1.2 km Shuttle Run Test (1.2SRT), colloquially referred to as the 'Bronco Test' (Baker and Heaney, 2015; Brew and Kelly, 2014). However, the use of successive exhaustive assessments within the in-season phase of team sport competition is considered impracticable and unfeasible, given congested training and fixture schedules, high numbers of athletes, time constraints and several interrelated factors such as motivation, physical qualities and season stage (Carling et al., 2018; Lacome, Simpson and Buchheit, 2018; Impellizzeri et al., 2020). In response, submaximal fitness tests (SMFT) have grown in popularity within team sport contexts within the last decade (Shushan et al., 2022). Allowing practitioners to feasibly, pragmatically, and systematically assess athlete physiological states in response to a standardised exercise stimulus using a time-efficient and simple-to-administer methodology with low physical/physiological strain (Buchheit, 2014; Buchheit, Simpson and Lacome, 2020; Scott et al., 2018).

Additionally, despite numerous objective markers of player fitness and health available, Lamb (1992) succinctly stated that the simplest method of evaluating fitness is to ask how one perceives this. However, contemporary practitioners such as sports scientists and strength and conditioning coaches now collect a wide range of data using various commercially accessible technologies and devices (West et al., 2021). This has resulted in a disconnect, with objective monitoring strategies often favoured over subjective assessment techniques for evaluating athlete health and performance (Montull et al., 2022). Recently, greater investigation of subjective monitoring techniques has been suggested to determine how athlete perceptions may relate to objective performance measures (Windt et al., 2022). As well as how accepted psychometric principles may be used singularly or in combination with objective measures to improve the monitoring of athlete fitness and health in team sports (Saw et al., 2016; Montull et al., 2022; Windt et al., 2022).

1.2 Rationale

To monitor athlete training effects in team sports, a systematic approach is necessary to allow for informed decisions concerning athlete and training management through changes to programming, delivery or recovery interventions (Shushan et al., 2022; Kalkhoven, Watsford and Impellizzeri, 2020; Impellizzeri et al., 2020). As a result, the approach should be based on a thorough conceptual framework, be frequently implementable, use sufficiently sensitive proxy outcome measures, and be able to detect acute and chronic training effects (Vanrenterghem et al., 2017; Jeffries et al., 2021). Therefore, the current study aimed to examine the relationships between perceived fitness, SMFT heart rate (HR) measures, and a field-based measure of aerobic capacity (1.2SRT) in a sample of high-performance rugby union players representing a British university rugby performance squad.

Field-based team sports such as rugby require players to tolerate extensive periods of activity exceeding the speed at maximal oxygen uptake ($\dot{V}O_{2max}$) (Sandford, Laursen and Buchheit, 2021). With this knowledge and using low-cost field tests, maximal aerobic speed

(MAS), the minimal running velocity eliciting $\dot{V}O_{2max}$, is a commonly used fitness marker of aerobic capacity in team sport athletes (Buchheit and Laursen, 2013a). Specifically within rugby, MAS has been shown to strongly correlate (r = 0.746) with distance covered during match play in professional rugby players (Swaby, Jones and Comfort, 2016). Therefore the current study utilised the 1.2SRT to assess MAS as a commonly used estimative measure of maximal aerobic capacity (Baker and Heaney, 2015). Additionally, given that motivation to perform maximally is crucial for practically useful outcomes in these measures, HR measures were collected as markers of internal load to evaluate the relative physiological strain of work completed and to confirm maximal efforts (Thorpe et al., 2017; Lemmink et al., 2004).

The study compared MAS with a modified rating of perceived fitness (RPF) scale, focussing on aerobic capacity, adapted from Borg, Skinner, and Bar-Or (1972). Systematic reviews from Jeffries et al., (2020) and Saw et al., (2016) identified that studies concerning athlete subjective monitoring have grown exponentially whilst also determining subjective measures hold superior sensitivity and reliability than objective measures, providing enhanced observations of changes in athlete psychophysiological state. Whilst the use of subjective data in applied sports science has primarily centred around athlete-reported outcome measures (AROM) of training loads such as ratings of perceived exertion (RPE) or responses to training such as wellness, recovery, sleep and muscle soreness (Jeffries et al., 2020). Athlete-perceived fitness is an area which has received less attention, with few studies to date having examined the use of perceived fitness scales with athletes or directly compared the relationship between perceived and actual fitness measures (Germain and Hausenblas, 2006). Germain and Hausenblas (2006) identified that combined perceived fitness scores of men and women of multiple ages related to physical test outcomes (r = 0.38, n = 33, CI = ±0.058), with results further augmented in younger people (r = 0.37, n = 25, CI = ±0.09) and studies employing standardised perceived fitness measures (r = 0.43, n = 18, CI = ±0.071). However, the authors noted that many studies utilised either un-justified modifications to scales or author-developed scales with unknown levels of construct validity and reliability whilst often combining scores for different components of fitness into a general score of 'fitness' (Germain and Hausenblas, 2006). Given the multidimensionality of the physical fitness construct, the present study examined the accuracy and relationship between a standardised measure of athlete-perceived aerobic capacity and an objective measure of aerobic capacity (MAS) as a single fitness component.

Lastly, as exhaustive field-based tests of aerobic capacity are preferred but have limited feasibility to be repeated in-season, the resultant interest in time-efficient and non-exhaustive SMFT has resulted in numerous methods being applied across multiple team sports (Shushan et al., 2022; Scott et al., 2018; Buchheit, 2014). Recently, changes to athlete aerobic capacity, through the monitoring of exercise heart rate (HRex) during SMFT in comparison to endurance test performance, has been meta-analysed by Shushan et al., (2023a) finding good absolute (MD = 0.5 [95% CI: 0.1 – 0.9] and TE = 1.6 [1.4 – 1.9] % points), and high relative (ICC = 0.88 [0.84 to 0.91]) reliability as well as good convergent validity (r = –0.58 [–0.62 to –0.54]). Shushan et al., (2022) further identified five distinct SMFT protocols (Continuous-fixed, Continuous-incremental, Intermittent-fixed, Intermittent-incremental and Intermittent-variable) with further customisable subdivisions applied across 12 different team sports. However, of only nine studies to date which have assessed the use of SMFT in rugby, no study has yet employed the ultimately recommended protocol of a continuous-fixed SMFT using a pitch-based protocol and minimum dose of 3-4 min to attain more reliable HR data in rugby union players (Shushan et al., 2022). Also, whilst the relationship between SMFT and maximal exhaustive tests shows good convergent validity, the extent to which SMFT HRex is predictive of outcomes such as MAS is unknown (Shushan et al., 2022). Given submaximal aerobic capacity is defined as the ability to perform non-exhausting activity below ‘all-out’ maximal intensities, that would trigger voluntary cessation of exercise or produce an excessive training stimulus (Shushan et al., 2022). The study evaluated the relationships and predictive qualities between HR outcomes of a continuous-fixed, shuttle-based SMFT (e.g., 4 min, 12 $km \cdot h^{-1}$, to elicit ~75 – 85% HRmax), RPF and 1.2SRT derived MAS.

Given the study recruited highly-trained team sport athletes it was expected players would be able to compare their perception of their aerobic capacity with that of others in the squad and rate themselves accordingly. However, given little work has been undertaken to compare athlete perceptions of fitness with objective measures, it was unclear how athletes would physiologically anchor their perceptions. Darrall-Jones et al., (2022) recently reported professional male rugby union players subjectively under- and overestimate submaximal sprint velocities compared to objective measures. Therefore, the relationships between RPF and SMFT HRex as a measure of submaximal aerobic capacity and MAS as a measure of maximal aerobic capacity were compared to indicate if players could correctly anchor their responses to the construct under investigation.

1.3 Study Aims and Research Questions

The overall purpose of the study was to investigate the relationships and predictive qualities between field-based measures of perceived, submaximal and maximal aerobic fitness in a sample of high-performance British university rugby union players. To evaluate the associations and predictive qualities between RPF, SMFT HRex and MAS in rugby union players. Three specific research questions were identified to guide the study:

1. To what extent is MAS, measured using the 1.2SRT, associated with RPF and SMFT HRex?

2. To what extent do player RPF associate with SMFT HRex as a proxy cardiovascular fitness measure of submaximal aerobic capacity?
3. Are player RPF, SMFT HRex, or both variables combined predictive of MAS measured using the 1.2SRT, and are player RPF predictive of SMFT HRex?

1.4 Significance

The study is the first to examine the relationships and predictive qualities between perceived fitness, SMFT HRex and MAS using commonly employed field-based methods in a sample of team sport players. From a practical standpoint, the findings of this study are relevant for the assessment and monitoring of aerobic capacity in rugby union players and team sport players more broadly. Practitioners such as sports scientists and strength and conditioning coaches may use this information to inform effective monitoring strategies and enhance training interventions at both the individual and group levels. The study is also fundamental in examining the predictive quality of relationships between subjective and objective fitness measures in an athlete population. Contributing to the growing evidence base for using SMFT in team sport settings to monitor aerobic capacity when maximal exhaustive tests are impracticable due to congested training and fixture schedules (Shushan et al., 2022). Whilst providing greater insight into athlete awareness of physiological capacities, supporting the application of perceived fitness scales in sporting settings, and informing how subjective data may be used to complement traditional objective methods of athlete monitoring (Montull et al., 2022). From an applied perspective, perceived fitness scales may prove a valuable tool in helping ascertain fitness qualities in athletes during rehabilitation from injury or when objective physical assessment methods are unfeasible, allowing practitioners to estimate MAS more closely to individually optimise training prescription (Balagué et al., 2020).

CHAPTER 2. LITERATURE REVIEW

2.1 Rugby Union

Rugby Union formed as a professional sport in 1995 (Reilly, 1997). Since professionalism, scientific investigation of the sport has rapidly advanced. Providing almost three decades of empirical research concerning the required physical capacities, demands and responses to match play and the subsequent physical development of players across multiple playing levels (Nicholas, 1997). Given the constant evolution of laws and playing structures over time, the game has increased in physicality and speed and is played more regularly than ever before (Duthie, Pyne, and Hooper, 2003; van Rooyen et al., 2008). As a result, contemporary knowledge of the requirements of the game, the necessary physical characteristics of players and the training processes for players to progress to higher levels has increased (Duthie, Pyne, and Hooper, 2003; Read et al., 2017).

2.1.1 Overview

Rugby union is played worldwide, with the international governing body of the sport, World Rugby, encompassing 128 member unions and associations, comprising 110 full members and 18 associate members from six different regional associations (World Rugby, 2022b). The invasion sport is played for 80 minutes across two 40-minute halves separated by a half-time break of 10 – 15 minutes; stoppages are only permitted in the event of an injury. Two teams of 15 players compete on the field of play, except when players have been sent off for misconduct offences. Players ultimately aim to outscore the opposing team through a range of scoring methods comprising tries (5 points), conversions (2 points), and penalty or drop goals (3 points, respectively). A try is successfully scored on the attacking team, grounding the ball past the opposition goal line, at which point a conversion attempt is awarded. Conversions, penalty goals and drop goals must all be successfully kicked over the crossbar and between the goalposts for respective points to be awarded (World Rugby, 2022a). A standard field of play measures 94 – 100 m in length and 68 – 70 m in width, with an additional 6 – 22 m at each end behind the goal line (World Rugby, 2022a) (Figure 1).

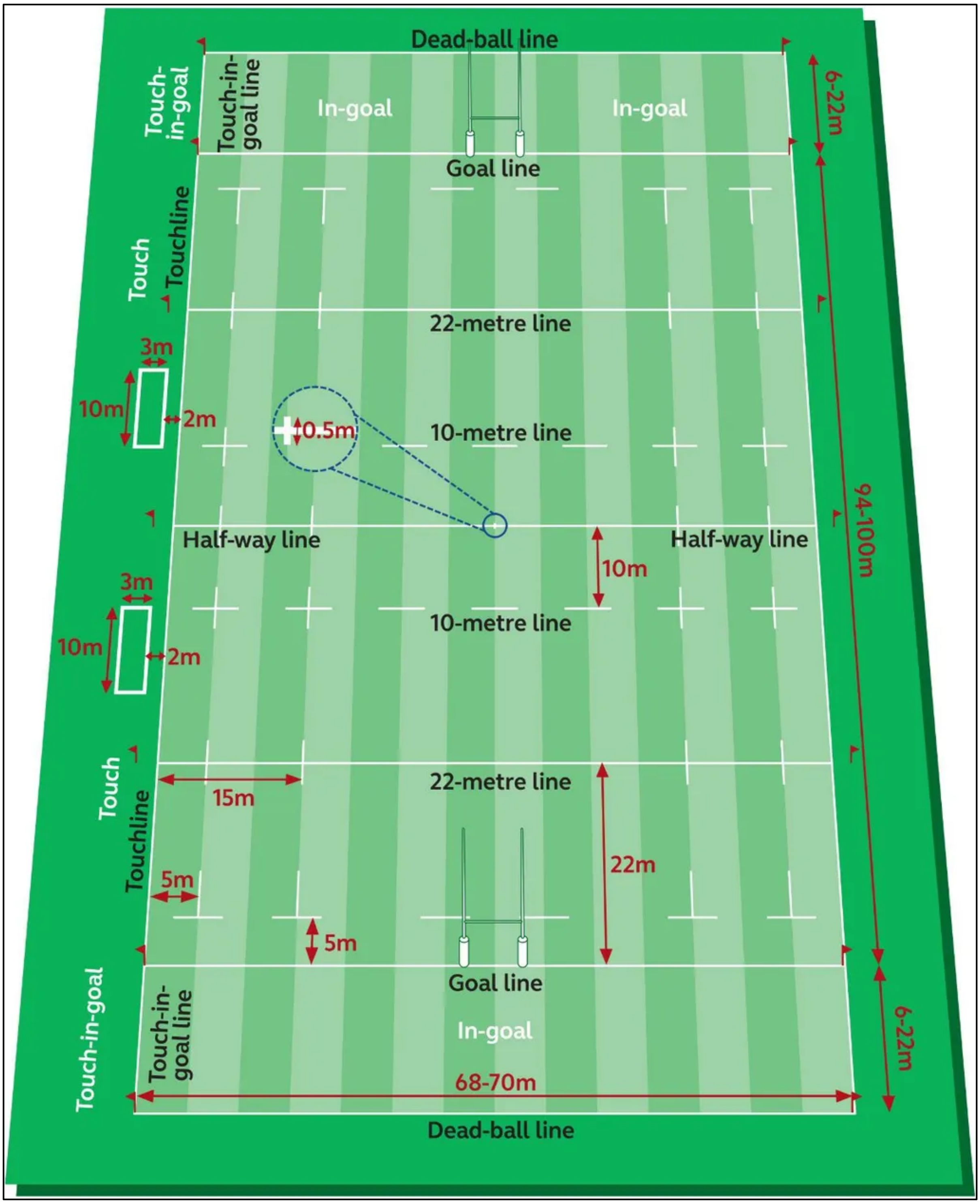


Figure 1. Rugby union pitch dimensions (from World Rugby, 2022a).

Compared to individual sports (e.g., running, cycling, swimming), the field-based nature of football codes, such as rugby union, imposes complex intermittent demands (Smart, Hopkins and Gill, 2013). Though like field sports such as football and hockey, several unique physiological responses are observed through repeated periods of high-speed running, contact incidents and static exertions, interspersed with periods of active and passive recovery (Roberts et al., 2008; Cunniffe et al., 2010; Reardon, Tobin and Delahunt, 2015; Reardon et al., 2017a). Across an 80-minute match, the demands of match play can be broadly classified as the time when the ball is in play (BIP) and when the ball is out of play (BOP) (Quarrie et al., 2013). The ball is generally in play for an average of 30 minutes, with remaining time encompassing injury stoppages, conversions, penalties or when the ball is out of play (Duthie, Pyne, and Hooper, 2003). However, between 1992 and as recently as 2010, a trend in BIP time increases has been identified, increasing from 29 minutes (1992) to approximately 31 minutes (2002) and again to 36.3 minutes between 2004 and 2010 (McLean, 1992; Eaves and Hughes, 2003; Quarrie et al., 2013).

2.1.2 Positions, Positional Groups and Player Roles

A rugby union team is made up of 15 on-field players split by two broad positional clusters comprising eight 'Forwards' (ball winners) and seven 'Backs' (ball carriers) (Figure 2) (World Rugby, 2022a; Duthie, Pyne, and Hooper, 2003). Differentiating players from other team sports, where similar physique and physical performance qualities are shared. Players must possess differing levels of a wide range of physical fitness qualities comprising muscular strength, power, speed, agility, and anaerobic and aerobic capacity (Duthie, Pyne, and Hooper, 2003). Consequently, players will instinctively and logically orient towards positions compatible with their natural anthropometric profile (MacQueen and Dexter, 2010; Coughlan et al., 2011).

Figure 2. Rugby union players and starting positions (from World Rugby, 2022a).

Forwards are numbered 1 to 8, whilst backs are numbered 9 to 15. Though some variation in terminology across studies, players are further organised by additional specific groupings, within the main positional clusters, according to positional demands (Quarrie and Williams, 2001). Of the forwards, the 'front row' comprises players 1 to 3, the 'tight 5' involves players 1 to 5, and the 'second row' includes the locks, players 4 and 5 (Till et al., 2020). The 'loose forwards' or 'back row' includes players 6 to 8 (Till et al., 2020). Whilst of the backs, players 9 to 10 form the 'half backs', players 9, 10 and 12 form the ‘inside backs’, players 12 and 13 make up the 'midfield backs' or 'centre-three-quarters', and players 11, 14 and 15 make up the 'outside backs' or 'back three' (Till et al., 2020).

Pollard et al., (2018) report that backs perform more running, whilst forwards have greater involvement in collisions and contact incidents. Front-row players are primarily responsible for gaining possession of the ball, necessitating well-developed muscular strength and power to sustain repeated high-force impacts with opposing players and provide stability in the scrum (Duthie, Pyne, and Hooper, 2003). Whilst props generally cover greater distances at lower speeds ($< 4.0\ m{\cdot}s^{-1}$) and play a pivotal role in lineouts, supporting the locks to compete for the ball, favouring vertical force production over the ability to run with the ball (Quarrie et al., 2013; World Rugby Passport, 2022). Locks generally possess a greater anthropometrical profile and, as a result, longer leavers provide superior momentum and mechanical power during the scrum and added height advantage when lifted in the lineout to quickly and accurately secure possession of the ball (Duthie, Pyne, and Hooper, 2003). The loose forwards preserve possession of the ball, requiring well-developed strength and power to gain and retain the ball whilst remaining mobile during open play through superior speed, acceleration and aerobic endurance (Deutsch, Kearney and Rehrer, 2007).

The scrum half and fly half positions possess greater acceleration, speed and aerobic endurance controlling possession of the ball once obtained by the forwards (Duthie, Pyne, and Hooper, 2003). These positions also evade defenders through a smaller anthropometrical profile, frequently handling, passing and kicking the ball whilst covering substantial distances at speeds from 4.0 to $6.0\ m{\cdot}s^{-1}$ but less than the back three at maximal velocity ($> 8.0\ m{\cdot}s^{-1}$) (Quarrie et al., 2013). Muscular strength, power and speed are also attributed to the midfield backs to sustain regular high-force collisions and ruck involvements, making and receiving kicks and running the ball back during match play (Duthie, Pyne, and Hooper, 2003; Quarrie et al., 2013). Whilst the back three provide a support running role, chasing kicks and providing defensive cover, necessitating the highest speed capabilities to out-manoeuvre opposition players and increased aerobic capacity to support internal load responses to covering larger total distances (Duthie, Pyne, and Hooper, 2003). Subsequently, considerable distances are covered at low speeds (< 2.0 m·s^{-1}) by this position, maintaining on-field position and making fewer tackles but covering greater distances at high speeds (≥8.0 m·s^{-1}) to gain territory and score tries (Quarrie et al., 2013). Finally, the fullbacks primarily handle and kick the ball more than the wingers, though wingers typically score more tries (Quarrie et al., 2013).

2.2 Physical and Physiological Demands of Rugby Union Match-Play

The quantification of sport-specific demands is vital in ensuring players possess the necessary fitness levels to meet the required loads of competition, avoiding fatigue and overtraining while simultaneously decreasing injury risk and recovery time (Taylor et al., 2017; Windt et al., 2017). Consequently, player match activity may be broadly classified as external match load, concerning the physical work performed during a match, and internal match load, representing the resultant physiological and biomechanical stress responses to external loads (McLellan, Lovell and Gass, 2011; Chamari and Padulo, 2015; McLaren et al., 2018a).

2.2.1 Physical and Movement Demands

2.2.1.1 Measurement

No single method of assessing movement patterns and external workloads in team sports has been established as a 'gold standard' (Cummins et al., 2013; Randers et al., 2010). Traditionally, the simplest method of match activity quantification in team sports is observational time-motion analysis (TMA). In which the types (locomotor, collision, technical and tactical), durations, and frequencies of movements of intermittent activity patterns are counted from live or recorded video footage (Roberts et al., 2008). However, the method is considered time-consuming, costly, potentially variable, and impractical for providing actionable real-time insights (Taylor et al., 2017). As an alternative to labour-intensive video coding, practically efficient, commercially available and wearable global positioning system (GPS) microtechnology units have now been expansively used to measure rugby union physical movement demands (Cunniffe et al., 2009; Chambers et al., 2015; Howe et al., 2020). Providing practitioners with absolute and relative locomotive measures of distances covered in different velocity zones (level 1 variables), changes in velocity, acceleration, deceleration, and direction (level 2 variables) and body orientation change events derived from inertial sensors or accelerometers (level 3 variables) such as impacts and jumps (Cummins et al., 2013; Lacome, Simpson and Buchheit, 2018).

Though GPS micro-electrical mechanical system (MEMS) microtechnology units, encompassing inertial measurement units (IMU), such as tri-axial accelerometers, gyroscopes and magnetometer microsensors, have been found to provide differing levels of validity, reliability, and time-efficiency (Chambers et al., 2015; Cummins et al., 2013). With the sampling rates of GPS MEMS units ranging from 1, 5, 10 to 15 Hz providing differing levels of accuracy at 1 to 5 Hz (TEM: <5% to >10%) and instantaneous velocity measures reported to be six times more reliable when using 10 Hz units compared to 5 Hz units (Bridgeman and Gill, 2021; Ziv and Lidor, 2016; Varley et al., 2012; Johnston et al., 2012). Caution is also advised when interpreting GPS-derived variables through decreases in reliability for higher intensity or change of direction activities (CV: 77.2% at 1 Hz), given differing numbers of satellites connected, set vs individualised velocity bands and variances in acceleration and deceleration counts between device manufacturers and software versions (Jennings et al., 2010; Buchheit et al., 2014). GPS micro-technology units are also not considered a reliable tool for accurately coding collisions in rugby union compared to video analysis, through substantial over or underestimation of collisions through inability to identify optimal g force bands to identify collisions (ranging from 1 to > 10 g) (Reardon et al., 2017a; Reardon et al., 2017b).

In contrast, Eaves and Hughes (2003) postulate that notational analysis has been extensively used to provide objective feedback regarding technical and tactical contributions, on both match behaviours and player actions, by identifying incidences of common key performance indicators (KPI). Using the method, KPI are then applied to produce performance profiles at a positional and team level from which performance patterns can be identified, in addition to predicting future performances through combining KPI (James, Mellalieu and Jones, 2005). Though parallax error (different perceptions of displacement from differing lines of sight) and heterogeneity of coding systems are acknowledged methodological limitations affecting the reliability of findings through unclear identification, development, selection, definition and relevance of match behaviours reported (Barris and Button, 2008; James, Mellalieu and Jones, 2005).

2.2.1.2 Locomotor Demands

Whilst rugby union players cover between 5-7 km per game, significant differences in locomotor demands between positional groups and playing positions are clear (Jones et al., 2014; Cunningham et al., 2016a; Cunningham et al., 2016b). Using GPS MEMS technology, Reardon et al., (2017b) reported backs to experience lesser contact loads resulting from scrums, rucks and mauls despite covering greater distances than forwards. Clear variances are also evident within general positional groups (forwards and backs), including back row players producing greater relative and high-speed running (HSR) distances, high acceleration and deceleration events, and a higher number of tackles than front row players (James, Mellalieu, and Jones, 2005; Jones et al., 2015). Scrum halves are reported to cover the most extensive total distances (TD) and tight forwards the least, whilst outside backs achieve the highest speeds but occupy the greatest time walking (Tee, Lambert, and Coopoo, 2016; Cahill et al., 2013).

Studies utilising GPS MEMS devices have examined the average movement demands of each half of a game (40 mins) or full games (80 mins) (Roberts et al., 2008; Cunniffe et al., 2009; Cunningham et al., 2016a). Using the method, Cahill et al., (2013) quantified the median (± IQR) movement characteristics of ninety-eight elite rugby union players from eight English Premiership Clubs across 44 competitive matches. Across a season, a greater TD (6545 m ± 1055 m) and subsequent relative TD (71.1 $m \cdot min^{-1}$ ± 11.7 $m \cdot min^{-1}$) was covered by backs in comparison to forward players (5850 m ± 1101 m) (64.6 $m \cdot min^{-1}$ ± 6.3 $m \cdot min^{-1}$) (Cahill et al., 2013). Backs exhibited the greatest maximum speed (30.4 $km \cdot h^{-1}$ ± 3.3 $km \cdot h^{-1}$) vs forwards (26.3 $km \cdot h^{-1}$ ± 4.0 $km \cdot h^{-1}$), with little difference in average speeds of 5.4 $km \cdot h^{-1}$ ± 0.6 $km \cdot h^{-1}$ and 5.5 $km \cdot h^{-1}$ ± 0.6 $km \cdot h^{-1}$ between forwards and backs respectively (Cahill et al., 2013). This may be explained by the greater number of static exertions and wrestling actions performed by forwards during tackling, scrum, rucking and mauling events, which make up 14% of total game time for forwards, but only 2% of game time for backs (Austin, Gabbett and Jenkins, 2011; Pollard et al., 2018). The analysis by Cahill et al., (2013) further reported that match play is performed mainly at lower speeds with small distances covered 'sprinting'. Supporting this, later research from Cunningham et al., (2016a) identified comparable between-position differences for relative distance covered and HSR in senior international players with forwards and backs covering 66.8 $m \cdot min^{-1}$ and 3.1 $m \cdot min^{-1}$ and 73.3 $m \cdot min^{-1}$ and 7.2 $m \cdot min^{-1}$, respectively. U20s international backs were shown to perform more relative HSR (7.3 $m \cdot min^{-1}$ ± 2.1 $m \cdot min^{-1}$ vs 7.2 $m \cdot min^{-1}$ ± 2.1 $m \cdot min^{-1}$) and $sprint \cdot min^{-1}$ (0.26 ± 0.07 vs 0.25 ± 0.07) than senior backs (Cunningham et al., 2016a).

Whilst singular locomotor profiling measures such as TD and HSR can provide an understanding of general physical demands, Sheehan et al., (2022) reported that given the intermittent nature of rugby union, the method fails to report subtle distinctions in match-play, where players may repeatedly accumulate bouts of a combination of effort types during separate phases of play. Here, the quantification of repeated high-intensity efforts (RHIE), defined as three distinct high-intensity efforts completed within a single twenty-one-second (21 s) bout, characterises the highest levels of effort attributed to running, acceleration and collision events combined during match-play (Johnston et al., 2015; Couderc et al., 2019). For example, in a season-long study of 40 elite rugby union players competing in Pro 12 and European cup competitions, Sheehan et al., (2022) reported players perform 11 ± 6 RHIE bouts with mean efforts per RHIE bout of 4 ± 1 and a maximum of 6 ± 2.

2.2.1.3 Peak Locomotor Demands

Profiling the general demands of rugby union match-play provides an understanding of absolute locomotor match demands (Whitehead et al., 2018). However, the intermittent nature of the sport indicates that the technique cannot account for the most intense periods of the game, often defined as the peak demands or worst-case scenarios (WCS) (Cunningham et al., 2018a; Tierney et al., 2017). Given the risk that utilising average demands may under prepare players for certain situations within a game, research in team sports has turned to the profiling of the most severe periods of gameplay, ensuring players are optimally prepared to cope with all intensities of competition demands (Gabbett, 2016; Delaney et al., 2017).

Level 1, 2 and 3 variables (e.g., TD, HSR, accelerations and decelerations, collisions, RHIE) are often investigated in combination with several analysis methods such as: segmental analysis splitting matches into short time periods (e.g., 0 – 5, 5 – 10, 10 – 15 min), rolling averages across a game, identifying the longest periods of BIP time, or comparing peak demands between temporal durations (e.g., 5 min periods) (Whitehead et al., 2018). For example, Jones et al., (2015) reported intensity changes across match-play, using 10 min fixed-time periods in which the highest demands (relative distance covered) were observed in the first 10 minutes of each half (75.3 and 74.3 m·min^{-1}, respectively), beyond whole match averages (66.2 m·min^{-1}) then subsequently decreasing. Whilst Delaney et al., (2017) utilised rolling average periods of 1-10 min and three locomotor variables (relative distance, average number of acceleration/decelerations and average metabolic power), reporting relative distances covered ranging from 184 m·min^{-1} (1 min period) for half backs to 79 m·min^{-1} for tight fives (10 min period), in international players above previously reported average GPS values (Jones et al., 2015; Cunningham et al., 2016a; Cunningham et al., 2016b). Moreover, peak relative distance values ranging from ~ 139 to 185 m·min^{-1} for 1 min periods and ~ 86 to 116 m·min^{-1} for 5-min periods have been reported using rolling averages (Delaney et al., 2017; Cunningham et al., 2018a; Read et al., 2019). In line with values of average demands, relative HSR distance during rugby union match play has been reported by both Reardon et al., (2017a) and Cunningham et al., (2018a) to be greater for backs than forwards. Overall, necessitating a need for all players to possess well-developed aerobic fitness to sustain increases in the speed of the game and recover from bouts of peak intensity (Swaby, Jones and Comfort, 2016).

2.2.1.4 Collisions and Impacts

In contrast, to other field-based team sports, such as football and hockey, rugby union is characterised by frequent HSR and physical collisions resulting from tackles, scrums, rucks and mauls (Hendricks, Karpul and Lambert, 2014; Tierney, Blake and Delahunt, 2021; Paul et al., 2022). These collisions and impacts are considered physically and technically taxing due to higher speeds or numbers of collisions experienced (Schwellnus et al., 2014). Collisions are also associated with increased injury incidence and burden (Schwellnus et al., 2014; Fuller, 2018). Though a larger number of collisions won during match-play is related to overall team success and player performance, with winning teams shown to complete more tackles in comparison to losing teams (Ortega, Villarejo, and Palao, 2009; Wheeler, Askew and Sayers, 2010; Hendricks, Karpul and Lambert, 2014). For practitioners to optimally prepare players for competition demands, quantifying the frequency and intensity of level 3 variables during match-play is considered vital in ensuring injury risk reduction and successful team performance outcomes (Paul et al., 2022).

Collision frequency and type have primarily been measured using video-based analysis methods, whilst GPS devices have been employed to quantify collision intensity, commonly categorised as very heavy (8–10 g) to severe (> 10 g) (Paul et al., 2022; McLellan, Lovell and Gass, 2011). With frequency and intensity of collisions and impacts recorded as: collisions and impacts per match, per position, per broad or specific positional group, per minute, per minute per position, and load per collision (Tierney, Blake and Delahunt, 2020; Reardon et al., 2017b; Macleod et al. 2018; McLaren et al., 2015, Tierney, Blake and Delahunt, 2021). In a systematic review of collision frequencies and intensities in adult rugby union, Paul et al., (2022) reported an average frequency of 22.0 (19.0 – 25.0) scrums, 116.2 (62.7 – 169.7) rucks, and 156.1 (121.2 – 191.0) tackles per match, with forwards experiencing the highest number of tackles 12.8 (7.5 – 18.1) compared to backs 7.6 (4.3 – 10.9) in studies using TMA. In studies using GPS MEMS devices, forwards were shown to experience 52.5 (29.8 – 75.2) very heavy impacts and 10.8 (4.4 – 17.1) severe impacts per match, when compared to backs with 41.7 (26.4 – 57.0) very heavy impacts and 6.7 (5.1 – 8.4) severe impacts per match (Paul et al., 2022). No differences in >8G•min^{-1} impacts between forwards and backs during a game were reported (Tee and Coopoo, 2015). Though, for lower-level impact frequency (> 5 g), Tee, Coopoo and Lambert (2020) reported 8.3 ± 2.7 >5G•min^{-1} and 9.5 ± 3.1 >5G•min^{-1} impacts for forwards and backs, respectively, in a sample of nineteen professional rugby union players across 23 matches.

Tee, Lambert and Coopoo (2017) also previously reported that within the first 20 – 30 min of match-play, players sustain the highest number of contacts and the fewest between the 60- and 70-min periods. Forwards sustain a greater number of very heavy contacts during the second half of a match, whilst backs experience fewer impacts overall when compared to the first half (McLellan et al., 2013). Furthermore, during the 0 – 10 and 50 – 60 min periods of a match, forwards are shown to sustain a greater frequency of >5G•min^{-1} impacts and the fewest within 20 – 30 min, 40 – 50 min and 60 – 70 periods (Tee and Coopoo, 2015). Conversely, backs exhibit more > 5 g impacts during the 0 – 10 min and 20 – 30 min periods and the fewest within the final 10 minutes of a match (Tee and Coopoo, 2015). Indicating a strong need for all players to hold sufficient aerobic fitness to enable the efficient uptake of oxygen for energy production and the removal of waste products accumulated during these anaerobic events (Swaby, Jones and Comfort, 2016; Wasserman, 1986).

2.2.1.5 Technical Actions and Tactical Contributions

The profile of rugby union match-play is everchanging, with technological advances allowing for intense analysis of match-play, consequently enabling tactical models to push the laws of the game to their limits (Vahed, Kraak and Venter, 2016). Accordingly, between 2007 and 2013, several rule changes were introduced, accommodating changing game styles to advance speed of play, competitiveness, game continuity and spectator appeal (Colomer et al., 2020). Given legislators' constant redevelopment of rugby laws which predominantly focus on the technical and tactical features of the game, investigation has turned to how different technical and tactical contributions may relate to or affect the physical demands experienced by players (Vahed, Kraak and Venter, 2016). Teams are now shown to commit additional players in defence in preparation for subsequent phases of play, resulting in increased game actions through added pressure on attacking teams to accelerate the speed of play (Vahed, Kraak and

Venter, 2016). With fewer scrums, line-outs, stoppages, handling errors, offloads and kicks now evident (Van den Berg and Malan, 2012; Hughes et al., 2017). Though the number of passes, rucks, mauls and tackles completed, metres gained and penalties conceded have all increased, resulting in a more physical and continuous game (Van den Berg and Malan, 2012; Vahed, Kraak and Venter, 2016).

Numerous studies have employed GPS MEMS devices and notational analysis to examine locomotor demands and technical and tactical performance in rugby union. However, few have aimed to identify relationships between them, preventing further insight into the relationship between match intensity and technical performance (Reardon, Tobin and Delahunt, 2015; Lacome et al., 2017). Lacome et al., (2017) reported small to moderate declines (−42, ±10 to −21, ±7%) in high-speed running within the final 10-min and 5-min periods of eighteen matches, in comparison to all other 10-min and 5-min periods, alongside small changes (−18, ±51 to 13, ±41%) in skill-related performance in international-level forwards and backs. Findings also proposed that international players can largely maintain skill-related performance across match-play during declines in running performance and during the immediate periods after the most intense 5-min periods of play (Lacome et al., 2017). Whilst Ungureanu, Brustio and Lupo (2020) reported that greater physical demands during the early phases of matches are also observed in combination with more defensive collisions than attacking collisions through a higher cost of defensive gameplay.

Further identifying increased measures of running activity to be influenced by tackles, passes, positive work rate in forwards and passes and possession for backs in thirty U20 elite players across five 2018 U20 Six Nations Championship matches. Regaining possession was also suggested to be linked with the on-pitch organisation of players rather than HSR

(Ungureanu, Brustio and Lupo, 2020). However, caution is advised in interpreting findings through difficulty in accurately replicating technical, tactical and locomotor demands due to differing team playing styles and match-to-match variability (Ungureanu, Brustio and Lupo, 2020; McLaren et al., 2016). Consequently, "contest for possession", which occurs before all phases of play, becomes the central element of matches, with outcomes of these physical contests dictating the physical work rates of team attacking and defending strategies (Figure 3) (Tee, Ashford and Piggott, 2018). Consequently, as MAS is strongly related to distance covered during match play, the ability of players to control the game may influence recovery from periods of attacking and defensive play and vice versa (Swaby, Jones and Comfort, 2016).

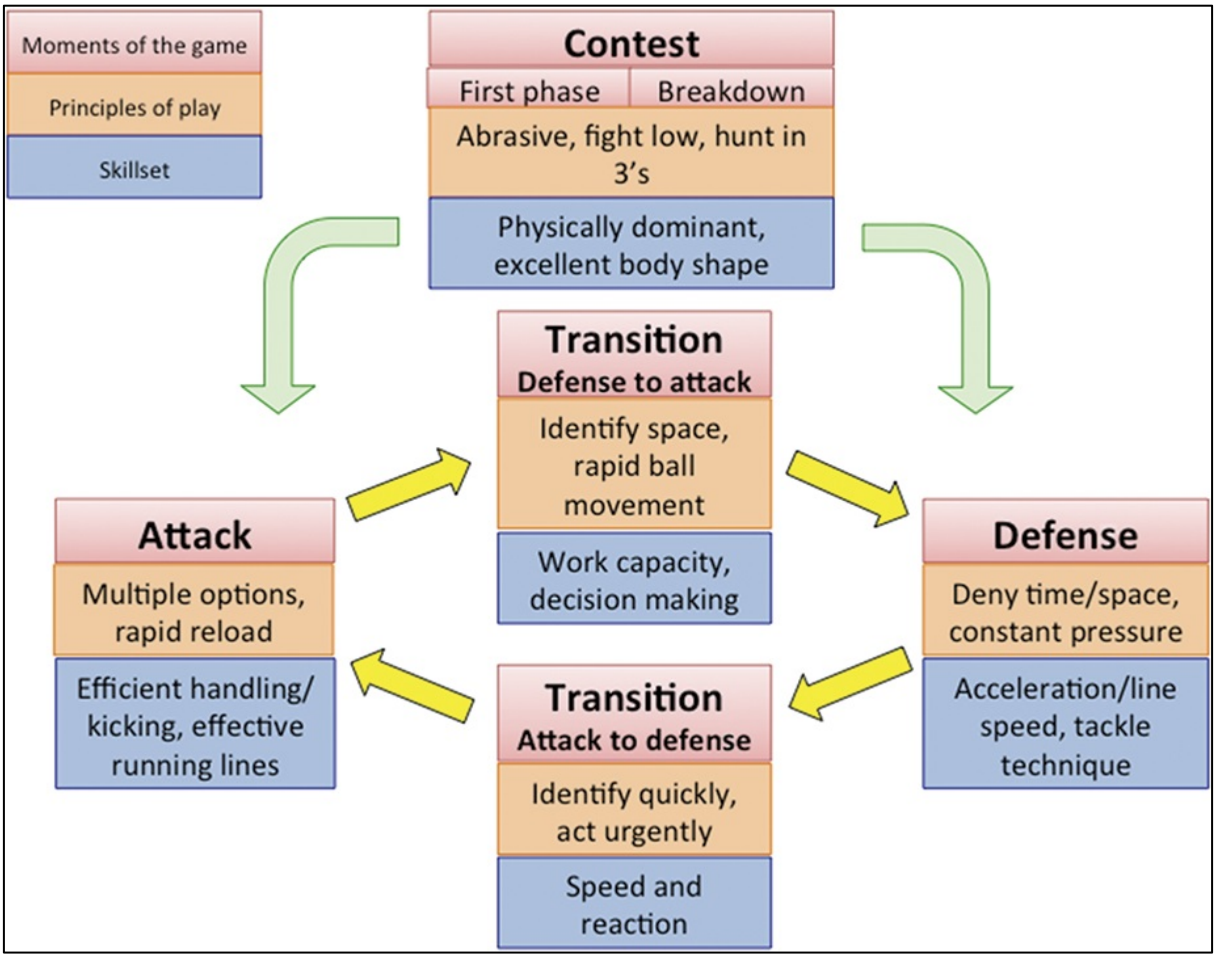


Figure 3. Principles and sub-principles of tactical responses to match-play in rugby union (from Tee, Ashford and Piggott, 2018).

2.2.2 Physiological Demands of Rugby Union

Given the physically challenging nature of locomotor and movement demands observed across rugby union competition, it is essential to consider the relative physiological response to the work performed, otherwise known as the internal load, resulting from the sum of mechanical stresses associated with locomotor activity and collisions experienced by players (Jones et al., 2015; Quarrie et al., 2017; McLaren et al., 2016). Principally, internal loads to match performance have been reported pre-, during- and post-match using both objective measures such as: HR, oxygen uptake, endocrine, haematological, immunological and direct performance measures, as well as subjective measures comprising assessments of sleep, mood, stress, and RPE (Quarrie et al., 2017). Though given prominent variances in physical demands experienced by positional groups and position-specific roles, responses may also differ due to technical competencies, opposing team behaviours, win/lose margin or frequency, use of substitutes and season phase (McLaren et al., 2016). The physiological demands of match-play are also considered variable, between-players and within-players (between-match), through the well-established, complex, and chaotic nature of team sport performance (McLaren et al., 2016; Duthie, Pyne, and Hooper, 2003).

2.2.2.1 Cardiometabolic Responses

Although time-consuming and vulnerable to technical problems, the measurement of HR responses to intense, intermittent team sport activity may be utilised to infer cardiometabolic work rates throughout a match through the linear relationship with oxygen uptake at sub-maximal workloads (Brink et al., 2010; Thorpe et al., 2017; Duthie, Pyne, and Hooper, 2003). However, HR monitoring remains limited in investigating the physiological demands of rugby union match-play, particularly at the professional level, potentially due to the physical nature of contact sport providing logistical difficulties in achieving accurate measurements (Cunniffe et al., 2009; Dubois et al., 2017). For example, in a case study of 2 elite rugby union players, Cunniffe et al., (2009) reported mean (HRavg) and peak HR (HRpeak) of 172 and 200 $b·min^{-1,}$ respectively, with both players reaching maximum HR (HRmax) during a competitive team selection match but, exhibiting higher HRavg during the first half than the second (173 vs 169 $b·min^{-1}$). Moreover, the back was shown to spend more time at 80 to 90% HRmax (42%) than the forward (27.7%), though the forward completed more time at 90 to 95% HRmax (15.4%) than the back (4.7%) (Cunniffe et al., 2009). Although the small sample size used largely prevents wider generalisability

In a sample of university-level players (n = 21) across three games, Sparks and Coetzee (2013) reported a HRmax ($b·min^{-1}$) of 192.2 ± 8.8 and HRavg ($b·min^{-1}$) of 165.0 ± 12.3 for an average on-field time (min:ss) of 56:23 ± 16:55. Using match HRs and graded maximal test values, the first and second ventilatory thresholds were identified, then percentages of HRmax were organised by three intensity zones: low (<VT1), 141 – 152 $b·min^{-1}$ (76.2 – 82.0% HRmax); moderate (VT1 – VT2), 153 – 169 $b·min^{-1}$ (82.7 – 91.4% HRmax); and high (>VT2), 170 – 182 $b·min^{-1}$ (91.9 – 100% HRmax) (Sparks and Coetzee, 2013). Time spent in each zone comprised 22.8% low-intensity, 33.6% moderate-intensity, and 43.6% high-intensity (Sparks and Coetzee, 2013). Players also spent a significantly greater amount of time at anaerobic threshold 13:00 ± 09:48 (37.4%) than aerobic threshold 08:03 ± 06:45 (23.2%) during the second halves of matches, despite no significant differences observed during first halves (Sparks and Coetzee, 2013). Further demonstrating that players spend long periods of time accruing lactate and metabolites through working at intensities above aerobic energy production, requiring players to recover efficiently during periods of lower intensity (Wasserman, 1986).

Dubois et al., (2017) also investigated the physiological responses of fourteen professional players across five European challenge cup games. Reporting a mean %HRmax of 80.6 ± 4.3% during a typical match half and 20.0 ± 7.8 min (42.2 ± 16.5%) of time >85 %HRmax during an average half, with forward players occupying more time at 85-92% of HRmax than backs ($p<0.01$; +67.6 ± 6.3%; d = 1.2 ± 0.6; ES: large) despite no significant difference found. Green et al., (2017) reported a high metabolic stimulus to simulated match-play in twelve university-level players, identifying significant differences in blood lactate (mmol·1) between pre- and half-time periods of 1.8 ± 1.6, 3.5 ± 3.6 and 2.9 ± 3.3 at pre-, half- and full-time respectively. However, due to a small sample size, the study possesses limited inference to the broader elite population.

The analysis of the research demonstrates the relatively intense nature of match-play but is characterised by highly variable responses, limited sample size and diverse reporting methods. As such, generalising intensity zones using %HRmax is contested as an accurate method for determining different intensity zones. Between-player differences in fitness and exercise economy are considered to reduce the sensitivity of exercise intensity and energy system contribution estimates when using HR responses in isolation (Sparks and Coetzee, 2013; Achten and Jeukendrup, 2003). Blood lactate sampling may also not provide a true reflection of match demands, negatively affecting accuracy by sampling being dictated by stoppages in play (Sparks and Coetzee, 2013). Therefore, simulated match-play scenarios allowing greater access to players for sampling may also differ from actual match demands (Sparks and Coetzee, 2013; Green et al., 2017).

2.2.2.2 Subjective Perceptual Reponses

In comparison, subjective perceptual measures such as RPE (arbitrary units [AU]) and session RPE (sRPE) (RPE multiplied by match duration) have been utilised as practical and effective methods for quantifying the relative physiological stress of team sport performance, post-competition (Foster et al., 2001; Impellizzeri, Rampinini and Marcora, 2005). Furthermore, the method has been shown to associate with HR-derived internal load measures consistently and positively (r = 0.50 to 0.85), and sRPE shows a strong association (r = 0.82; 90% CI: 0.75 to 0.87) with total running distance during team sport competition (Impellizzeri et al., 2004; McLaren et al., 2018a).

Using a 10-point RPE scale (CR10®), McLaren et al., (2016) investigated player match loads in 28 male professional English Championship players over 15 competitive matches, reporting perceived exertions of 8.2 ± 0.9, 8.7 ± 0.7, 7.8 ± 0.9 for all players, forwards and backs respectively. Within- and between-player variability in RPE was shown as stable with moderate variability in match loads (8.2%; ±1.8%, 10.8%; ±2.1%), and a threshold of ∼10% was identified for likely substantial between-match change, concluding match RPEs may be interpreted with high accuracy (McLaren et al., 2016). Supporting this and also employing the CR10 RPE scale, Hudson et al., (2019) reported sRPE in seventeen elite English Premiership rugby union players across an eight-day competitive microcycle, reporting match loads of 622.36 ± 98.70, 595.13 ± 106.45 and 658.67 ± 81.85 for all players, forwards and backs respectively. Furthermore, game day (GD) match load was reported as higher than training load on all other days apart from GD+3, which comprised a high-volume overload training day of activity similar to match demands (Hudson et al., 2019).

The exploration of the current evidence base indicates high relative physiological stress imposed on all players during competition compared to training, with greater perceived exertions experienced by forward players. Whilst RPE is considered a valid and reliable method for assessing internal load, few studies have investigated player match loads in larger sample sizes or divided by positional groupings (e.g. ‘front row’, ‘inside backs’, etc.), which may support the understanding of high variability in physical performance observed in matches (McLaren et al., 2016). Additionally, sRPE is considered to lack sensitivity when employed with measures of external load; therefore, differential RPE (dRPE) has been suggested to help contextualise match load monitoring by separating central and peripheral exertion signals (McLaren et al., 2016; McLaren et al., 2015; Weston et al., 2015).

2.3 Player Physical Fitness Characteristics

2.3.1 Relationships with On-Field Performance

Rugby union players require an extensive range of well-developed fitness qualities to ensure efficient tolerance of the varying physical and physiological demands of intermittent team-sport competition (McLaren et al., 2018b). Smart et al., (2014) identified relationships between anthropometric values, fitness test performance, game behaviours and match tasks reporting moderate to small negative correlations between 10 m speed and line breaks (r = 0.26), 20 m speed and metres advanced (r = -0.32) and 30 m speed and tries scored (r = -0.16) in elite games. Forwards, average 12 repeat sprint time, % body fat and repeated sprint fatigue (% reduction in repeated sprint time) also presented moderate to small correlations with activity rate measures (count of any actions performed, divided by game time) on and around the ball (r = −0.38, r = −0.17, and r = −0.17, respectively) (Smart et al., 2014). Consequently, players must possess well-developed muscular strength and power, speed, agility and aerobic and anaerobic capacity (Argus et al., 2009; Posthumus et al., 2020; Brazier et al., 2020).

2.3.2 General Physical Fitness Qualities

2.3.2.1 Muscular Strength and Power

The ability to rapidly generate high levels of muscular force is fundamental to effective tackling, wrestling, rucking, jumping, sprinting, and changes of direction (Brazier et al., 2020). Accordingly, elite forward players present greater maximal strength in comparison to backs in back squat 1RM (forwards: 186 ± 35 kg vs backs: 168 ± 32 kg) and bench press 1RM (forwards: 136 ± 19 kg vs backs: 125 ± 17 kg) (Smart, Hopkins and Gill, 2013; Smart et al., 2014). Conversely, for muscular power, backs are reported to produce greater vertical jump performance than forwards, potentially due to lower body mass improving relative power production (Brazier et al., 2020). Argus, Gill and Keogh (2012) reported elite players generate greater absolute and relative power outputs in bench throw and jump squat exercises (1,140 ± 220 W and 5,240 ± 670 W, respectively) in comparison to semi-professional (880 ± 90 W and 4,880 ± 660 W) and academy players (800 ± 110 W and 4,430 ± 950 W). Given that team sports such as rugby require athletes to frequently accelerate, decelerate, and change direction, utilising all three energy systems (Phosphogen, Glycolytic, and Aerobic), aerobic fitness is therefore considered critical for team success, allowing efficient recovery from high-intensity muscular outputs (Baker and Heaney, 2015).

2.3.2.2 Acceleration and Speed

Smart et al., (2014) reported that well-developed linear acceleration and speed capability influence defensive positioning, tackle breaks, evasion of the opposition and frequency of tries scored. Speed is also a distinctive physical quality differentiating between positions, playing levels (elite players the fastest) and competition type with greater distances at high speeds (≥5 $m \cdot s^{-1}$) observed during tier-one international matches in comparison to professional club matches (Brazier et al., 2020; Quarrie et al., 2013). As a result, speed over distances of 5-10 m may be used to assess acceleration, whilst maximal sprinting velocity is considered to occur between 20-40 m (Barr et al., 2014). Hansen et al., (2011) reported sprint times of 1.91 ± 0.10 and 4.40 ± 0.25 s for 10 and 30 m, respectively, in an elite squad. Cross et al., (2015) reported 10 m sprint times of 2.04 ± 0.12 s for forwards and 2.01 ± 0.10 s for backs, whilst Crewther et al. (2009) reported 20 m sprint times of 3.16 ± 0.10 s for forwards and 2.96 ± 0.09 s for backs. However, across greater distances of 30 or 40 m, backs are faster than forwards (Smart, Hopkins and Gill, 2013). Consequently, outside backs display the fastest times over 10 – 40 m, whilst front and second row forwards present the slowest (Smart, Hopkins and Gill, 2013; Brazier et al., 2020). Mirroring the consistent trend in backs exhibiting superior maximal aerobic fitness when compared with forwards (Roberts et al., 2008)

2.3.2.3 Agility and Change of Direction (COD) Ability

During a match, all players must quickly read and decide how to respond to game situations, requiring the ability to perform multiple successive decelerations, COD and accelerations (Cahill et al., 2013). Green, Blake and Caulfield (2011) investigated 10 and 30 m linear speed (LS), COD speed, and reactive agility speed (RAS) in academy (n = 17) and Club-level (n = 11) players using the Y-test. Reporting COD and RAS times of 2.09 ± 0.11 s and 2.35 ± 0.22 s for club players and 1.87 ± 0.07 s and 2.15 ± 0.11 s for academy players, identifying academy players to perform LS, COD and RAS activities significantly faster compared to Club players, which may be due to skill level differences as opposed to player training and game history (Green, Blake and Caulfield, 2011). In a sample of elite players (n = 24), Freitas et al., (2018) investigated LS using a 40 m linear sprint test and COD ability using the Pro-agility, L-Drill, and Zig-zag COD tests. Backs performed LS and COD speed tests faster than forwards with no significant differences in COD deficit (difference between LS and COD task of equal distance) between positional groups, though faster players displayed greater COD deficits

(Freitas et al., 2018). A trend which is observed in various team sports (e.g. rugby union, football, handball), indicating current training methods concentrate on enhancing straight-line sprinting speed, meaning faster players may have difficulty maintaining high approach velocities during COD movements (Freitas et al., 2018; Loturco et al., 2018). Overall, agility tests, specifically within elite rugby union players, remain underreported, with many different test typologies employed in the few studies available (Freitas et al., 2018; Brazier et al., 2020). Consequently, requiring players possess well-developed cardiorespiratory capacity to enable the removal of metabolites accumulated during higher-intensity locomotive activity (Swaby, Jones and Comfort, 2016).

2.3.2.4 Aerobic Capacity

Given that 15% of game time comprises repeated intermittent high-intensity activity, the remaining 85% involves standing, walking, and jogging, providing the opportunity for recovery between efforts (Swaby, Jones and Comfort, 2016). Consequently, a well-developed level of aerobic fitness above the nonathletic population is considered essential for competition success, facilitating performance through effective recovery from the metabolic demands experienced (Swaby, Jones and Comfort, 2016). Whilst $\dot{V}O_{2max}$, a common indicator of aerobic fitness, may be considered a useful measure of performance, players largely display lower $\dot{V}O_{2max}$ values than other field sport equivalents such as football (60.1 ± 2.3 ml·kg^{-1}·min^{-1}) and hockey (55.8 ± 4.0 ml·kg^{-1}·min^{-1}) (Sporis et al., 2009; Hinrichs et al., 2010). Scott et al., (2003) reported greater aerobic fitness in backs (48.3 ± 2.1 ml·kg^{-1}·min^{-1}) when compared with forwards (41.2 ± 2.7 ml·kg^{-1}·min^{-1}). However, decreased ecological significance is likely due to the use of laboratory methods and the potential for between-athlete differences in running economy, lactate metabolism, and training status (Brazier et al., 2020). Brooks and Kemp (2008) identified a greater relative $\dot{V}O_{2max}$ (accounting for body mass) in backs and lower absolute $\dot{V}O_{2max}$ in forward players. Consequently, Brazier et al., (2020) postulate that elite players may possess a greater absolute $\dot{V}O_{2max}$ in comparison to other field sports, with lower relative $\dot{V}O_{2max}$ scores resulting from greater body mass, especially in forwards. However, published $\dot{V}O_{2max}$ data remains dated and unlikely to reflect present-day levels of aerobic fitness, which may be attributed to the poor relationship between match performance and $\dot{V}O_{2max}$ reducing applicability in applied settings (Brazier et al., 2020). Hence the development and use of MAS for assessing and developing aerobic qualities in team sport players (Buchheit and Laursen, 2013a).

2.3.2.5 Anaerobic Capacity

Given the frequency of high-speed running (>5 $m \cdot s^{-1}$) events and sustained RHIE involving combinations of repeated running, tackling, collisions, and scrummaging (Couderc et al., 2019; Sheehan et al., 2022). A suitable anaerobic capacity is vital to compete at a high level under a high physiological load (Dobbin et al., 2018). However, a wide range of intermittent running ability tests have been employed, such as the Yo-Yo Intermittent Recovery Test (Yo-Yo IRT L1) (Dobbin et al., 2018); the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$) (Darrall-Jones, Jones and Till, 2016); the Rugby-Specific Repeated-Speed (RS^2) test (Smart, Hopkins and Gill, 2013); and the RHIE backs and RHIE RU forward tests (Austin, Gabbett, and Jenkins, 2013).

Cunningham et al., (2018b) reported a higher Yo-Yo IRT L1 of 1429.3 ± 363.31 for forwards compared to 682.9 ± 289.1 for backs in a squad of international rugby union players (n = 29). Darrall-Jones, Jones and Till (2016) identified a higher Yo-Yo IRT L1 in U18 compared with U16 academy rugby union players but unclear differences when comparing Yo-Yo IRT L1 and $30\text{-}15_{IFT}$ in backs. Potentially due to maturation, in which Yo-Yo IRT L1 scores appear to increase with playing level and age, in addition to higher maximal velocities exhibited between age groups (Bangsbo, Iaia and Krustrup, 2008; Darrall-Jones, Jones and Till, 2016). Supporting the knowledge that forwards demand a greater anaerobic capacity to support RHIE and collision demands associated with their on-field positional responsibilities (Brazier et al., 2020). However, little homogeneity between anaerobic capacity profiling methods has resulted in highly variable findings through varying associations between tests used and match performance through manipulation of distance, running speed, time, turns, use of weights and down-ups (moving from standing to the prone position and back) (Brazier et al., 2020). Given the reliance on anaerobic metabolism in both positional groups inducing increases in blood lactate and carbon dioxide ($\dot{V}CO_2$) production, player maximal aerobic capacity, therefore, plays a vital role in the cumulative attainment of high-intensity actions during match play (Dobbin et al., 2018; Zamparo et al., 2016).

2.4 Maximal Aerobic Speed (MAS)

2.4.1 Overview of Physiological Profiling in Team Sports

Well-developed aerobic and anaerobic capacity is considered a major contributing factor to match performance, consequently employing all three energy systems (Phosphagen, Glycolytic and Aerobic systems) to support performance (Swaby, Jones and Comfort, 2016; Baker and Heaney, 2015). However, given the impractical nature of laboratory assessments of measures such as $\dot{V}O_{2max}$ within the fast-paced team sport environment requiring costly treadmill and gas analysis equipment (Baker and Heaney, 2015). Physiological profiling has been widely adopted as a practical and time-efficient method to assess the complex interaction of metabolic, neuromuscular, and mechanical capabilities in team sport athletes (Figure 4) (Sandford, Laursen and Buchheit, 2021).

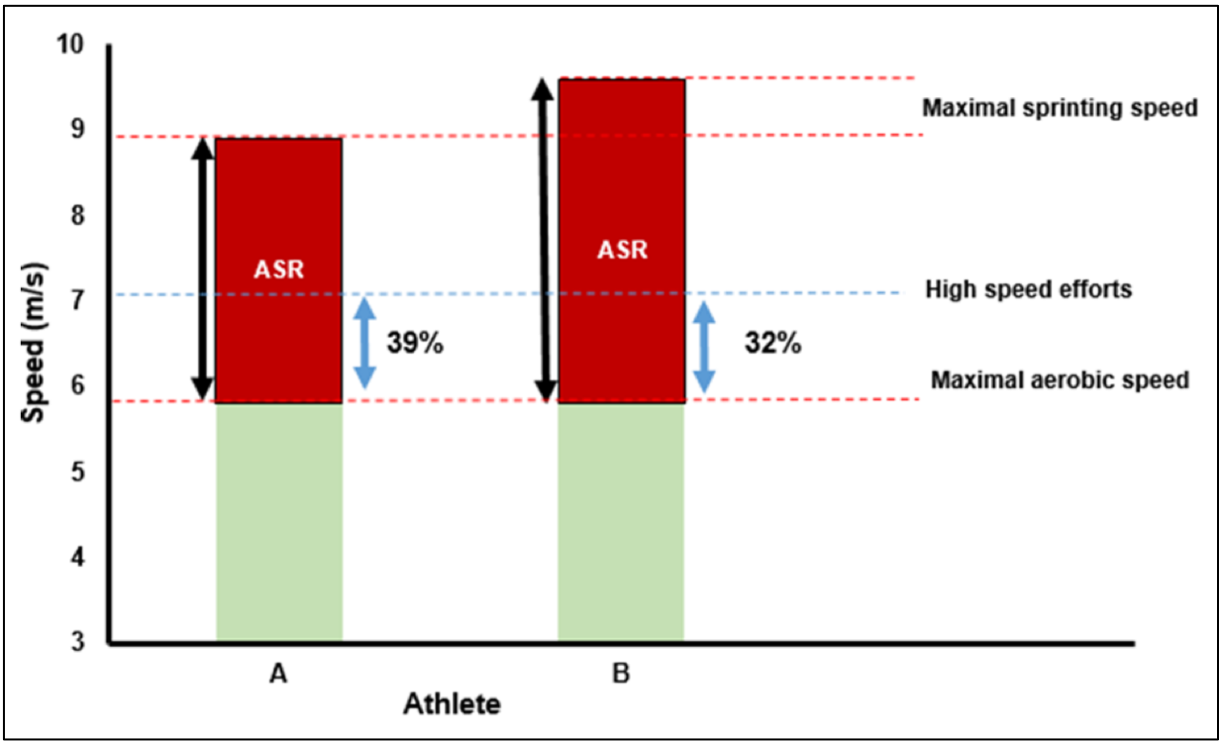


Figure 4. Example athlete physiological profiles (from Sandford, Laursen and Buchheit, 2021).

Using simple, time efficient and cost-effective field assessments, two physiological landmarks, MAS and maximal sprinting speed (MSS), can be assessed and further utilised to calculate anaerobic speed reserve (ASR), allowing estimation of athlete tolerance to high-intensity exercise (Sandford, Laursen and Buchheit, 2021). Consequently, as team sports require a greater focus on the top part of the speed duration relationship, speed reserve ratio (SRR), defined as MSS divided by MAS, may be further extrapolated to infer muscle fibre typologies (Harper, Carling and Kiely, 2019; Sandford et al., 2019). Allowing practitioners to quasi-estimate and categorise athletes by athlete physiological profile, with players with <SRR considered speed-biased (type II fibre dominant), >SRR considered aerobic-biased (type I fibre dominant) and athletes between these groups considered a hybrid-biased profile (Sandford, Laursen and Buchheit, 2021; Sandford et al., 2019). This assessment method can provide greater individualisation of training prescription relative to athlete physiology at a given time, optimising physiological stress through improved training programming whilst reducing nonresponder incidences (Buchheit and Laursen, 2013b; Sandford, Laursen and Buchheit, 2021). As a result, MAS forms a large proportion of an athlete's physiological profile and given that full-time professional sport environments require practitioners to accommodate large numbers of athletes, without trading reliability, field-based MAS assessments provide a practical alternative (Deuchrass et al., 2019).

2.4.2 MAS Assessment

With laboratory-based performance testing often requiring time-consuming procedures, expensive equipment and only allowing the testing of one athlete at a time (Paradisis et al., 2014). Field-based testing is favoured as a more practical method due to greater time efficiency, lower associated costs and improved ecological validity (Bellenger et al., 2015; Paradisis et al., 2014). Pertaining to this, Léger and Boucher (1980) developed and validated the Université de Montréal Track Test as a continuous, running-based field method to assess MAS in track athletes as an alternative to laboratory-based graded exercise tests. Building on this knowledge and applying the method to a team sport context, investigators adopted the Multistage Fitness Test and Yo-Yo IRT L1 as valid measures of aerobic performance (Bellenger et al., 2015). Though as the outcome measures of these methods are recorded as stage or level completed instead of a speed, pace or power output, the limited practical application of these newer tests prevents individualised training prescription (Dupont et al., 2010).

Practitioners turned to developing further estimative field-based tests which better reflected the differences between track athletes on which Léger and Boucher's (1980) original test was based and the high-intensity intermittent nature of team sport competition involving COD ability, inter-effort recovery ability and anaerobic capacity (Buchheit, 2010; Baker and Heaney, 2015). As a result, tests such as the 30-15_{IFT}, 1.2SRT and set time/distance trials have been proposed to better reflect the movement characteristics of team sport competition through the assessment of MAS (Buchheit, 2008; Hamlin et al., 2019; Baker and Heaney, 2015). For example, Buchheit (2008), identified the 30-15_{IFT} to be significantly correlated ($r = 0.87$) with all physiological variables elicited by the 20 m Shuttle Run Test, accounting for 75% of the total variance in 30-15_{IFT} maximal running speeds. Despite the popularity of the test within applied sport science in rugby, research on the 1.2SRT is sparse, though the test is shown to correlate strongly ($r = 0.73 – 0.93$) with 30-15_{IFT} maximal running speeds (Deuchrass et al., 2019; Kelly, Jackson and Wood, 2014). Whilst allowing greater individualisation of training running distances and speeds, the estimative nature of these tests means inconsistencies remain in the equations used to determine MAS through varying allowances for differences in body mass and COD requirements (Baker and Heaney, 2015).

2.4.3 1.2 km Shuttle Run Test (1.2SRT)

Methods such as the 1.2 km Shuttle Run Test (1.2SRT) or 'Bronco Test' comprising a 1200 m time trial of out and back shuttles (1 × 20 m, 40 m, 60 m × 5 reps), have become commonplace in the assessment of aerobic capacity in rugby union players (Kelly, Jackson and Wood, 2014; Hamlin et al., 2019; Teece et al., 2021). As the test only requires a stopwatch and cones, can be run on a marked rugby pitch, increasing ecological validity and takes ~6 minutes to complete (Deuchrass et al., 2019; Kelly, Jackson and Wood, 2014). Access to at least a 60 m length pitch, ~4 testing personnel, one at each of the turning points (0, 20, 40 and 60 m), and the outdoor nature of the test incorporating environmental influences on performance reducing repeatability are acknowledged limitations (Deuchrass et al., 2019).

Using the method elite rugby union players are reported to achieve times of 303.9 ± 24.8 s, 319.6 ± 25.1 s and 287.4 ± 8.5 s for all players (n = 39), forwards (n = 20) and backs (n = 19) respectively (Vachon et al., 2021). Whilst in elite younger rugby union players (19.8 ± 1.4 years), Deuchrass et al., (2019) identified inside backs (n = 14) to complete the test markedly faster in 284.1 s in comparison to 297.0 s, 301.0 s and 317.0 s for outside backs (n = 8), loose forwards (n = 9) and tight forwards (n = 16) respectively. As a result, MAS scores of 4.32 $m \cdot s^{-1}$ have been reported in a whole squad of elite Australian rugby union players (Backs: 4.41 $m \cdot s^{-1}$; Forwards 4.23 $m \cdot s^{-1}$), whilst in a sample of South African U20 players, 4.23 $m \cdot s^{-1}$ was reported for backs and 4.04 $m \cdot s^{-1}$ for Forwards (Baker and Heaney, 2015; Lombard et al., 2015).

2.5 Submaximal Fitness Tests (SMFT)

2.5.1 Overview of SMFT

Traditionally in team sports such as rugby union, improvements in maximal-effort exhaustive tests have been used to assess improved aerobic capacity, with declines in test outcomes (e.g. MAS) interpreted as a negative training response (Buchheit and Rabbani, 2014; Kelly, Jackson and Wood, 2014). In response to this, Submaximal Fitness Tests (SMFT) have grown in popularity as a method highly applicable to the team sport environment, encompassing a wide range of protocols that can vary in exercise mode, intensity, outcome measures, and purposes (Shushan et al., 2022). Allowing the evaluation of positive and negative training effects via a time-efficient and easily administrated method whilst inducing low physiological loading during the microcycle (Shushan et al., 2023a).

Shushan et al., (2022) define a SMFT as a non-exhaustive exercise bout undertaken at a standardised intensity in which relevant outcome measures are monitored to infer an athlete's physiological state. Specifically, exercise must form a cyclic activity using large muscle groups (e.g. running or cycling), be performed at a group or individualised internal or external intensity without eliciting an excessive training stimulus, whilst monitoring a proxy measure (cardiorespiratory, subjective, mechanical or combination) of athlete physiological state to infer the direction and duration of training effects (Shushan et al., 2022; Shushan et al., 2023a; Jeffries et al., 2021). Given the increasing popularity of the test modality, numerous protocols, applications, outcome measures and considerations have been identified across multiple team sport settings when employing SMFT (Shushan et al., 2023b).

2.5.2 Protocol Classifications and Application

SMFT protocols can be classified based on exercise regimen (continuous or intermittent) and the manipulation of exercise intensity (fixed, incremental, or variable) (Shushan et al., 2022). Shushan et al., (2022) systematically reviewed and meta-analysed 87 studies identifying 100 independently described SMFT synthesised into five distinct categories and further subdivided by activity mode, movement pattern, and exercise environment (Figure 5). Continuous-fixed refers to a fixed-intensity exercise bout that remains constant for the entire SMFT (e.g., 4 min running, 12 $km \cdot h^{-1}$, to elicit ~75 – 85% HRmax), whilst Continuous-incremental protocols are categorised by progressive increases in intensity within or between exercise bouts (e.g., 4 min running, 3 × 3-min bouts at 10, 11, and 12 $km \cdot h^{-1}$, 1 min rest periods) (Rabbani, Kargarfard and Twist, 2018; Buchheit, Simpson and Lacome, 2020). In contrast, Intermittent-fixed protocols are considered repetitive activity performed at constant intensities and rest intervals (4 × 50–60 m running at 18–22.5 $km \cdot h^{-1}$, 30 s rest periods), and Intermittent-incremental protocols form activity with fixed rest periods and increasing intensity between exercise bouts (e.g., 30 s running, 10-14 $km \cdot h^{-1}$, increasing by 0.5 $km \cdot h^{-1}$, 15 s rest periods) (Garrett et al., 2019; de Freitas et al., 2015). Whilst Intermittent-variable protocols involve specific and non-specific drills, with fluctuating locomotive demands during exercise (e.g., passing drills or small-sided games [SSG]) (Dello Iacono, Beato and Unnithan, 2021; Rowell et al., 2018).

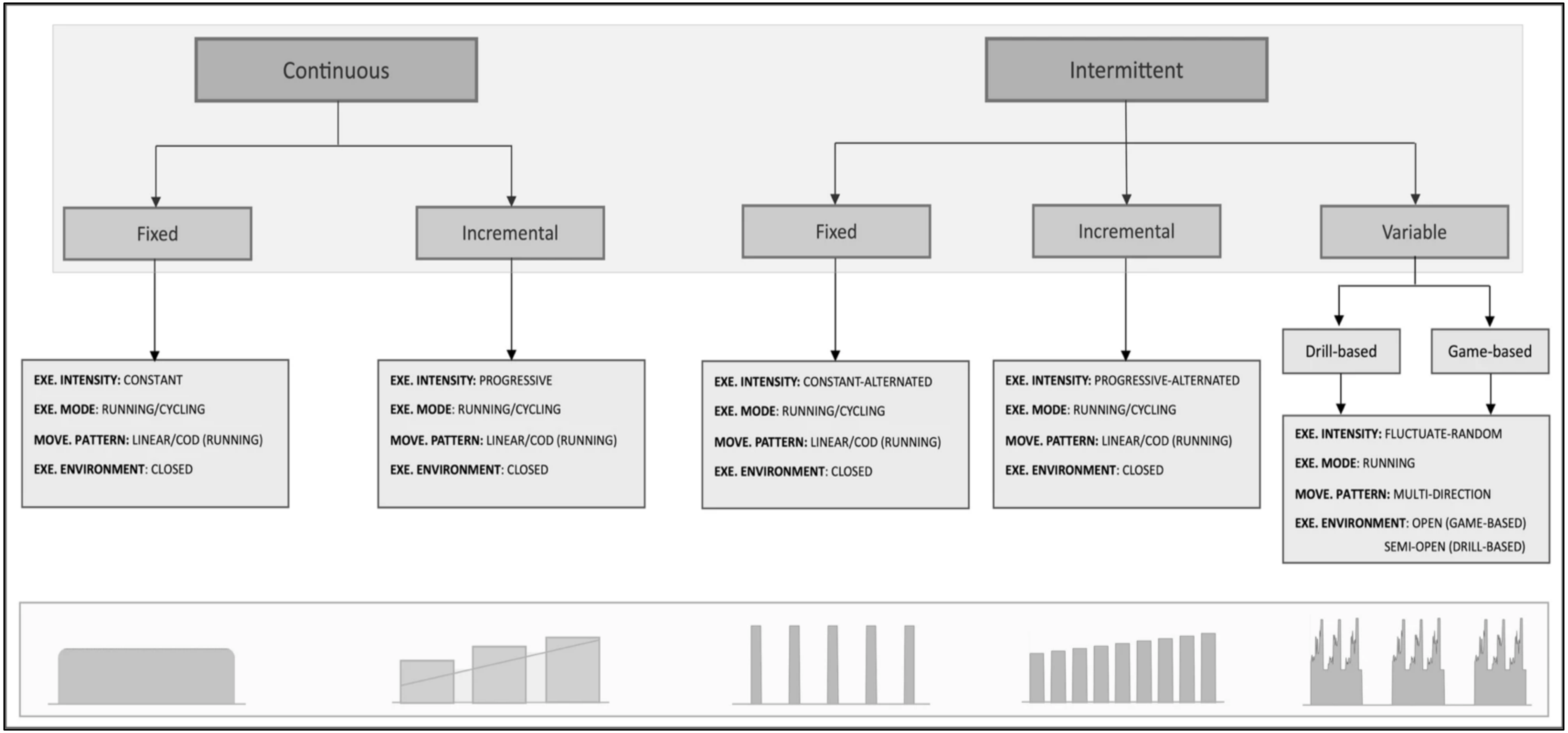


Figure 5. Taxonomy of SMFT protocols (from Shushan et al., 2022).

Ultimately, given that team sport environments often involve a large cohort of athletes, the prescription of SMFT using individualised internal intensity measures (e.g., HR) may account for between-athlete differences in physiological capacity (Carling et al., 2018; Shushan et al., 2022). However, external intensity measures (duration and velocity) are recommended as a more practical solution, given that further periodic fitness assessments throughout different season stages would be impracticable (Shushan et al., 2022). As a result, continuous (fixed or incremental) SMFT protocols for a duration of 3–4 min are currently recommended when collecting the most popular (66% of studies) type of outcome measure, HR (e.g., HRex), to ensure reliable HR traces (Shushan et al., 2022; Shushan et al., 2023a).

2.5.3 Outcome Measures and Monitoring Purposes

HR variables such as exercise HR (HR during the final minute of the test [HRex]), recovery (difference between HR at the end of SMFT and 2 min post-test [HRR]) and vagal-related variability (HRV) are the most studied outcome measures in SMFT research (Figure 6) (Shushan et al., 2023a; Thorpe et al., 2016; Buchheit et al., 2012). Relatively fewer studies have also employed subjective measures such as RPE (6% of studies) and level 1, 2 and 3 mechanical outputs (28% of studies) collected via GPS MEMS units to infer athlete physiological state during SMFT (Shushan et al., 2022; Owen et al., 2020b; Garrett et al., 2021).

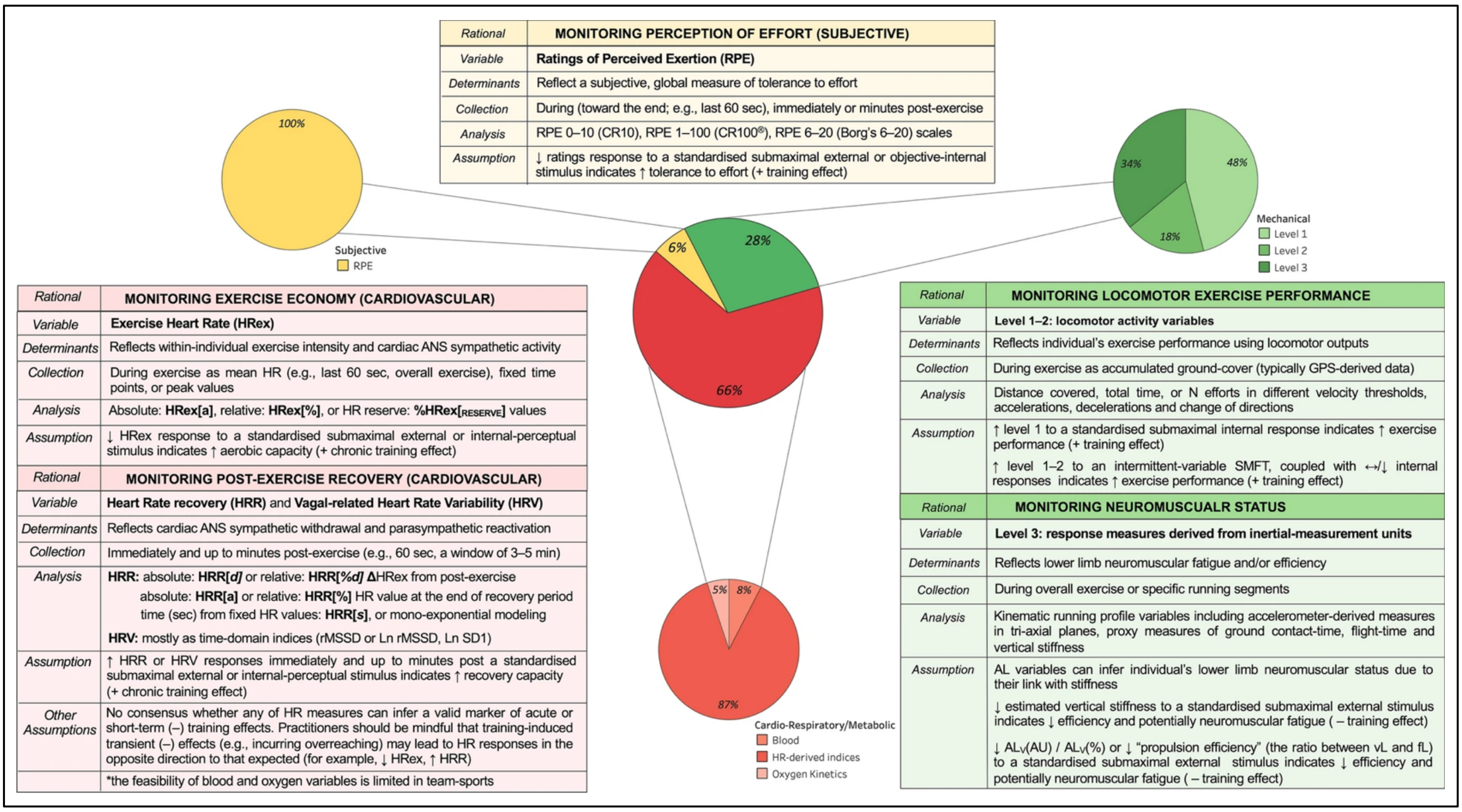


Figure 6. Currently used SMFT outcome measures and rationales (from Shushan et al., 2022).

Given the popularity of HR measures during SMFT, HRex is proposed to relate strongly with oxygen uptake during continuous steady-state exercise, therefore providing a proxy indicator of within-athlete changes in aerobic capacity with a lower HRex, indicating a positive training effect in cardiovascular fitness (Buchheit, 2014; Mann, Lamberts and Lambert, 2013). HRex is also considered sensitive to exposure to extreme environments (e.g., heat and altitude) and training-induced overreaching providing practitioners with further useful indications of short-term physiological stress (Brink et al., 2013; Buchheit et al., 2014; Schneider et al., 2018). SMFT HRex has also been meta-analysed as a reliable and valid proxy measure of endurance performance in team sports; HRex measurement properties also remain unchanged with differences in test protocols (Shushan et al., 2023a). Though the predictive quality of SMFT HRex in estimating field-based aerobic capacity test outcomes remains uncertain

(Shushan et al., 2023a). Additionally, the inclusion of HRR provides descriptive insight into athlete cardiac autonomic nervous system state, with increases indicating parasympathetic reactivation and more efficient hemodynamic adjustments post-exercise (Buchheit, 2014). However, values are acknowledged to be affected by body positioning, environmental factors, measurement time, and any preceding high-intensity exercise, reducing post-exercise HRR and vagal-related HRV results (Buchheit, 2014; Thorpe et al., 2015).

2.6 Perceived Fitness

2.6.1 Overview

Indirect field-based methods of physical fitness assessment allow the efficient measurement of various physical fitness qualities with large cohorts of athletes without requiring time-consuming, expensive or sophisticated equipment and trained administrators (Windt et al., 2022; Aandstad, 2021). Whilst these measures are less susceptible to human biases, field-based methods still require a minimal amount of time, equipment, multiple trained practitioners and often maximal efforts from athletes to undertake, which may still limit feasibility within specific environmental contexts (e.g. limited time within/outside of training and match schedules in team sports) (Windt et al., 2022; Aandstad, 2021). Therefore, the utility of subjective perceptions of performance and physical fitness may provide an additional cost- and time-effective testing method (Windt et al., 2022; Keith, Stump and Clark, 2012).

In team sport contexts, Windt et al., (2022) define subjective performance evaluations as measures that may capture human perceptions of sport performance constructs (e.g., physical, psychological, technical, tactical). Subjective assessments of performance constructs have mainly centred around informal and formal coach, practitioner and scout perceptions of athletes and teams, often guiding decision-making around team/squad selections, starting lineups and in-game decisions (Windt et al., 2022; Jokuschies, Gut and Conzelmann, 2017). From athlete perspectives, several AROM are also widely used across applied sport science to quantify concepts such as training load using RPE and other responses to training and competition performance (e.g., wellness, recovery, sleep and muscle soreness) (Jeffries et al., 2020). Recent work by Darrall-Jones et al., (2022) also reported professional male rugby union players (n = 12) to subjectively underestimate (ran faster) submaximal sprint velocities when verbally instructed to run at 60%, 70% and 80% of their maximal velocity (Vmax) and overestimated (ran slower) when asked to run at 90% Vmax in comparison to objective measures. Though, instrumented athlete perceptions of fitness and how they relate to objective fitness measures commonly used in applied sport science are yet to be addressed (Germain and Hausenblas, 2006).

To date, the topic has been somewhat explored within physical activity research. However, findings remain unclear through an inability to agree upon an operational definition reflective of the multidimensionality of the physical fitness construct and subsequent failure to examine the relationship between perceptions and individual components of physical fitness (Germain and Hausenblas, 2006). Germain and Hausenblas (2006) also reported no differences in the relationship between perceived and actual fitness between sexes, though recent studies have refuted this, indicating men overestimate their perceptions of fitness compared with women (Obling et al., 2015; Petersen et al., 2021). This absence of consistency between studies has resulted in disparities in validity and reliability in assessment methods, sample characteristics (e.g., size, age, gender, fitness levels) and statistical methods used, making generalisable inferences challenging (Germain and Hausenblas, 2006). Therefore, several questions pertaining to self-reported perceptions of fitness in athletic populations remain unaddressed.

2.6.2 Measurement of Perceived Fitness

When using subjective measures, the score produced by a measure can only approximate the construct in question, directly influencing the inference that can be made from that score (Windt et al., 2022). Few studies to date have utilised seminal work in this area from Borg, Skinner, and Bar-Or (1972) in which psychometric properties were employed to design a Stanine scale with a mean of 7 and standard deviation of 2, with verbal anchors placed at every second grade, validated to subjectively assess physical fitness. With the study reporting a strong correlation (r = 0.52) between perceived endurance capacity and a preferred workload on a treadmill, postulating stronger correlations may be achieved in specific or more representative populations (Borg, Skinner, and Bar-Or, 1972). In the most recent review of 28 studies concerning perceived and actual fitness, Germain and Hausenblas (2006) reported 27 studies to report the response rate (average: 91%, range: 40% to 100%), seven studies to define fitness (3 using an American College of Sports Medicine definition, 4 using a conceptual definition) and use of 22 different perceived fitness measures (author-developed questionnaire = 12 [1 item = 9, did not report the number of items = 3], standardised instruments = 16 [average of 24 items, range: 6 to 55]). Of which the scale by Borg, Skinner, and Bar-Or, (1972) was utilised with modifications to the design and verbal anchorage without any reasoning, therefore altering the optimal psychometric properties of the scale.

Additionally, learnings from RPE research using dRPE scores have suggested that separating items in subjective measures may help contextualise monitoring by separating central and peripheral exertion signals (McLaren et al., 2015). However, in more recent work investigating perceived vs objective measures of fitness. Petersen et al., (2021) identified perceived fitness assessed using a single question and five response options in a Likert style (3441 men and women, age: 18 – 85 years) mainly captures cardiorespiratory fitness (r_{men} =

0.69 and r_{women} = 0.65) with only moderate correlations for muscular strength and body composition. Therefore the study still failed to provide any description of the delivery of the scale to participants, define physical fitness, measure each component of physical fitness separately or attempt to understand the psychometric properties of the method used (Germain and Hausenblas, 2006). Despite past work highlighting the need for careful instrumentation to capture scores accurately, studies to date have largely failed to appropriately select scale items or report delivery mediums and timings (Windt et al., 2022).

2.6.3 Psychometric Principles, Measurement Properties and Considerations

Accepted principles of psychometrics dictate that when using scales for subjective assessments, illegal alteration in the formatting, positioning or wording of verbal anchors can affect their functional relationship and effectiveness as intersubjective points of reference (Borg, 1998; McLaren, Coutts and Impellizzeri, 2022). Additionally, any changes to the direction of change in a scale (e.g., horizontally or vertically), or design such as the use of conditional icons, images or colouring, can also alter perceptions of the meaning of steps in a scale (Borg, 1998; McLaren, Coutts and Impellizzeri, 2022). As a result, any changes to a measure may materially violate the optimal psychometric properties of a scale and, subsequently, the measurement properties of subjective responses. Given that these unjustified modifications are prevalent in the current body of work on perceived fitness, this brings into question the measurement properties of the assessment methods currently in use.

Measurement properties in subjective measurement tools are broadly organised by validity and reliability and their subdomains (Figure 7) (McLaren, Coutts and Impellizzeri, 2022).

Measurement property	Description
Reliability domain	The extent to which subjective scores for athletes who have not changed are the same for repeated measurement under several conditions
Internal consistency	The degree of interrelatedness among the items
Reliability	The proportion of the total variance in the measurements that is attributable to true difference among athletes
Measurement error	The systematic and random error of an athlete's subjective measure that is not attributed to true changes in the target constructs
Validity	The degree to which subjective outcomes and their tools (scales, instrument, etc.) measure the constructs they are intended to measure
Content validity	The degree to which the content of a subjective outcome or its measurement tool is an adequate reflection of the construct to be measured
Face validity	The degree to which the items of a subjective outcome or its measurement tool indeed appear to be an adequate reflection of the construct to be measured
Construct validity	The degree to which a subjective outcome is consistent with hypotheses (for instance, with regard to internal relationships, relationships to scores of other instruments, or differences between relevant groups) based on the assumption that the measurement tool provides a valid assessment of the target construct
Structural validity	The degree to which the scores of a subjective measurement are an adequate reflection of the dimensionality of the construct to be measured
Cross-cultural validity	The degree to which the performance of the items on a translated or culturally adapted measurement tool is an adequate reflection of the performance of the items on the original version of the measurement tool
Responsiveness domain	The ability of subjective outcomes and their tools to detect change over time in the construct to be measured

Figure 7. Key measurement properties for subjective monitoring tools in athlete monitoring (from McLaren, Coutts and Impellizzeri, 2022).

Validity refers to the degree to which a measure reflects the construct being measured, while reliability refers to the repeatability of a measure (Impellizzeri and Marcora, 2009; Ary et al., 2018). Additionally, the degree to which two measures of a theoretical construct which should be related are related is referred to as convergent validity, a sub-domain of construct validity (Krabbe, 2016). Any unjustified modifications, therefore, introduce sizable bias to ratings and effectively creates a new unvalidated scale which may not be measuring the construct in question preventing comparison with other work (Mokkink et al., 2016; McLaren, Coutts and Impellizzeri, 2022). Furthermore, given the multidimensionality of the physical fitness construct, the assessment of single items (e.g. aerobic capacity) aims to provide good face validity and clarity to athletes regarding which construct is being measured, though may lower sensitivity in construct validity (McLaren, Coutts and Impellizzeri, 2022). Therefore within the framework of this study, both RPF and SMFT HRex should, theoretically, be associated with both positive and negative training effects (e.g., changes in an exhaustive field test such as the 1.2SRT) (Borg, Skinner, and Bar-Or, 1972; Shushan et al., 2023a).

Lastly, further sources of conscious reporting bias can occur from the delivery, environment or timing of subjective evaluations, which may further disturb the accuracy of collected data through cognitive and situational factors consistent with the team sport environment (Impellizzeri and Marcora, 2009). Cognitive factors refer to the level of misconception or comprehension of the construct under investigation whilst situational factors are characterised by deliberate deception in response to environmental, social or personal stimuli (McLaren, Coutts and Impellizzeri, 2022). Consequently, measures must accurately instruct the user of the concept under investigation to reduce the risk of confusion, which may be paired with verbal instruction, habituation and education to increase athlete understanding and buy-in (McLaren, Coutts and Impellizzeri, 2022). Whilst situational factors are recognised as more difficult to control for, given deliberate deception may be a result of confirmation bias (e.g., imitating other responses perceived as ‘good’), personal gain (e.g., reducing the time of a task) or social desirability bias through a lack of confidentiality, anonymity or privacy (e.g., providing responses in the presence/view of other athletes/staff) (McLaren, Coutts and Impellizzeri, 2022; Coventry et al., 2023). Therefore, the method by which subjective data is collected may significantly affect the validity, reliability and accuracy of responses and any relationships with other constructs of interest. (Coventry et al., 2023).

2.7 Summary

In summary, rugby union encompasses a wide array of physical and physiological demands underpinned by well-developed physical fitness attributes. Aerobic capacity and cardiometabolic fitness form a large proportion of a player's ability to sustain these demands and therefore require considered assessment (e.g. MAS) and monitoring (e.g. SMFT, RPF, etc.) to indicate detraining, maintenance or positive adaptations to training. Whilst field-based tests provide a helpful alternative to laboratory assessment, SMFT and perceived fitness may offer greater utility without trading validity or sensitivity of measurement. However, the relationships between and the predictive nature of these measures are yet to be investigated in a team sport population. Consequently, an observational study investigating these measures, their relative associations and predictive qualities seems warranted. Accordingly, the overarching aims of the study were to: (1) evaluate the relationships between perceived fitness, SMFT HRex and MAS; (2) compare the predictive qualities between perceived fitness, SMFT HRex and MAS; and (3) conclude with practical recommendations and directions for future research.

CHAPTER 3. METHODS

3.1 Theoretical Approach

For a study to provide high-quality findings, consideration must be made to the theoretical underpinning, allowing for an appropriate, succinct and coherent flow of information and presentation of any practical applications developed from collected data (Abt et al., 2022; Barroga and Matanguihan, 2021). Therefore, both ontological (how knowledge is determined in reality) and epistemological (how knowledge is created and appraised) positions must be taken to guide the design of a study and any subsequent interpretation of findings (Thomas, Nelson and Silverman, 2015; Scotland, 2012). Both the ontological and epistemological positions of a researcher guide the methodology of a study, justifying the procedures employed to create and contextualise findings.

The study was underpinned by a post-positivist approach to allow for the observation, measurement and evaluation of relationships between perceived fitness, submaximal fitness and MAS whilst rejecting interactional factors to allow for objective outcomes (McNamee, 2004). Drawing from the epistemology of objectivism and ontology of realism within sport and exercise science research, post-positivism is a consistently adopted philosophical approach in natural sciences such as physiology (Scotland, 2012; Pisk, 2014; Jones, 2022). Therefore, an impartial, deductive and repeatable approach, using a single data collection and statistical analysis of quantitative data, was used to allow for generalisable outcomes (Gratton and Jones, 2014; Jones, 2022). Whilst the position may be limited through the exclusion of participants' lived experiences, personal opinions or emotions, the post-positivist approach allows for objectivity and statistical confidence in research outcomes whilst acknowledging the prior experiences and theories held by a researcher and the influence of bias and social contexts may also impact findings (Gratton and Jones, 2014; Petrovic, Koprivica and Bokan, 2017).

Therefore the epistemology of objectivism was utilised to inform methodological design using objective assessment methods routinely used in sports science (McNamee, 2004).

3.2 Study Design

The study investigated relationships between perceived fitness, submaximal fitness and MAS in rugby union players. A cross-sectional approach was employed, in which data were collected during one evening training session on the first day of the pre-season phase of the season (Halperin et al., 2018). Compared to longitudinal studies allowing for greater control of confounders, acute intervention periods are considered more feasible with high-performance athletes, given recognised difficulties in the planning and preparation required for high-quality data collection (Halperin et al., 2018). Cross-sectional approaches are also considered an appropriate correlational research strategy when investigating associations and the extent of relationships between two or more variables (Smith, 2010). While a high degree of internal validity may be achieved, considering how variables relate when observed together, it is recognised that external validity may be impacted through reduced ecological significance and the inability to identify cause and effect (Smith, 2010).

Following the recommendations of Halperin et al., (2018), the study design was planned in consultation with performance staff responsible for the players involved in the study, allowing for greater participant availability, involvement and compliance. Data collection formed part of a yearly pre-season testing day consisting of gym-based physical performance testing in the morning and an evening session, in which field-based methods were utilised comprising player ratings of perceived fitness, a SMFT and 1.2SRT to calculate MAS (Figure 8). All testing was undertaken in typical conditions (15 °C; humidity: 59%; pressure: 1028 hPa; wind speed and direction: 8 mph^{-1}, SW) on an outdoor 3G marked rugby pitch, with all players wearing competition standard studded footwear and lightweight training clothing (Haugen and Buchheit, 2016). Participants were advised to stay fully hydrated throughout the whole testing session.

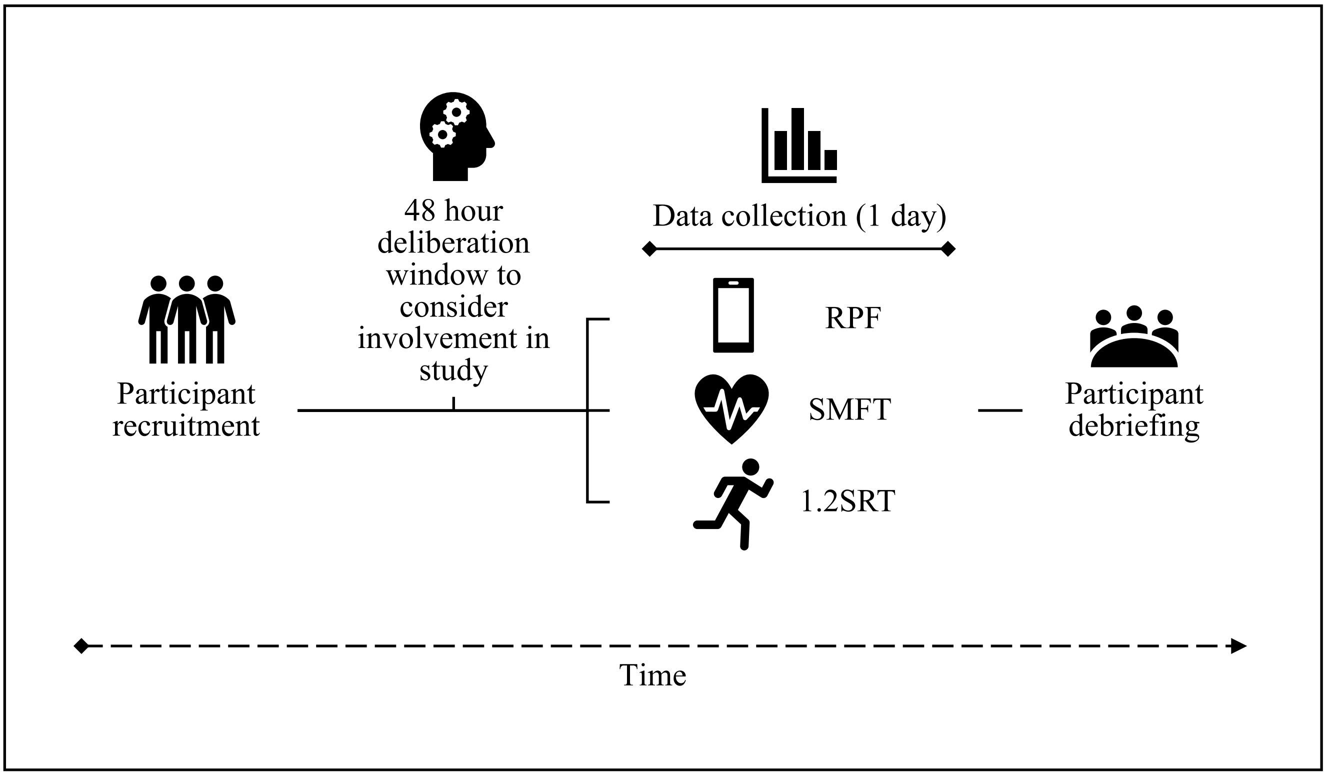


Figure 8. Schematic of study design.

3.3 Study Sample and Recruitment

A total of 50 male rugby union players participated in the study and were recruited from a university men's performance squad of 113 players. At the time, the squad were twice consecutive national champions of the BUCS (British Universities and Colleges Sport) Super Rugby League, the highest level of men's university rugby union, comprising ten teams from universities across England and Wales (BUCS Super Rugby, 2022). Players were identified and recruited through non-probability purposive sampling via a 'gatekeeper' (Team Strength and Conditioning Coach), allowing for enhanced data quality through greater trust between the researcher, participants and relevant stakeholders (Gratton and Jones, 2014). Whilst the method is known to increase the risk of unavoidable sampling bias, the method accurately identified cases relevant to both the aims and design of the study (Gratton and Jones, 2014). Following the Participant Classification Framework for defining the training and performance calibre of athletes developed by McKay et al., (2022), the sample included a combination of Tier 3 (Highly Trained/National Level) and Tier 4 (Elite/International Level) athletes (Appendix 1). The overall squad comprised players: with a professional contract; in contract discussions; recently offered a professional contract; recently trained with a professional club; included in national team training camps; and players with one or more caps for their national team.

Whilst 50 players took part in the overall study, some were unable to complete all aspects of the testing session due to an unscheduled team meeting immediately before the session started. Consequently, 36 players were included in the analysis of relationships and predictive qualities between perceived fitness, SMFT HRex and MAS, whilst 47 were included in the analysis between SMFT HRex and MAS (Table 1).

Table 1. Participant characteristics (mean ± standard deviation) (min–max).

Positional Group:	**Number (n =):**	**Age (years):**	**Height (cm):**	**Body Mass (kg):**
All	47	21.1 ± 1.2 (18.0 – 25.0)	184.86 ± 7.28 (167.50 – 197.60)	97.82 ± 14.31 (67.50 – 127.70)
Forward	26	21.0 ± 1.4 (18.0 – 25.0)	189.00 ± 5.86 (177.80 – 197.60)	107.15 ± 11.39 (80.00 – 127.70)
Back	21	21.3 ± 0.9 (20.0 – 23.0)	179.73 ± 5.40 (167.50 – 189.90)	86.28 ± 7.46 (67.50 – 97.00)

3.4 Ethical Approval

In accordance with the Department of Sport and Exercise Sciences research ethics policy, the study received ethical approval from the departmental Ethics Sub Committee (Appendix 2).

There were several ethical considerations relating to this study. All players voluntarily contributed to the study and were aware they could withdraw at any time without reason (Gratton and Jones, 2014). After data collection, all data was anonymised, securely stored on a password-protected university account, and only shared with named individuals on the research team. Before the testing session, all test protocols were explained to players and time was provided to ask questions. The inclusion criteria required study participants to be high-performance rugby union players in regular training and competition. Exclusion criteria stated that participants must be free from injury or illness and be otherwise well to participate. All players provided written informed consent and were provided with a study information sheet, consent form and university privacy policy (Appendix 3, Appendix 4 & Appendix 5). The three documents summarised the study requirements, benefits, risks, data handling and withdrawal process. After a 48-hour deliberation window to consider involvement in the study and ask any further questions, players returned the required documentation to the lead researcher.

Health and safety are primary considerations in the research ethics application process (Davison et al., 2022). The primary ethical consideration was the field-based nature of the test protocols. Comprehensive risk assessment was carried out for all physiological testing methods, facilities and equipment used to lessen potential hazards during data collection. All physical performance testing protocols were conducted in accordance with the British Association of Sport and Exercise Sciences (BASES) Sport and Exercise Physiology Testing Guidelines for Sport Testing (2022) (Davison et al., 2022). Lastly, to safeguard professional research conduct throughout the study, all communication and interaction between the research team, players and staff was completed per the BASES Code of Conduct (BASES, 2021). Consequently, any potential mitigated risks outweighed any benefits to the players through involvement in the study. All players received a copy of their results and a participant debriefing sheet (Appendix 6) on completion of their involvement in the study.

3.5 Protocols

3.5.1 Anthropometry and Player Information

Body mass was weighed to the nearest 0.1 kg wearing minimal clothing, using an electronic scale (Seca, 876, Seca Weighing and Measuring Systems, Birmingham, UK). Stature was measured to the nearest 0.1 cm using a stadiometer (Seca 217, Seca Weighing and Measuring Systems, Birmingham, UK). Predicted HRmax (pred. HRmax) was calculated using the equation for athletes by Tanaka et al., (2001) HRmax = 206 − (0.7 × age), and values were interpreted ± 10 $b \cdot min^{-1}$ given under and overestimation when using predictive equations (Nikolaidis, 2014).

3.5.2 Athlete Rating of Perceived Fitness (RPF)

At the beginning of the evening testing session, players completed a newly modified athlete rating of perceived fitness (RPF) scale (Appendix 7). The increased Stanine rating scale was adapted from a perceived fitness scale from Borg, Skinner, and Bar-Or (1972), consisting of a mean of 7 and a standard deviation of 2 with 13 steps, increasing in increments of 1 ranging from extremely low to high capacity, together with idiomatic English verbal anchors explaining the meaning of each value at every second grade. The scale was adapted to include one item, "Aerobic Fitness", as an innate, popularly used and recognisable term for players to self-appraise their overall endurance capacity (Chamari and Padulo, 2015). Reflecting the study aims of assessing subjective and objective fitness; the scale instructions were modified to ask players to rate their perception of their aerobic fitness 'right now' against the rest of their team at that moment in time, which would then be measured by their performance in the 1.2SRT colloquially referred to as the ‘Bronco Test’ on the scale.

Before administering the scale, players were verbally instructed to read all instructions in full, to appraise their capacity as objectively as possible and not to underestimate or overestimate their ability. The scale was distributed to players via a QR code linked to a bespoke online form (Appendix 8) (Microsoft® Forms, Microsoft Office 365™ A3 2022, Microsoft Corp., Redmond, USA). Players recorded their RPF using their own mobile devices; then, the software uploaded their responses to a cloud-based spreadsheet (Microsoft Excel®, Microsoft Office 365 A3 2022, Microsoft Corp., Redmond, USA). The estimated silent reading time for the scale was calculated as 01:01 (240 [words on RPF form] / 238 [average English words per min for adults]; Brysbaert, 2019). The average response time to all three questions on the form (name, position and RPF) was 01:20 (range: 00:25 - 03:42) and used as an estimative measure of time-on-task (e.g. comprehension of the form instructions and active engagement with the scale). RPF data was collected within a 4 min period, including verbal instruction.

3.5.3 Submaximal Fitness Test (SMFT)

Following submission of RPF, a SMFT comprising 4 min continuous-fixed running at 12 $km \cdot h^{-1}$ was conducted to stimulate a steady state of ~75 – 85% HRmax. A shuttle-based continuous-fixed protocol was selected, having been shown to produce high relative reliability and convergent validity in assessing changes to athlete aerobic capacity through monitoring HRex (Shushan et al., 2023a; Shushan et al., 2022). The protocol was fully explained to all players before the test, and the test was led by the lead researcher. The exercise regimen used 50m shuttles (try line to halfway line of rugby pitch) comprising 15 × 180º COD (Figure 9).

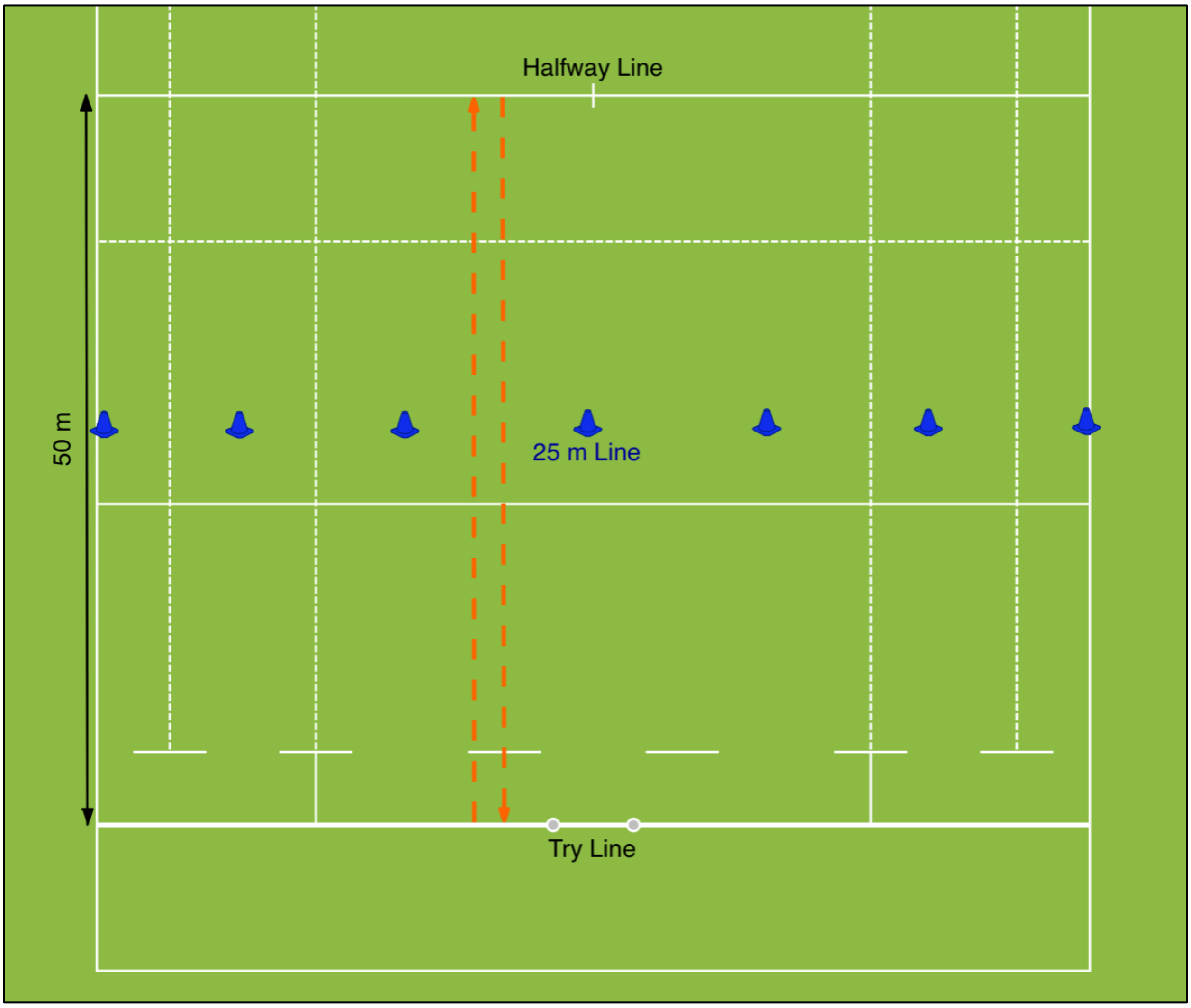


Figure 9. SMFT pitch configuration.

Additionally, a line of cones was placed at 25m (half of the total distance of one shuttle) as a reference point. To ensure the correct running speed was observed at all times, players were instructed to run in a line at the same pace as each other ensuring all players reached either line within 16 s at the same time. To aid pacing, a whistle was blown every 8 s to denote the start, 50% progress or finish of each 50m shuttle. Beat-to-beat heart rate was continuously monitored throughout the test using chest-worn heart rate monitors (Polar® H10, Polar Electro Oy, Kempele, Finland) and Polar Team (Version 1.9, Polar Electro Oy, Kempele, Finland). Immediately following the completion of the SMFT, HRR was measured. Instantaneously after the final whistle of the SMFT, players were instructed to stop, stand still, put their hands on their hips and close their eyes, remaining in the position for 2 min to limit sympathetic stimulation (Shushan et al., 2022). Heart rate was continually recorded at 1 Hz and then sampled every 5 s to enable the determination of HRex (average HR during the final 60 s of SMFT) and HRR (difference between HR at the end of SMFT and 2 min post-test) (Shushan et al., 2022). Following the conclusion of the test, all players rested for a period of 5 min before completing the 1.2SRT.

3.5.4 1.2 km Shuttle Run Test (1.2SRT)

Following the rest period, all players completed the 1.2SRT. Frequently used in rugby performance testing batteries, the test was utilised as a valid, field-based assessment of aerobic capacity, replicating the intermittent nature of team sports such as rugby union (Vachon et al., 2021). Originally developed by Kelly and Wood (2013), the test comprises a 1200 m time trial in a shuttle format combining accelerations, decelerations, and 29 × 180º COD to better reproduce the intermittent movement demands of rugby union. Players were required to complete five repetitions of 20 m and back, 40 m and back, and 60 m and back (1 rep total distance = 240 m) straight shuttle runs at maximal intensity (Figure 10) (Brew and Kelly, 2014).

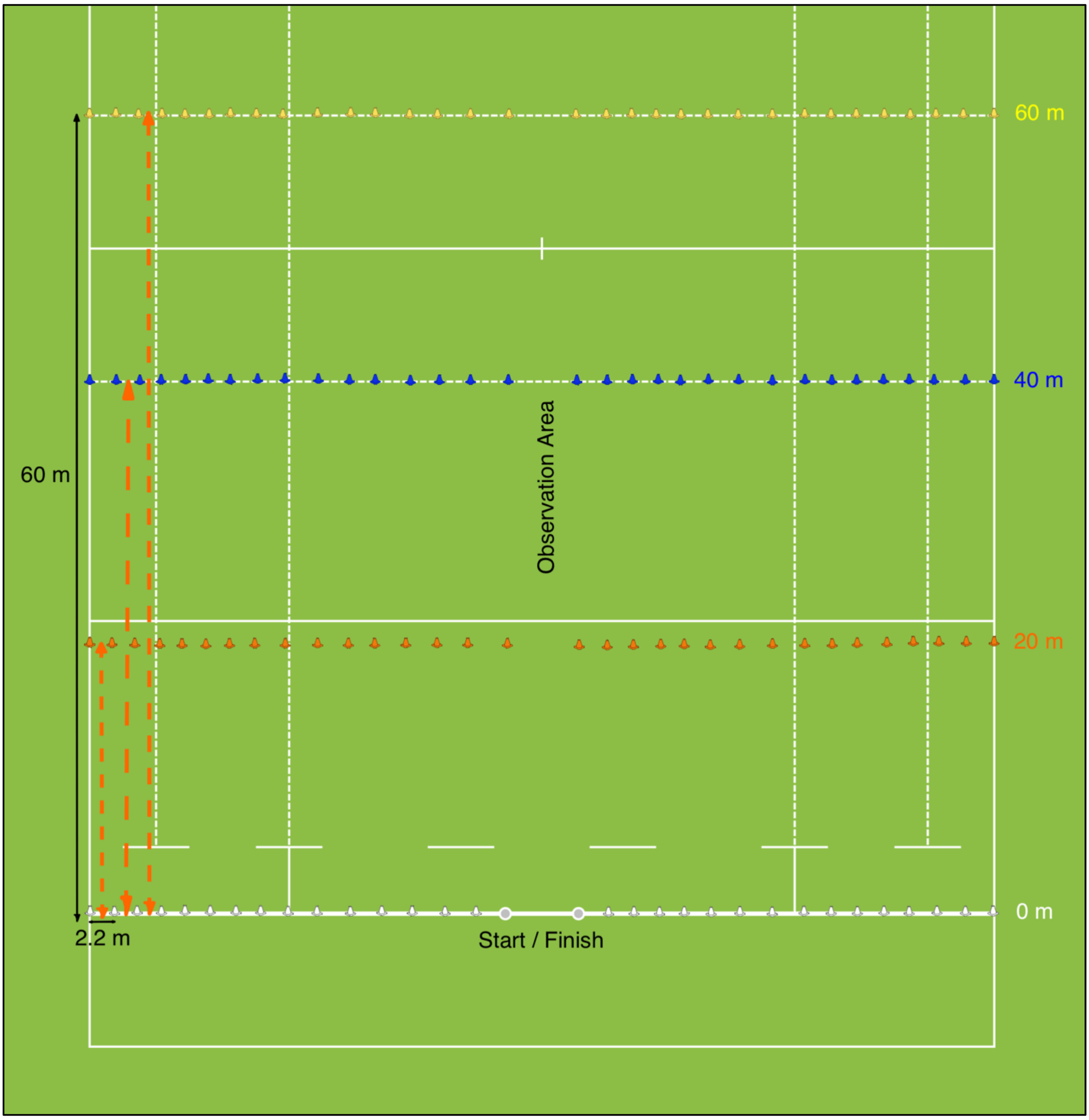


Figure 10. 1.2SRT pitch configuration.

Distances were measured using a 50 m tape measure, and cones were placed to noticeably identify the 0 m, 20 m, 40 m and 60 m distances. To further ensure the correct running distance of 1.2 km was achieved as closely as possible, all players were provided with an individual running lane (2.2 m) and were instructed before the test to touch each line with the whole of their foot before turning (Kelly and Wood, 2013). The lead researcher initiated the test using a whistle. All players were closely monitored and verbally encouraged throughout the test by the research team from both touchlines and an observation channel in the centre of the test area opposite the goalposts on the pitch. Failure to reach two consecutive lines resulted in the termination of the test for that player. Beat-to-beat heart rate was continuously monitored at 1 Hz throughout the test using chest-worn heart rate monitors (Polar H10, Polar Electro Oy, Kempele, Finland) and Polar Team (Version 1.9, Polar Electro Oy, Kempele, Finland) to establish relative physiological strain and confirm maximal efforts (Lemmink et al., 2004). Test performance was recorded using a stopwatch and video recording (30 fps, 1080p) to ascertain accurate finish times. Finish times were defined as the time in minutes, on completion of 5 consecutive repetitions, as fast as possible, when a foot crossed the finish line of the test (Currell and Jeukendrup, 2008; Kelly and Wood, 2013).

3.6 Calculation of MAS

MAS is calculated as the total distance in m (1200 m) divided by the time taken in s to complete the 1.2SRT (Sandford, Laursen and Buchheit, 2021). However, Buchheit (2008) proposed correcting MAS by 0.7 s for every 180º COD in shuttle-based tests in a sample of young Basketball and Handball players due to turns requiring greater effort than continuous tests. Consequently, MAS scores were corrected by subtracting 29 × 0.7 s from finish times to account for time to turn during the 29 × COD during the 1.2SRT.

3.7 Statistical Analysis

Data were collated and formatted using Microsoft Excel (Microsoft Excel, Microsoft Office 365 A3 2023, Microsoft Corp., Redmond, USA). Outliers were identified using visual inspection of raw data and removed before the analysis; 3 players were removed from the analysis due to measurement error during testing, resulting in intermittent HR data loss.

Statistical analysis was undertaken using R (v.4.2.2; R Core Team, 2022), the RStudio integrated development environment (IDE) (v.2023.3.0.386; Posit™ team, 2023) and the following R packages: tidyverse (v.2.0.0; Wickham et al., 2019), writexl (v.1.4.2; Ooms, 2023), mbir (v.1.3.5; Peterson and Caldwell, 2019), patchwork (v.1.1.2; Pedersen, 2022), modelsummary (v.1.4.0; Arel-Bundock, 2022), olsrr (v.0.5.3; Hebbali, 2020) and grateful (v.0.1.11; Rodríguez-Sánchez, Jackson and Hutchins, 2022) (Appendix 9 & Appendix 10). Visual inspection (histograms and Q–Q plots) and normality testing (Shapiro–Wilk test) of raw data revealed no violations of normality assumptions. Consequently, descriptive statistics and parametric models were utilised. Data are presented as the mean ± standard deviation (SD) and RPF in 1 to 13 arbitrary units (AU).

Unpaired two-sample t-tests were used to identify mean differences between forwards and backs. The strength of the association between variables was examined with linear correlation using Pearson's product-moment correlation coefficients. Correlation coefficients (r) were interpreted using the usual scale of thresholds: 0.1, small; 0.3, moderate; 0.5, large; 0.7, very large; and 0.9, extremely large (Hopkins et al., 2009). To avoid dichotomising the presence or absence of effects using traditional null hypothesis testing, the magnitude-based inference (MBI) approach was used to describe the uncertainty and magnitude of outcomes using the usual scale of probabilistic terms (Hopkins et al., 2009). Uncertainty in estimates were expressed as 90% confidence limits (±90% CL), inferring outcomes as unclear if the 90% CL overlapped both substantially positive and negative thresholds by ≥5% (Batterham and Hopkins, 2006; Hopkins et al., 2009). For clear associations, the predictive qualities of variables were modelled using linear and multiple linear regression with estimates of the coefficient of determination (R^2), standard error of the estimate (SEE), intercept and slope. Regression diagnostics were also conducted to assess model compliance with assumptions.

CHAPTER 4. RESULTS

4.1 Descriptive Statistics and Differences Between Positional Groups

The mean ± SD of perceived fitness, SMFT outcomes, 1.2SRT outcomes and differences between forwards and backs are provided in Table 2. The total study sample comprised players from Front Row (n = 8), Second Row (n = 8), Back Row (n = 10), Half Back (n = 10), Centre (n = 4) and Back Three (n = 7) positions. Comparisons between forwards and backs for perceived fitness, SMFT and 1.2SRT outcomes revealed differences ranging from almost certainly small for RPF (-2.4; ±1.1 AU); to most likely small for 1.2SRT total time (34.42; ±8.68 s); likely small for HRex as a percentage of pred. HRmax (1.67; ±2.18%); possibly small for MAS (-0.51; ±0.12 m•s^{-1}) and likely trivial for pred. HRmax (0.2; ±0.4 b·min^{-1}) (Table 2). All differences were unclear for HRex (3.4; ±4.1 b·min^{-1}); HRR (-0.2; ±4.7 b·min^{-1}); HRR as a percentage of pred. HRmax (-0.13; ±2.49%); HRavg (2.1; ±3.9 b·min^{-1}); HRavg as a percentage of pred. HRmax (1.01; ±2.06%); and 1.2SRT HRpeak (-0.3; ±3.5 b·min^{-1}) (Table 2).

Table 2. Descriptive statistics (mean ± standard Deviation) (min–max) and inferential statistics (90% confidence limits) of differences between positional groups for perceived fitness, SMFT and 1.2SRT outcomes.

Variable	**Positional Group**			**Difference between forwards and backs**	
	All (n = 47):	**Forward (n = 26):**	**Back (n = 21):**	**Mean difference; ±90% CL:**	**Uncertainty and magnitude of difference; MBI%[a]:**
Perceived Fitness					
RPF (AU)	7.5 ± 2.3 (2.0 – 11.0)	6.3 ± 2.4 (2.0 – 11.0)	8.8 ± 1.4 (5.0 – 11.0)	-2.4; ±1.1	Almost Certainly Small; 0.00/0.30/99.70%
SMFT Outcomes					
pred. HRmax (b·min^{-1})	191.2 ± 0.8 (188.5 – 193.4)	191.3 ± 1.0 (188.5 – 193.4)	191.1 ± 0.6 (189.9 – 192.0)	0.2; ±0.4	Likely Trivial; 13.80/85.90/0.30%
HRex (b·min^{-1})	176.8 ± 8.4 (157.6 – 194.2)	178.3 ± 8.5 (158.8 – 194.2)	174.9 ± 8.1 (157.6 – 186.2)	3.4; ±4.1	Unclear; 87.90/6.20/5.90%
HRex/pred. HRmax (%)	92.45 ± 4.45 (82.37 – 102.29)	93.19 ± 4.52 (83.33 – 102.29)	91.52 ± 4.29 (82.37 – 96.96)	1.67; ±2.18	Likely Small; 81.50/13.50/5.00%
HRR (b·min^{-1})	49.4 ± 9.5 (32.0 – 70.0)	49.3 ± 9.5 (36.0 – 70.0)	49.5 ± 9.8 (32.0 – 66.0)	-0.2; ±4.7	Unclear; 40.20/13.90/45.90%
HRR/pred. HRmax (%)	25.82 ± 5.00 (16.73 – 36.73)	25.76 ± 5.01 (18.89 – 36.73)	25.89 ± 5.10 (16.73 – 34.63)	-0.13; ±2.49	Unclear; 33.70/26.10/40.20%

1.2SRT Outcomes					
Total Time (s)	304.04 ± 24.55 (266.00 – 355.00)	319.42 ± 22.13 (271.00 – 355.00)	285.00 ± 9.29 (266.00 – 299.00)	34.42; ±8.68	Most Likely Small; 100.00/0.00/0.00%
MAS ($m•s^{-1}$)	4.26 ± 0.36 (3.59 – 4.88)	4.03 ± 0.31 (3.59 – 4.79)	4.54 ± 0.16 (4.31 – 4.88)	-0.51; ±0.12	Possibly Small; 0.00/47.20/52.80%
HRavg ($b·min^{-1}$)	189.6 ± 7.8 (168.0– 210.0)	190.6 ± 7.4 (179.0 – 210.0)	188.4 ± 8.3 (168.0 – 199.0)	2.1; ±3.9	Unclear; 76.20/11.10/12.70%
HRavg/pred. HRmax (%)	99.16 ± 4.16 (88.14 – 110.58)	99.61 ± 4.02 (93.91 – 110.58)	98.60 ± 4.36 (88.14 – 104.41)	1.01; ±2.06	Unclear; 66.10/22.70/11.20%
1.2SRT HRpeak ($b·min^{-1}$)	199.9 ± 7.1 (183.0 – 221.0)	199.8 ± 7.2 (189.0 – 221.0)	200.1 ± 7.2 (183.0 – 211.0)	-0.3; ±3.5	Unclear; 34.80/18.50/46.70%

a

MBI%: Negative/Trivial/Positive%.

Abbreviations: CL: confidence limits; *MBI*: magnitude-based inference; *RPF*: rating of perceived fitness; *AU*: arbitrary unit; *SMFT*: submaximal fitness test; *pred. HRmax*: predicted maximum heart rate; $b·min^{-1}$: beats per minute; *HRex*: exercise heart rate; *HRex/pred. HRmax*: exercise heart rate as a percentage of predicted maximum heart rate; *HRR*: heart rate recovery; *HRR/pred. HRmax*: heart rate recovery as a percentage of predicted maximum heart rate; *1.2SRT*: 1.2 km shuttle run test; *s*: seconds; *MAS*: maximal aerobic speed; $m•s^{-1}$: metres per second; *HRavg*: average heart rate; *HRavg/pred. HRmax*: average heart rate as a percentage of predicted maximum heart rate; *HRpeak*: highest heart rate recorded during the 1.2SRT.

4.2 Relationships between RPF, SMFT HRex and MAS

Linear models and pairwise correlations were used to determine within-player relationships between measures of perceived, submaximal and maximal aerobic fitness. The linear associations between RPF, SMFT HRex and MAS are presented in Figure 11 and Table 3.

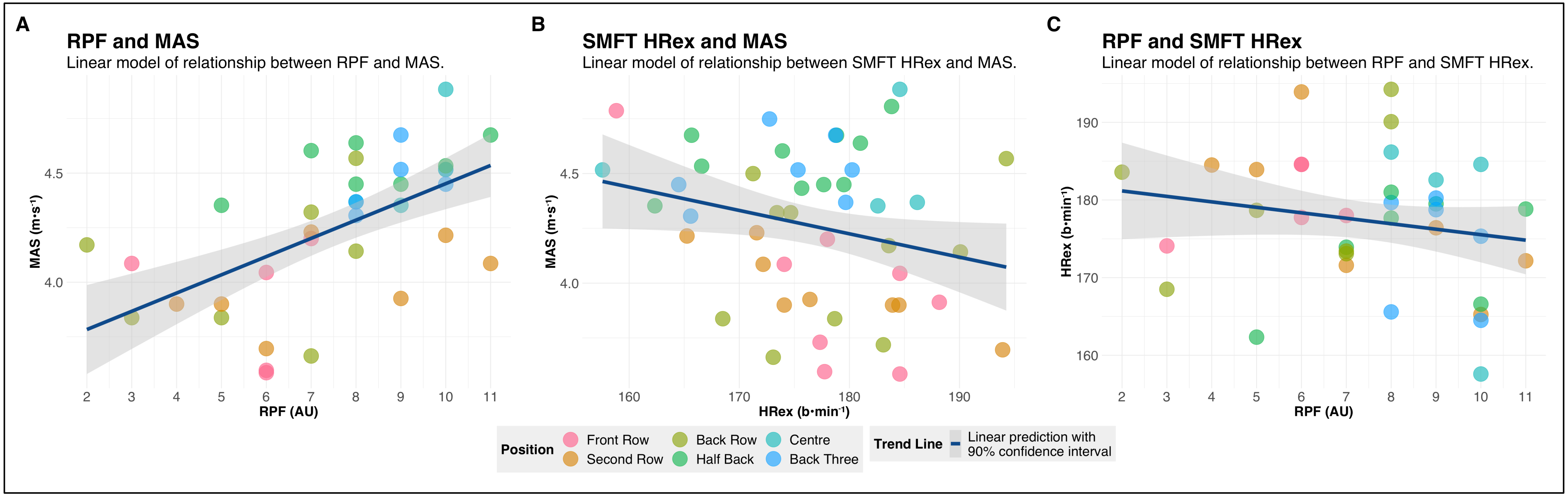


Figure 11. Linear models of relationships between RPF, SMFT HRex and MAS: A: scatter plot of RPF and MAS; B: scatter plot of SMFT HRex and MAS; C: scatter plot of RPF and SMFT HRex.

Table 3. Pearson's product-moment correlation coefficients of HRex, RPF and MAS.

Pairwise Correlation:	df:	*r*:	90% CL:	Uncertainty, magnitude and direction of relationship; MBI%[a]:
RPF and MAS	34	0.58	0.19	Almost Certainly Large Positive; 99.90/0.10/0.00%
HRex and MAS	45	-0.25	0.23	Likely Small Negative; 0.90/13.90/85.20%
RPF and HRex	34	-0.19	0.27	Possibly Small Negative; 4.60/25.00/70.40%

[a] *MBI%:* Negative/Trivial/Positive%.

Abbreviations: df: degrees of freedom; *r*: correlation coefficient; *CL*: confidence limits; *MBI*: magnitude-based inference; *HRex*: exercise heart rate; *MAS*: maximal aerobic speed; *RPF*: rating of perceived fitness.

Linear models and correlation coefficients revealed an almost certainly large positive association between RPF and MAS (r = 0.58; ±0.19), modelled by a linear homoscedastic distribution (Table 3; Figure 11, A). With backs reporting a higher RPF (almost certainly [small] increase) and achieving a higher MAS (possibly [small] increase) during the 1.2SRT in comparison to forwards (Figure 11, A; Table 2). A likely small negative association between SMFT HRex and MAS (r = -0.25; ±0.23) was also identified, modelled by a linear heteroscedastic distribution (Table 3; Figure 11, B). Backs achieved a higher MAS (possibly [small] increase) during the 1.2SRT in comparison to forwards, with no clear difference in HRex (unclear difference) observed (Figure 11, B; Table 2). A possibly small negative relationship between RPF and HRex (r = -0.19; ±0.27) was also revealed and modelled by a linear heteroscedastic distribution (Table 3; Figure 11, C). Backs largely reported a higher RPF (almost certainly [small] increase) in comparison to forwards, though no clear difference in HRex (unclear difference) was observed (Figure 11, C; Table 2).

4.3 Prediction of Submaximal and Maximal Aerobic Fitness

Linear and multiple linear regression was used to model the predictive qualities of perceived, submaximal and maximal aerobic fitness. Linear regression was first employed to identify if player RPF and SMFT HRex are predictive of MAS measured using the 1.2SRT and if player RPF is predictive of SMFT performance (HRex) as a measure of submaximal, aerobic, cardiovascular fitness. Multiple regression was then used to identify if player RPF and SMFT HRex combined provide an improved prediction of MAS measured using the 1.2SRT. Linear regression model outcomes are presented in Table 4 and the results of the multiple regression model are shown in Table 5.

Table 4. Linear regression analysis for the prediction of MAS from HRex and RPF, and HRex from RPF.

Model		**Summary**				
Outcome:	**Predictor:**	R^2**:**	**SEE:**	**Intercept:**	**Slope:**	**AIC:**
MAS	RPF	0.33	0.28	3.62	0.08	14.00
	HRex	0.06	0.35	6.14	-0.01	38.40
HRex	RPF	0.04	8.48	182.58	-0.71	260.00

Abbreviations: R^2: coefficient of determination; *SEE*: standard error of the estimate; *AIC*: Akaike information criterion; *MAS*: maximal aerobic speed; *HRex*: exercise heart rate; *RPF*: rating of perceived fitness.

Linear regression analysis revealed RPF to explain 33% of the variance in MAS with the lowest estimated prediction error (SEE: 0.28; AIC: 14.00) (Table 4). HRex was also revealed to explain 6% of the variance in MAS with a higher estimated prediction error (SEE: 0.35; AIC: 38.40) compared to RPF (Table 4). Whilst RPF represented 4% of the variance in HRex with the highest estimated prediction error (SEE: 8.48; AIC: 260.00) of all the linear models assessed (Table 4).

Table 5. Multiple linear regression analysis for prediction of MAS from HRex and RPF.

Model		**Summary**			
Outcome:	**Predictor:**	R^2**:**	**Adj.** R^2**:**	**SEE:**	**AIC:**
MAS	HRex + RPF[a]	0.33	0.29	0.28	15.90

[a] *Tolerance level:* 0.963; and *Variance Inflation Factor (VIF):* 1.038; for both predictor variables.

Abbreviations: R^2: coefficient of determination; *Adj.* R^2: coefficient of determination accounting for non-significant predictors; *SEE*: standard error of the estimate; *AIC*: Akaike information criterion; *MAS*: maximal aerobic speed; *HRex*: exercise heart rate; *RPF*: rating of perceived fitness.

Multiple linear regression analysis revealed HRex and RPF combined to explain 33% of the variance in MAS, with the second lowest estimated prediction error (SEE: 0.28; AIC: 15.90) of all models analysed (Table 5 & Table 4). Regression diagnostics revealed high tolerance and low VIF (tolerance: 0.963, VIF: 1.038), indicating no degrading multicollinearity between the predictor variables (Table 5). Overall, the regression analysis revealed RPF to be the strongest predictor of MAS ($R^2 = 0.33$; SEE: 0.28) compared to SMFT HRex ($R^2 = 0.06$; SEE:

0.35) and both variables combined (Adj. R^2 = 0.29; SEE: 0.28) (Table 4 & Table 5). RPF was also revealed to be a poor predictor of SMFT HRex as a proxy measure of submaximal aerobic fitness, with the highest estimated prediction error of all the models assessed (R^2 = 0.04; SEE: 8.48) (Table 4 & Table 5).

CHAPTER 5. DISCUSSION

The overall purpose of this study was to investigate the relationships and predictive qualities between field-based measures of perceived, submaximal and maximal aerobic fitness in a sample of high-performance British university rugby union players. To evaluate the associations and predictive qualities of RPF, SMFT HRex and MAS, three specific research questions guided the study. First, to quantify to what extent MAS, measured using the 1.2SRT, is associated with RPF and SMFT HRex. Second, to quantify to what extent player RPF associate with SMFT HRex as a proxy cardiovascular fitness measure of submaximal aerobic capacity. Finally, to evaluate the singular and combined predictive qualities of RPF and SMFT HRex in forecasting MAS measured using the 1.2SRT and SMFT HRex from RPF. To date, the study is the first to examine the relationships and predictive qualities between perceived fitness and objectively measured fitness using commonly employed field-based methods in a sample of team sport players. More specifically, the study is the first to modify and use a scale specifically designed to assess athlete perceptions of aerobic capacity in a team sport setting. Finally, the study is also the first to employ a pitch-based continuous-fixed SMFT protocol with a minimum dose of 3-4 min in a sample of rugby union players whilst also assessing the predictive qualities of RPF and SFMT HRex in forecasting MAS derived from the 1.2SRT.

5.1 Relationships and Predictive Qualities Between RPF, SMFT HRex and MAS

Windt et al., (2022) argue that applying best practice subjective assessment techniques and accepted psychometric principles in subjective performance evaluations may open new fields of investigation, demonstrating the value or perhaps limited utility of athlete intuition in understanding athletic capacity or performance. A systematic approach is also required to effectively manage training in team sports based on a thorough framework and utilising sensitive proxy outcome measures able to detect acute and chronic training effects (Kalkhoven, Watsford and Impellizzeri, 2020; Vanrenterghem et al., 2017; Jeffries et al., 2021). In this respect, SMFT provide a helpful solution in monitoring athletes in team sports by alleviating physical and mental inconveniences commonplace with maximal exhaustive testing methods (Shushan et al., 2022; Shushan et al., 2023b). In extension of previous work in these areas, this study demonstrated that athlete RPF for aerobic capacity hold acceptable levels of content, face and construct domains of validity, highlighting the potential benefit of athlete perceptions of fitness in a team sport setting. In addition, SMFT HRex was revealed to be weakly associated with or predictive of MAS, measured using the 1.2SRT, and RPF was not well associated or predictive of SMFT HRex as a proxy cardiovascular measure of submaximal aerobic capacity. Finally, this study revealed that a combined model of both RPF and SMFT HRex does not improve the association with or predictive power of MAS, measured using the 1.2SRT compared to RPF alone.

5.1.1 RPF and MAS

The study identified an almost certainly large positive within-player association between RPF and MAS measured using the 1.2SRT, with moderate predictive quality and low estimated prediction error. This represented a novel finding, indicating strong construct validity for the rating scale in a sample of team sport athletes and is in direct support of previous work on this topic in non-athletic populations. For example, seminal work by Borg, Skinner, and Bar-Or, (1972), upon which the scale used in the current study was based, reported a large correlation (r = 0.52) between perceived endurance capacity and a preferred workload on a treadmill (n = 70), postulating stronger correlations in more specific populations. Whilst more recently, Germain and Hausenblas (2006) revealed combined perceived fitness scores of men and women of multiple ages moderately related to physical test outcomes (r = 0.38, n = 33, CI = ±.058), with results further augmented in younger people (r = 0.37, n = 25, CI = ±0.09) and studies employing standardised perceived fitness measures (r = 0.43, n = 18, CI = ±0.071). Given the higher correlation coefficient observed in the current study, the findings indicate that rugby union players may more accurately perceive their aerobic capacity compared to no-athletic populations. Supporting the work conducted by Borg, Skinner, and Bar-Or, (1972) this greater ability to predict fitness may therefore be attributed to the notion that highly trained athletes who participate in regular training and competition may have a better sense of their fitness than the average person. Whilst also directly supporting the view that to accurately assess a target construct, alterations to subjective measures must be in keeping with accepted psychometric principles, ensuring subjective responses remain consistent with the observed relationships and assumptions of the measurement tool (Borg, 1998; McLaren, Coutts and Impellizzeri, 2022).

Comparisons between forwards and backs revealed an almost certainly small difference in RPF and a possibly small difference in MAS. This was a theoretically expected finding and is consistent with previous literature indicating MAS differences between forwards and backs while also providing evidence of content validity for athlete RPF in which subjective outcomes strongly reflect the objective measures investigated (McLaren, Coutts and Impellizzeri, 2022). Baker and Heaney (2015) reported MAS scores of 4.32 $m \bullet s^{-1}$ for a squad of elite Australian rugby union players and positional differences of 4.41 $m \bullet s^{-1}$ for backs and 4.23 $m \bullet s^{-1}$ for forwards. This positional difference has been extensively attributed to the relative variation in physical and movement demands between players, and resulting physiological responses, with MAS shown to strongly correlate (r = 0.746) with distance covered during match play in professional rugby players (Tierney et al., 2017; Cunningham et al., 2018b; McLaren et al., 2018a; Swaby, Jones and Comfort, 2016). The study, therefore, demonstrates that positional group differences in player RPF are consistent with differences in MAS, with players who report a higher RPF subsequently achieving a higher MAS during the 1.2SRT, and vice versa.

Given that motivation to perform maximally is vital in providing practically useful outcomes in measures such as MAS, HR measures were collected as markers of internal load to evaluate relative physiological strain during the test and confirm maximal efforts (Thorpe et al., 2017; Lemmink et al., 2004). During the 1.2SRT, all players performed the test at an HRavg close to pred. HRmax, with all players also displaying a mean HRpeak during the test exceeding pred. HRmax, suggesting that maximal efforts were achieved. However, it must be acknowledged that predictive equations for HRmax derived from age likely under and overestimate true HRmax, though even using the recommended conservative interpretation of ± 10 $b \cdot min^{-1}$, all players still completed the test within the region of 90 – 100% of pred. HRmax (Nikolaidis, 2014). No clear differences between forwards and backs in HRavg; HRavg as a percentage of pred. HRmax or 1.2SRT HRpeak were reported. Furthermore, a most likely small difference for 1.2SRT total time was observed with a possibly small difference in MAS. In comparison with previous literature, Vachon et al., (2021) reported similar completion times in elite rugby union players of 303.9 ± 24.8 s for all players (n = 39), 319.6 ± 25.1 s for forwards (n = 20), and 287.4 ± 8.5 s for backs (n = 19). Therefore, the subjective outcomes in this study appear to be an acceptable reflection of objectively measured aerobic capacity, indicating that player RPF demonstrate good face validity in relation to MAS (McLaren, Coutts and Impellizzeri, 2022). However, it must also be recognised that the players involved in this study were also full-time university students and by definition highly educated. This may also have an effect on the ability of athletes to accurately perceive components of fitness through a greater understanding or comprehension of the task at hand (Mátrai, 2016).

In summary, athlete RPF for aerobic capacity show strong levels of validity across several domains. However, further work is needed to assess the reliability (e.g., internal consistency, measurement error etc.) and sensitivity (responsiveness domain) of within- and between-athlete changes to perceptions of fitness in relation to acute or chronic and negative or positive training effects.

5.1.2 SMFT HRex and MAS

The study revealed a likely small negative association between SMFT HRex and MAS and poor predictive quality, with a high estimated prediction error compared to RPF. Whilst a novel finding concerning the athletic population selected and choice of maximal test used in this study, both Mohr and Krustrup (2014) and Fanchini et al., (2014) have also determined non-significant correlations between HRex and maximally derived cardiorespiratory function in samples of semi-professional and young soccer players respectively. Seemingly, while studies suggest strong convergent validity and associations between HRex and maximally derived cardiorespiratory function (Shushan et al., 2023a; Buchheit et al., 2012; Hulin et al., 2019), the current disparity in this area of research, suggests the combinations of SMFT and maximal tests may evaluate different constructs or mechanisms in the training process, which may be reflective of the interaction between internal load responses and diverse SMFT and maximal test modalities (Scott et al., 2022).

Further, the study reported a likely small difference between positional groups in HRex as a percentage of pred. HRmax. This may reflect the higher aerobic capacity observed in backs compared to forwards allowing for a reduced HRex and subsequent internal load for the same given physical output (Baker and Heaney, 2015; Vachon et al., 2021). Unclear differences for HRex, HRR, and HRR as a percentage of pred. HRmax were also observed, indicating that the

SMFT protocol intended dose of ~75 – 85%, HRmax was likely achieved by all players (± 10 b·min^{-1}), and therefore the likelihood of methodological error is low. However, the theoretical association between HRex and maximally derived cardiorespiratory function may also be limited by the currently known construct validity of methods such as the 1.2SRT (Scott et al., 2022). Despite the test being the most used method of MAS assessment in the monitoring and preparation of rugby union players, to the researcher's knowledge, the method is yet to be validated against a gold standard measure (Kelly, Jackson and Wood, 2014; Hamlin et al., 2019). There is also little consensus on the application of corrective equations developed to account for differences in anthropometric qualities of varying athletes and variable COD requirements of test methodologies (Appendix 11) (Teece et al., 2021; Baker and Heaney, 2015).

In summary, the study identifies a poor association and predictive quality between SMFT HRex, and MAS measured using the 1.2SRT. Therefore, the study advises against using SMFT HRex to predict MAS derived from the 1.2SRT in rugby union players until further work is conducted to assess the use and validity of differing SMFT and MAS assessment methods, which currently likely prevents any meaningful association.

5.1.3 RPF and SMFT HRex

Exploratively, the association and predictive qualities between RPF and SMFT HRex as a proxy measure of submaximal aerobic fitness were also assessed. Similarly, a possibly small negative relationship between RPF and HRex was also revealed alongside a poor representation of the variance in HRex, with the highest estimated prediction error of all models assessed in the current study. This represented an expected finding, given that the RPF scale instructions were specifically edited to anchor responses to performance in the 1.2SRT as a field measure of maximal aerobic capacity in rugby union players. Therefore, this finding reflects the notion that player RPF for aerobic capacity in their current form in this study are mainly reflective of maximal aerobic capacity rather than submaximal aerobic capacity. This is also supported by the existing literature on perceptions of fitness, which, regardless of the scale used, contends that perceptions of fitness largely represent cardiorespiratory fitness (Petersen et al., 2021). However, this represents a further avenue of investigation in which a second item, "submaximal aerobic capacity", may be added to the scale to assess if perceptions of aerobic fitness are nuanced between submaximal and maximal intensities.

5.1.4 RPF + SMFT HRex and MAS

Lastly, a multiple linear regression model combining HRex and RPF moderately explained the variance in MAS whilst exhibiting the second-lowest estimated prediction error of all models analysed. Regression diagnostics revealed high tolerance and low VIF, indicating no degrading multicollinearity between the predictor variables. However, the overall regression analysis showed RPF alone as the strongest predictor of MAS compared to SMFT HRex and both variables combined. Therefore, the addition of SMFT HRex to player RPF does not currently improve the association with or predictive quality for MAS estimation in rugby union players. This finding is also consistent with the previous models discussed in that given SMFT HRex proves to be a helpful monitoring tool in relation to some measures of maximally derived cardiorespiratory functioning (Shushan et al., 2023a; Scott et al., 2022; Buchheit et al., 2012; Hulin et al., 2019). The wide variety of currently used SMFT practices, possibly due to a lack of robust evidence across multiple team sport contexts, are not yet sufficiently investigated for this particular use case (Shushan et al., 2023b). Paired with the unknown construct validity of the maximal test used in this study, likely prevents the improved estimation of aerobic-oriented physical capacity in rugby union players (Kelly, Jackson and Wood, 2014; Teece et al., 2021;

Baker and Heaney, 2015). Additionally, it is important to consider that fitness and performance have relative and absolute connotations. For example, a forward may perceive themself to be at a high level of relative aerobic fitness compared to previous levels of fitness or compared to the rest of the forwards. Yet, in comparison to backs, which may possess a distinct anthropometry, their absolute maximal aerobic speed, may be considerably lower. Similarly, the completion of the SMFT at a given absolute speed, of 12 $km \cdot h^{-1}$ would present a different level of relative challenge to individuals.

To conclude, drawing definitive inferences as to the estimation of MAS from SMFT HRex remains an equivocal topic in the continued development of SMFT design and application in team sport contexts, making their use for this particular purpose somewhat challenging.

5.2 Study Limitations

5.2.1 Recruitment, Sample Size and Missing Data

Given the exploratory nature of the study, it is important not to over-interpret findings and to acknowledge study limitations. It is not uncommon for team sport research to be characterised by small sample sizes (Halperin et al., 2018). Windows of opportunity to conduct testing batteries are often limited by the coordination of time available, the imbalance of athletes to test administrators and frequent last-minute changes to plans, reducing the scope to conduct high-quality data collection required for robust research outcomes (Malone et al., 2019; Weakley et al, 2022). As a result, whilst data were collected for 50 players in the overall study, some players could not complete the RPF scale due to an unscheduled team meeting taking place on the pitch immediately before the start of the testing session. This meeting meant that a shorter period than was planned was allocated to testing, resulting in any player who arrived late being unable to participate in this aspect of the session due to the time required to appropriately deliver instructions and complete the task.

Additionally, three players were removed as outliers from the final sample due to measurement error. Consequently, 36 players were included in the analysis of relationships and predictive qualities between perceived fitness, SMFT HRex and MAS, whilst 47 were included in the analysis between SMFT HRex and MAS. Lastly, all players involved in the study were recruited from a single club, potentially strengthening or weakening the relationships observed between variables through all the players being accustomed to similar training patterns and match schedules.

5.2.2 Equipment and Testing Errors

As previously mentioned, three players were removed as outliers from the final sample due to measurement error pertaining to HR traces. Despite all heart rate monitors being tested to ensure their complete working order before data collection for the study, two HR monitors malfunctioned during testing resulting in intermittent data loss and rendering their data unusable. Furthermore, a third player's data was also unusable due to the incorrect placement of their chest-worn HR monitor. Whilst most players were familiar with wearing the devices previously, and despite instruction regarding correct use provided at the start of the testing session, the strap became loose, and the unit was incorrectly positioned for a substantial period resulting in instances of complete data loss. Given large inter-individual responses in sports science research, outliers can substantially adversely affect the mean of data sets and impact correlation and regression models relatively easily (Atkinson and Batterham, 2015; Hopkins, 2015; Halperin et al., 2018). Therefore the removal of these cases was justified to ensure accurate analysis and reporting of results. Furthermore, given the exploratory nature of the study, scatter plots were specifically chosen as the most transparent way to accurately represent raw within-player dose-response relationships, as the approach is particularly appropriate for smaller samples (Halperin et al., 2018).

Regarding the collection of heart rate data, multiple factors were not controlled for due to the timing of the testing session. As previously reported, several factors are known to acutely affect HR indices, such as plasma volume changes from heat acclimatisation, moderate to high-intensity exercise in the preceding 24 hours, hydration status, caffeine intake, sickness, or long-haul travel impeding sleeping patterns (Achten and Jeukendrup, 2003; Buchheit, 2014; Buchheit et al., 2011; Schneider et al., 2018). Whilst typically, these acute effects are reversed within a few days, there were no controls in place to quantify or account for these effects. Given that testing also formed an extra part of the first day of pre-season, the squad testing schedule was especially congested and spread out throughout the day and into the evening. Therefore it was impracticable to ask players to refrain from or differently control their travel, sleeping, eating or drinking habits throughout the day.

As a result of the testing session being scheduled in the evening, it is also acknowledged that the daily stresses of life and increased apprehension from players wanting to make a good impression on the first day of the season may also have influenced responses during testing. Collecting true HRmax values from players was also unfeasible due to their congested pre-season training schedule. Consequently pred. HRmax was calculated using the equation for athletes by Tanaka et al., (2001) HRmax = 206 − (0.7 × age). However, it is acknowledged that predictive equations for HRmax derived from age are unlikely to reflect true HRmax through under and overestimating values; as a result, all pred. HRmax values were conservatively interpreted ± 10 $b \cdot min^{-1}$ (Nikolaidis, 2014).

5.2.3 Other Considerations

Most notably, the study utilised an all-male sample commonplace in sport science research (Mujika and Taipale, 2019; Cowley et al., 2021). Whilst the study originally planned to include a sample of both male and female players, factors out of the control of the researcher such as the global Covid-19 pandemic severely limited the scope of the study. Subsequently, safety, modified laboratory and field testing and research procedures, considerably impacted research productivity reducing access to in-person research and large numbers of participants (Stenson et al., 2022). Also, whilst Germain and Hausenblas (2006) report no differences in the relationship between perceived and actual fitness between sexes, recent studies have refuted this, indicating men overestimate their perceptions of fitness compared with women (Obling et al., 2015; Petersen et al., 2021). Given these findings, it would be of interest to assess the relative differences in perceived and actual aerobic capacity between equivalent-level male and female athletes and athletes in comparison to a control group of non-athletic participants. Additionally, during data collection the tests were conducted in the same order on the same day. Whilst the order of the tests was planned based on the functional use of SMFTs as part of a warm-up, ensuring players would receive the least carry-over effect and leaving ample time for rest between tests, it is also unknown if the order of the tests may have influenced the findings of the study.

Lastly, while strategies were employed to minimise or quantify the impact of contextual and environmental factors throughout data collection (e.g., response bias in subjective data, environmental conditions, etc.), the true influence of these factors is unknown. For example, the time taken to complete the RPF form was compared against the estimated silent reading time of the scale form as an estimative measure of time-on-task (e.g. comprehension of the form instructions and active engagement with the scale) in an attempt to identify reporting bias (McLaren, Coutts and Impellizzeri, 2022; Coventry et al., 2023). It is clear from the average completion times reported of 01:20 that largely players appropriately engaged with the scale, exceeding the estimated silent reading time of 1:01. However, it is evident from the range of completion times (00:25 – 03:42) that conscious reporting bias via deliberate deception for personal gain (e.g., to reduce the time spent on the task) and/or cognitive factors may have contributed to a level of misconception or comprehension of the construct under investigation (McLaren, Coutts and Impellizzeri, 2022). While this is acknowledged as a limitation, the study is therefore naturally representative of ecologically valid conditions, allowing interpretation of these findings as they would occur in an applied team sport environment. Further to this, a key strength of the current study was that the study design was appropriately and effectively employed to investigate the study aims, allowing for a sizable representative sample within a notoriously changeable and challenging period of the season to conduct any form of athlete testing (Weakley et al., 2022). Which was made possible via considered planning and consultation with performance staff responsible for the players involved in the study, allowing for greater player availability, involvement and buy-in (Halperin et al., 2018).

CHAPTER 6. CONCLUSIONS, DIRECTIONS FOR FUTURE RESEARCH AND PRACTICAL APPLICATIONS

6.1 Conclusion

In summary, this study found RPF to be the most strongly related to and strongest predictor of MAS measured using the 1.2SRT in high-performance rugby union players. This finding was also supported by differences in RPF, 1.2SRT total time and MAS consistent with positional group differences. Indicating subjective performance evaluations in team sports such as RPF may be a valuable tool for monitoring aerobic capacity through promising levels of content, face and construct domains of validity. SMFT HRex was also poorly related to or predictive of MAS measured using the 1.2SRT in high-performance rugby union players. Indicating that while some measures of aerobic fitness show good convergent validity with SMFT HRex, the 1.2SRT commonly used within rugby union does not follow this trend. Lastly, RPF was revealed to be poorly associated with or predictive of SMFT HRex as a measure of submaximal cardiovascular/aerobic fitness. Given the strong association and predictive qualities between RPF and MAS, further modification of the scale may provide more accurate representations of submaximal aerobic fitness in the future. Lastly, MAS measured using the 1.2SRT is not better predicted or associated with a combined RPF and SMFT HRex model compared to RPF alone.

6.2 Directions for Future Research

Future research in the use of athlete RPF should focus on longitudinal and test-retest studies to better understand the reliability (e.g., internal consistency, measurement error etc.) and sensitivity (responsiveness domain) of athlete perceptions of fitness. Providing a greater understanding of the practical utility of athlete RPF in raising athlete awareness of physical performance capacity, identification of changes over time and closer estimation of objective measures such as MAS. Though, physiological measurements are always subject to random within-athlete variation (Atkinson and Batterham, 2015; Hopkins, 2015). Therefore, the inability to distinguish true changes in physiological capacity from biological fluctuation makes broader generalisations challenging when examining the dose-response nature of team sport training (McLaren et al., 2018b). Therefore, the sensitivity of RPF should be considered alongside quantifying typical error to appropriately assess individual responses (negative or positive training effects) in relation to the detection of acute and chronic training adaptations within- and between-athletes. Also, given that the current study was conducted during pre-season after a period of substantially reduced training load, where players may be at differing stages of fitness decay (e.g., undesirable reductions in physiological and anthropometric characteristics), factors such as baseline fitness and fatigue may further influence responses (Gabbett and Domrow, 2007; Mujika, 2010). The collection of RPF at different periods of the season (e.g., pre-, mid-, and end-of-season) should also be investigated to understand if confounding factors may influence athlete perceptions throughout a season. A further route may be through anchoring normative data to respective steps in the scale (structural validity) to increase athlete understanding of the concept under investigation.

Additionally, given that the study observed a small negative relationship between RPF and HRex, it would be of interest to further assess the construct and face validity of submaximal aerobic fitness through a further item on the scale 'submaximal aerobic capacity'. Therefore improving the instruction (written and verbal), habituation and education around using the scale to increase athlete understanding and buy-in (McLaren, Coutts and Impellizzeri, 2022). Given that the findings of this study indicated a strong relationship between RPF and MAS, this opens new opportunities in this area, such as the assessment of any differences in perceived vs objectively measured aerobic capacity between equivalent-level male and female athletes and athletes in comparison to a control group of the wider non-athletic population (Obling et al., 2015; Petersen et al., 2021). Naturally, using the approach adopted in this study, it would be of interest to assess if athlete RPF in other sports (e.g., team vs individual sports) or other measures of athletic physical performance (e.g. speed, strength, power, COD etc.) commonly used in applied sport science share the same levels of association and predictive quality.

Regarding the associations with and predication of MAS from SFMT HRex, a greater understanding of the construct validity of the 1.2SRT in accurately estimating MAS is needed before moving to revalidation of the predictive qualities of these measures (Appendix 11). If the 1.2SRT cannot accurately estimate MAS or requires further correction in the assessment of rugby union players, it is unlikely any relationships or predictive qualities of proxy measures such as RPF or SMFT HRex will improve. Additionally, given a wide variety of SMFT practices (e.g. scheduling strategies; protocol characteristics; outcome measures, collection and analysis methods; inference approaches; and practitioner perceptions of the influence of extraneous factors) are currently in use across team sports, possibly due to a lack of strong evidence (Shushan et al., 2022; Shushan et al., 2023b). Further increasing research into the use of SMFT may help guide evidence-informed decisions regarding the routine implementation of SMFT in team sports and their application with other measures (Shushan et al., 2023b).

6.3 Practical Applications

- RPF for aerobic capacity show promising levels of content, face and construct domains of validity, with moderate predictive quality for MAS measured using the 1.2SRT in high-performing rugby union players. Whilst the RPF scale used in this study, in isolation, could be a practically useful monitoring tool in team sports, further work is needed to fully assess the structural validity, reliability (e.g., internal consistency, measurement error etc.) and sensitivity (responsiveness domain) to changes in athlete perceptions of fitness. The scale may also be useful in assisting players with understanding changes in their fitness on a more regular basis, in between performing more physiologically taxing testing protocols at specific points within the playing season.

- SMFT HR measures (e.g., HRex and HRR) show good convergent validity with some measures of aerobic fitness. However, this study demonstrates that the currently recommended SMFT protocol (shuttle-based, continuous-fixed, 4 min running at 12 $km \cdot h^{-1}$) is poorly associated with and not predictive of MAS in high-performing rugby union players when measured using the 1.2SRT. Therefore, in the measurement of within-player changes in MAS across the course of a training programme, judicious use of one specific test at particular points in a season may be more practically useful than the use of current SMFT protocols.

- RPF in its form derived from this study is not well related or predictive of proxy measures of submaximal cardiovascular/aerobic fitness such as SMFT HRex. However, with further modification to the scale (complying with accepted psychometric principles and best practice recommendations for collecting subjective data with athletes), this may be achievable in the future.

BIBLIOGRAPHY

Aandstad, A. (2021). Relationship between self-reported and objectively measured physical fitness in young men and women. *European Journal of Sport Science*, pp.1-9.

Abt, G., Jobson, S., Morin, J.B., Passfield, L., Sampaio, J., Sunderland, C. and Twist, C. (2022). Raising the bar in sports performance research. *Journal of Sports Sciences*, pp.1-5.

Achten, J. and Jeukendrup, A.E. (2003). Heart rate monitoring. *Sports medicine*, *33*(7), pp.517-538.

Arel-Bundock, V. (2022). modelsummary: Data and Model Summaries in R. *Journal of Statistical Software*, *103*, pp.1-23. https://doi.org/10.18637/jss.v103.i01.

Argus, C.K., Gill, N.D. and Keogh, J.W. (2012). Characterization of the differences in strength and power between different levels of competition in rugby union athletes. *The Journal of Strength & Conditioning Research*, *26*(10), pp.2698-2704.

Argus, C.K., Gill, N.D., Keogh, J.W., Hopkins, W.G. and Beaven, C.M. (2009). Changes in strength, power, and steroid hormones during a professional rugby union competition. *The Journal of Strength & Conditioning Research*, *23*(5), pp.1583-1592.

Ary, D., Jacobs, L.C., Irvine, C.K.S. and Walker, D. (2018). *Introduction to research in education*. Cengage Learning.

Atkinson, G. and Batterham, A.M. (2015). True and false interindividual differences in the physiological response to an intervention. *Experimental physiology*, *100*(6), pp.577-588.

Austin, D.J., Gabbett, T.J. and Jenkins, D.G. (2013). Reliability and sensitivity of a repeated high-intensity exercise performance test for rugby league and rugby union. *The Journal of Strength & Conditioning Research*, *27*(4), pp.1128-1135.

Baker, D. and Heaney, N. (2015). Review of the literature normative data for maximal aerobic speed for field sport athletes: a brief review. *Journal of Australian Strength and Conditioning*, *23*(7), pp.60-67.

Balagué, N., Hristovski, R., Almarcha, M.D.C., Garcia-Retortillo, S. and Ivanov, P.C. (2020). Network physiology of exercise: Vision and perspectives. *Frontiers in Physiology*, p.1607.

Bangsbo, J., Iaia, F.M. and Krustrup, P. (2008). The Yo-Yo intermittent recovery test: a useful tool for evaluation of physical performance in intermittent sports. *Sports medicine*, *38*, pp.37-51.

Barr, M.J., Sheppard, J.M., Gabbett, T.J. and Newton, R.U. (2014). Long-term training-induced changes in sprinting speed and sprint momentum in elite rugby union players. *The Journal of Strength & Conditioning Research*, *28*(10), pp.2724-2731.

Barris, S. and Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine*, *38*(12), pp.1025-1043.

Barroga, E. and Matanguihan, G.J. (2021). Creating logical flow when writing scientific articles. *Journal of Korean medical science*, *36*(40).

Batterham, A.M. and Hopkins, W.G. (2006). Making meaningful inferences about magnitudes. *International journal of sports physiology and performance*, *1*(1), pp.50-57.

Bellenger, C.R., Fuller, J.T., Nelson, M.J., Hartland, M., Buckley, J.D. and Debenedictis, T.A. (2015). Predicting maximal aerobic speed through set distance time-trials. *European journal of applied physiology*, *115*(12), pp.2593-2598.

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL, USA: Human kinetics.

Borg, G., Skinner, J.S. and Bar-Or, O. (1972). *Self-Appraisal of Physical Performance Capacity*. Reports from the Institute of Applied Psychology, The University of Stockholm, No. 32.

Brazier, J., Antrobus, M., Stebbings, G.K., Day, S.H., Callus, P., Erskine, R.M., Bennett, M.A., Kilduff, L.P. and Williams, A.G. (2020). Anthropometric and physiological characteristics of elite male rugby athletes. *The Journal of Strength & Conditioning Research*, *34*(6), pp.1790-1801.

Brew, D.J. and Kelly, V.G. (2014). The reliability of the 1.2 km shuttle run test for intermittent sport athletes. *Journal of Australian Strength and Conditioning*, *22*(5), pp.127-131.

Bridgeman, L.A. and Gill, N.D. (2021). The use of global positioning and accelerometer systems in age-grade and senior rugby union: a systematic review. *Sports Medicine-Open*, *7*(1), pp.1-34.

Brink, M.S., Nederhof, E., Visscher, C., Schmikli, S.L. and Lemmink, K.A. (2010). Monitoring load, recovery, and performance in young elite soccer players. *The Journal of Strength & Conditioning Research*, *24*(3), pp.597-603.

Brink, M.S., Visscher, C., Schmikli, S.L., Nederhof, E. and Lemmink, K.A. (2013). Is an elevated submaximal heart rate associated with psychomotor slowness in young elite soccer players?. *European journal of sport science*, *13*(2), pp.207-214.

Brooks, J.H. and Kemp, S.P. (2008). Recent trends in rugby union injuries. *Clinics in sports medicine*, *27*(1), pp.51-73.

Brysbaert, M. (2019). How many words do we read per minute? A review and meta-analysis of reading rate. *Journal of memory and language*, *109*, p.104047.

Buchheit, M. (2008). The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *The Journal of Strength & Conditioning Research*, *22*(2), pp.365-374.

Buchheit, M. (2010). The 30–15 intermittent fitness test: 10 year review. *Myorobie J*, *1*(9), p.278.

Buchheit, M. (2014). Monitoring training status with HR measures: do all roads lead to Rome?. *Frontiers in physiology*, *5*, p.73.

Buchheit, M. and Laursen, P.B. (2013a). High-intensity interval training, solutions to the programming puzzle. Part I: Cardiopulmonary Emphasis. *Sports medicine, 43*(10), pp.927-954.

Buchheit, M. and Laursen, P.B. (2013b). High-Intensity Interval Training, Solutions to the Programming Puzzle. Part II: Anaerobic Energy, Neuromuscular Load and Practical Applications. *Sports Medicine, 43*(10), p.927.

Buchheit, M. and Rabbani, A. (2014). The 30–15 intermittent fitness test versus the yo-yo intermittent recovery test level 1: relationship and sensitivity to training. *International journal of sports physiology and performance*, *9*(3), pp.522-524.

Buchheit, M., Al Haddad, H., Simpson, B.M., Palazzi, D., Bourdon, P.C., Di Salvo, V. and Mendez-Villanueva, A. (2014). Monitoring accelerations with GPS in football: time to slow down?. *International journal of sports physiology and performance*, *9*(3), pp.442-445.

Buchheit, M., Simpson, B.M. and Lacome, M. (2020). Monitoring cardiorespiratory fitness in professional soccer players: is it worth the prick?. *International Journal of Sports Physiology and Performance*, *15*(10), pp.1437-1441.

Buchheit, M., Simpson, B.M., Schmidt, W.F., Aughey, R.J., Soria, R., Hunt, R.A., Garvican-Lewis, L.A., Pyne, D.B., Gore, C.J. and Bourdon, P.C. (2013). Predicting sickness during a 2-week soccer camp at 3600 m (ISA3600). *British Journal of Sports Medicine*, *47*(Suppl 1), pp.i124-i127.

Buchheit, M., Simpson, M.B., Al Haddad, H., Bourdon, P.C. and Mendez-Villanueva, A. (2012). Monitoring changes in physical performance with heart rate measures in young soccer players. *European journal of applied physiology*, *112*, pp.711-723.

Buchheit, M., Voss, S.C., Nybo, L., Mohr, M. and Racinais, S. (2011). Physiological and performance adaptations to an in-season soccer camp in the heat: Associations with heart rate and heart rate variability. *Scandinavian journal of medicine & science in sports*, *21*(6), pp.e477-e485.

BUCS Super Rugby. (2022). *About*. Available at: https://www.bucs.org.uk/premier-sports/super-rugby/about.html (Accessed: 18/03/2022).

Cahill, N., Lamb, K., Worsfold, P., Headey, R. and Murray, S. (2013). The movement characteristics of English Premiership rugby union players. *Journal of Sports Sciences*, *31*(3), pp.229-237.

Carling, C., Lacome, M., McCall, A., Dupont, G., Le Gall, F., Simpson, B. and Buchheit, M. (2018). Monitoring of post-match fatigue in professional soccer: welcome to the real world. *Sports Medicine*, *48*, pp.2695-2702.

Chamari, K. and Padulo, J. (2015). 'Aerobic'and 'Anaerobic'terms used in exercise physiology: a critical terminology reflection. Sports Medicine-Open, 1(1), pp.1-4.

Chambers, R., Gabbett, T.J., Cole, M.H. and Beard, A. (2015). The use of wearable microsensors to quantify sport-specific movements. *Sports medicine*, *45*(7), pp.1065-1081.

Colomer, C.M., Pyne, D.B., Mooney, M., McKune, A. and Serpell, B.G. (2020). Performance analysis in rugby union: a critical systematic review. *Sports Medicine-Open*, *6*(1), pp.1-15.

Couderc, A., Gabbett, T.J., Piscione, J., Robineau, J., Peeters, A., Igarza, G., Thomas, C., Hanon, C. and Lacome, M. (2019). Repeated high-intensity effort activity in international male rugby sevens. *J Strength Cond Res*, *22*, p.22.

Coughlan, G.F., Green, B.S., Pook, P.T., Toolan, E. and O'Connor, S.P. (2011). Physical game demands in elite rugby union: a global positioning system analysis and possible implications for rehabilitation. *Journal of orthopaedic & sports physical therapy*, *41*(8), pp.600-605.

Coventry, M., Timler, A., Mosler, A.B., Russell, K., Travers, M., Oam, L.M. and Murphy, M.C. (2023). "I lied a little bit." A qualitative study exploring the perspectives of elite Australian athletes on self-reported data. *Physical Therapy in Sport*, *60*, pp.91-97.

Cowley, E.S., Olenick, A.A., McNulty, K.L. and Ross, E.Z. (2021). "Invisible sportswomen": the sex data gap in sport and exercise science research. *Women in Sport and Physical Activity Journal*, *29*(2), pp.146-151.

Crewther, B.T., Lowe, T.I.M., Weatherby, R.P., Gill, N. and Keogh, J. (2009). Neuromuscular performance of elite rugby union players and relationships with salivary hormones. *The Journal of Strength & Conditioning Research*, *23*(7), pp.2046-2053.

Cross, M.J., Williams, S., Trewartha, G., Kemp, S.P. and Stokes, K.A. (2016). The influence of in-season training loads on injury risk in professional rugby union. *International journal of sports physiology and performance*, *11*(3), pp.350-355.

Cross, M.R., Brughelli, M., Brown, S.R., Samozino, P., Gill, N.D., Cronin, J.B. and Morin, J.B. (2015). Mechanical properties of sprinting in elite rugby union and rugby league. *International Journal of Sports Physiology and Performance*, *10*(6), pp.695-702.

Cummins, C., Orr, R., O'Connor, H. and West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports medicine*, *43*(10), pp.1025-1042.

Cunniffe, B., Hore, A.J., Whitcombe, D.M., Jones, K.P., Baker, J.S. and Davies, B. (2010). Time course of changes in immuneoendocrine markers following an international rugby game. *European journal of applied physiology*, *108*(1), pp.113-122.

Cunniffe, B., Proctor, W., Baker, J.S. and Davies, B. (2009). An evaluation of the physiological demands of elite rugby union using global positioning system tracking software. *The Journal of Strength & Conditioning Research*, *23*(4), pp.1195-1203.

Cunningham, D., Shearer, D.A., Drawer, S., Eager, R., Taylor, N., Cook, C. and Kilduff, L.P. (2016b). Movement demands of elite U20 international rugby union players. *PloS one*, *11*(4), p.e0153275.

Cunningham, D.J., Shearer, D.A., Carter, N., Drawer, S., Pollard, B., Bennett, M., Eager, R., Cook, C.J., Farrell, J., Russell, M. and Kilduff, L.P. (2018a). Assessing worst case scenarios in movement demands derived from global positioning systems during international rugby union matches: Rolling averages versus fixed length epochs. *PloS one*, *13*(4), p.e0195197.

Cunningham, D.J., Shearer, D.A., Drawer, S., Pollard, B., Cook, C.J., Bennett, M., Russell, M. and Kilduff, L.P. (2018b). Relationships between physical qualities and key performance indicators during match-play in senior international rugby union players. *PLoS One*, *13*(9), p.e0202811.

Cunningham, D.J., Shearer, D.A., Drawer, S., Pollard, B., Eager, R., Taylor, N., Cook, C.J. and Kilduff, L.P. (2016a). Movement demands of elite under-20s and senior international rugby union players. *PloS one*, *11*(11), p.e0164990.

Currell, K. and Jeukendrup, A.E. (2008). Validity, reliability and sensitivity of measures of sporting performance. *Sports medicine*, *38*(4), pp.297-316.

Darrall-Jones, J., Roe, G., Cremen, E. and Jones, B. (2022). Can Team-Sport Athletes Accurately Run at Submaximal Sprinting Speeds? Implications for Rehabilitation and Warm-Up Protocols. *Journal of Strength and Conditioning Research*, *36*(8), pp.2218-2222.

Darrall-Jones, J.D., Jones, B. and Till, K. (2016). Anthropometric, sprint, and high-intensity running profiles of English academy rugby union players by position. *The Journal of Strength & Conditioning Research*, *30*(5), pp.1348-1358.

Davison, R.C.R., Smith, P.M., Hopker, J., Price, M.J., Hettinga, F., Tew, G., & Bottoms, L. (2022). Sport and Exercise Physiology Testing Guidelines: Volume I – Sport Testing: The British Association of Sport and Exercise Sciences Guide. (5th ed.). London: Routledge.

de Freitas, V.H., Pereira, L.A., de Souza, E.A., Leicht, A.S., Bertollo, M. and Nakamura, F.Y. (2015). Sensitivity of the Yo-Yo Intermittent Recovery Test and cardiac autonomic responses to training in futsal players. *International Journal of Sports Physiology and Performance*, *10*(5), pp.553-558.

Delaney, J.A., Thornton, H.R., Pryor, J.F., Stewart, A.M., Dascombe, B.J. and Duthie, G.M., (2017). Peak running intensity of international rugby: implications for training prescription. *International journal of sports physiology and performance*, *12*(8), pp.1039-1045.

Dello Iacono, A., Beato, M. and Unnithan, V. (2021). Comparative effects of game profile–based training and small-sided games on physical performance of elite young soccer players. *Journal of strength and conditioning research*, *35*(10), pp.2810-2817.

Deuchrass, R., Smith, H.K., Elliot, C., Lizamore, C. and Hamlin, M.J. (2019). The 1.2 km shuttle run test: Reliability and comparison with the Yo-Yo intermittent recovery level 1 test in young elite rugby union players.

Deutsch, M.U., Kearney, G.A. and Rehrer, N.J. (2007). Time–motion analysis of professional rugby union players during match-play. *Journal of sports sciences*, *25*(4), pp.461-472.

Dobbin, N., Moss, S.L., Highton, J. and Twist, C. (2018). An examination of a modified Yo-Yo test to measure intermittent running performance in rugby players. *European Journal of Sport Science*, *18*(8), pp.1068-1076.

Dubois, R., Paillard, T., Lyons, M., McGrath, D., Maurelli, O. and Prioux, J. (2017). Running and metabolic demands of elite rugby union assessed using traditional, metabolic power, and heart rate monitoring methods. *Journal of sports science & medicine*, *16*(1), p.84.

Dupont, G., Defontaine, M., Bosquet, L., Blondel, N., Moalla, W. and Berthoin, S. (2010). Yo-Yo intermittent recovery test versus the Universite de Montreal Track Test: relation with a high-intensity intermittent exercise. *Journal of science and Medicine in Sport*, *13*(1), pp.146-150.

Duthie, G., Pyne, D. and Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports medicine*, *33*(13), pp.973-991.

Eaves, S. and Hughes, M. (2003). Patterns of play of international rugby union teams before and after the introduction of professional status. *International journal of performance analysis in sport*, *3*(2), pp.103-111.

Fanchini, M., Castagna, C., Coutts, A.J., Schena, F., McCall, A. and Impellizzeri, F.M. (2014). Are the Yo-Yo intermittent recovery test levels 1 and 2 both useful? Reliability, responsiveness and interchangeability in young soccer players. *Journal of sports sciences*, *32*(20), pp.1950-1957.

Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., Doleshal, P. and Dodge, C. (2001). A new approach to monitoring exercise training. *The Journal of Strength & Conditioning Research*, *15*(1), pp.109-115.

Freitas, T.T., Alcaraz, P.E., Bishop, C., Calleja-González, J., Arruda, A.F., Guerriero, A., Reis, V.P., Pereira, L.A. and Loturco, I. (2018). Change of direction deficit in national team rugby union players: Is there an influence of playing position?. *Sports*, *7*(1), p.2.

Fuller, C.W. (2018). Injury risk (burden), risk matrices and risk contours in team sports: a review of principles, practices and problems. *Sports medicine*, *48*(7), pp.1597-1606.

Gabbett, T.J. (2016). The training—injury prevention paradox: should athletes be training smarter and harder?. *British journal of sports medicine*, *50*(5), pp.273-280.

Gabbett, T.J. and Domrow, N. (2007). Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *Journal of sports sciences*, *25*(13), pp.1507-1519.

Gabbett, T.J. and Gahan, C.W. (2016). Repeated High-Intensity-Effort Activity in Relation to Tries Scored and Conceded During Rugby League Match Play. *International Journal of Sports Physiology & Performance*, *11*(4).

Gabbett, T.J. and Seibold, A.J. (2013). Relationship between tests of physical qualities, team selection, and physical match performance in semiprofessional rugby league players. *The Journal of Strength & Conditioning Research*, *27*(12), pp.3259-3265.

Garrett, J., Akyildiz, Z., Leduc, C., van den Hoek, D., Manuel Clemente, F. and Ardigò, L.P. (2021). Peak running speed can be used to monitor neuromuscular fatigue from a standardized running test in team sport athletes. *Research in Sports Medicine*, pp.1-12.

Garrett, J., Graham, S.R., Eston, R.G., Burgess, D.J., Garrett, L.J., Jakeman, J. and Norton, K. (2019). A novel method of assessment for monitoring neuromuscular fatigue in Australian rules football players. *International journal of sports physiology and performance*, *14*(5), pp.598-605.

Germain, J.L. and Hausenblas, H.A. (2006). The relationship between perceived and actual physical fitness: a meta-analysis. *Journal of Applied Sport Psychology*, *18*(4), pp.283-296.

Gratton, C. and Jones, I. (2014). *Research methods for sports studies*. Routledge.

Green, A., Kerr, S., Olivier, B., Meiring, R., Dafkin, C. and McKinon, W. (2017). A simulated rugby match protocol induces physiological fatigue without decreased individual scrummaging performance. *South African Journal of Sports Medicine*, *29*(1).

Green, B.S., Blake, C. and Caulfield, B.M. (2011). A valid field test protocol of linear speed and agility in rugby union. *The Journal of Strength & Conditioning Research*, *25*(5), pp.1256-1262.

Halperin, I., Vigotsky, A.D., Foster, C. and Pyne, D.B. (2018). Strengthening the practice of exercise and sport-science research. *International journal of sports physiology and performance*, *13*(2), pp.127-134.

Hamlin, M.J., Deuchrass, R., Smith, H., Elliot, C. and Lizamore, C. (2019). Reliability of the 1.2 km shuttle run test in young elite rugby union players.

Hansen, K.T., Cronin, J.B., Pickering, S.L. and Douglas, L. (2011). Do force–time and power–time measures in a loaded jump squat differentiate between speed performance and playing level in elite and elite junior rugby union players?. *The Journal of Strength & Conditioning Research*, *25*(9), pp.2382-2391.

Harper, D.J., Carling, C. and Kiely, J. (2019). High-intensity acceleration and deceleration demands in elite team sports competitive match play: a systematic review and meta-analysis of observational studies. *Sports Medicine*, *49*(12), pp.1923-1947.

Haugen, T. and Buchheit, M. (2016). Sprint running performance monitoring: methodological and practical considerations. *Sports Medicine*, *46*(5), pp.641-656.

Hebbali, A. (2020). *Olsrr: Tools for Building OLS Regression Models*. https://CRAN.R-project.org/package=olsrr.

Hendricks, S., Karpul, D. and Lambert, M. (2014). Momentum and kinetic energy before the tackle in rugby union. *Journal of sports science & medicine*, *13*(3), p.557.

Hinrichs, T., Franke, J., Voss, S., Bloch, W., Schänzer, W. and Platen, P. (2010). Total hemoglobin mass, iron status, and endurance capacity in elite field hockey players. *The Journal of Strength & Conditioning Research*, *24*(3), pp.629-638.

Hopkins, W.G. (2015). Individual responses made easy. *Journal of applied physiology*, *118*(12), pp.1444-1446.

Hopkins, W.G., Marshall, S.W., Batterham, A.M. and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), pp.3-13.

Howe, S.T., Aughey, R.J., Hopkins, W.G., Cavanagh, B.P. and Stewart, A.M. (2020). Sensitivity, reliability and construct validity of GPS and accelerometers for quantifying peak periods of rugby competition. *Plos one*, *15*(7), p.e0236024.

Hudson, J.F., Cole, M., Morton, J.P., Stewart, C.E. and Close, G.L. (2019). Daily changes of resting metabolic rate in elite rugby union players. *Medicine & Science in Sports & Exercise*, *52*(3), pp.637-644.

Hughes, A., Barnes, A., Churchill, S.M. and Stone, J.A. (2017). Performance indicators that discriminate winning and losing in elite men's and women's Rugby Union. *International Journal of Performance Analysis in Sport*, *17*(4), pp.534-544.

Hulin, B.T., Gabbett, T.J., Johnston, R.D. and Jenkins, D.G. (2019). Sub-maximal heart rate is associated with changes in high-intensity intermittent running ability in professional rugby league players. Science and Medicine in Football, 3(1), pp.50-56.

Impellizzeri, F.M. and Marcora, S.M. (2009). Test validation in sport physiology: lessons learned from clinimetrics. *International journal of sports physiology and performance*, *4*(2), pp.269-277.

Impellizzeri, F.M., Menaspà, P., Coutts, A.J., Kalkhoven, J. and Menaspà, M.J. (2020). Training load and its role in injury prevention, part I: back to the future. *Journal of athletic training*, *55*(9), pp.885-892.

Impellizzeri, F.M., Rampinini, E. and Marcora, S.M. (2005). Physiological assessment of aerobic training in soccer. *Journal of sports sciences*, *23*(6), pp.583-592.

Impellizzeri, F.M., Rampinini, E., Coutts, A.J., Sassi, A.L.D.O. and Marcora, S.M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in sports & exercise*, *36*(6), pp.1042-1047.

James, N., Mellalieu, S. and Jones, N. (2005). The development of position-specific performance indicators in professional rugby union. *Journal of sports sciences*, *23*(1), pp.63-72.

Jeffries, A.C., Marcora, S.M., Coutts, A.J., Wallace, L., McCall, A. and Impellizzeri, F.M. (2021). Development of a revised conceptual framework of physical training for use in research and practice. *Sports Medicine*, pp.1-16.

Jeffries, A.C., Wallace, L., Coutts, A.J., McLaren, S.J., McCall, A. and Impellizzeri, F.M. (2020). Athlete-reported outcome measures for monitoring training responses: a systematic review of risk of bias and measurement property quality according to the COSMIN guidelines. *International journal of sports physiology and performance*, *15*(9), pp.1203-1215.

Jennings, D., Cormack, S., Coutts, A.J., Boyd, L. and Aughey, R.J. (2010). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International journal of sports physiology and performance*, *5*(3), pp.328-341.

Johnston, R.D., Gabbett, T.J. and Jenkins, D.G. (2015). Influence of playing standard and physical fitness on activity profiles and post-match fatigue during intensified junior rugby league competition. *Sports medicine-open*, *1*(1), pp.1-10.

Johnston, R.D., Gabbett, T.J., Walker, S., Walker, B. and Jenkins, D.G. (2015). Are three contact efforts really reflective of a repeated high-intensity effort bout?. *The Journal of Strength & Conditioning Research*, *29*(3), pp.816-821.

Johnston, R.J., Watsford, M.L., Pine, M.J., Spurrs, R.W., Murphy, A.J. and Pruyn, E.C. (2012). The validity and reliability of 5-Hz global positioning system units to measure team sport movement demands. *The Journal of Strength & Conditioning Research*, *26*(3), pp.758-765.

Jokuschies, N., Gut, V. and Conzelmann, A. (2017). Systematizing coaches'‘eye for talent': Player assessments based on expert coaches' subjective talent criteria in top-level youth soccer. *International Journal of Sports Science & Coaching*, *12*(5), pp.565-576.

Jones, I. (2022). *Research methods for sports studies*. Oxford: Routledge.

Jones, M.R., West, D.J., Crewther, B.T., Cook, C.J. and Kilduff, L.P. (2015). Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. *European journal of sport science*, *15*(6), pp.488-496.

Jones, M.R., West, D.J., Harrington, B.J., Cook, C.J., Bracken, R.M., Shearer, D.A. and Kilduff, L.P. (2014). Match play performance characteristics that predict post-match creatine kinase responses in professional rugby union players. *BMC sports science, medicine and rehabilitation*, *6*(1), pp.1-7.

Kalkhoven, J.T., Watsford, M.L. and Impellizzeri, F.M. (2020). A conceptual model and detailed framework for stress-related, strain-related, and overuse athletic injury. *Journal of science and medicine in sport*, *23*(8), pp.726-734.

Keith, N.R., Stump, T.E. and Clark, D.O. (2012). Developing a self-reported physical fitness survey. *Medicine and science in sports and exercise*, *44*(7), p.1388.

Kelly, V. and Wood, A. (2013). The correlation between the 30-15 intermittent fitness test and a novel test of running performance. *Journal of Australian Strength and Conditioning*, *21*(S1), pp.91-94.

Kelly, V., Jackson, E. and Wood, A. (2014). Typical scores from the 1.2 km shuttle run test to determine maximal aerobic speed. *Journal of Australian Strength and Conditioning*, *22*(5), pp.183-185.

Krabbe, P. (2016). *The measurement of health and health status: concepts, methods and applications from a multidisciplinary perspective*. (1st ed). Academic Press. Amsterdam: Elsevier

Lacome, M., Piscione, J., Hager, J.P. and Carling, C. (2017). Fluctuations in running and skill-related performance in elite rugby union match-play. *European journal of sport science*, *17*(2), pp.132-143.

Lacome, M., Simpson, B. and Buchheit, M. (2018). Monitoring training status with player-tracking technology. *Still on the way to Rome. Aspetar. J*, *7*, pp.55-63.

Lamb, K.L. (1992). Correlates of self-perceived fitness. *Perceptual and motor skills*, *74*(3), pp.907-914.

Léger, L. and Boucher, R. (1980). An indirect continuous running multistage field test: the Université de Montréal track test. *Canadian Journal of Applied Sport sciences. Journal Canadien des Sciences Appliquees au Sport*, *5*(2), pp.77-84.

Lemmink, K.A.P.M., Visscher, C., Lambert, M.I. and Lamberts, R.P. (2004). The interval shuttle run test for intermittent sport players: evaluation of reliability. *Journal of Strength and Conditioning Research*, *18*, pp.821-827.

Lombard, W.P., Durandt, J.J., Masimla, H., Green, M. and Lambert, M.I. (2015). Changes in body size and physical characteristics of South African under-20 rugby union players over a 13-year period. *The Journal of Strength & Conditioning Research*, *29*(4), pp.980-988.

Loturco, I., Nimphius, S., Kobal, R., Bottino, A., Zanetti, V., Pereira, L.A. and Jeffreys, I. (2018). Change-of direction deficit in elite young soccer players. *German Journal of Exercise and Sport Research*, *48*(2), pp.228-234.

MacLeod, S.J., Hagan, C., Egaña, M., Davis, J. and Drake, D. (2018). The use of microtechnology to monitor collision performance in professional rugby union. *International journal of sports physiology and performance*, *13*(8), pp.1075-1082.

MacQueen, A.E. and Dexter, W.W. (2010). Injury trends and prevention in rugby union football. *Current sports medicine reports*, *9*(3), pp.139-143.

Malone, J.J., Harper, L.D., Jones, B., Perry, J., Barnes, C. and Towlson, C. (2019). Perspectives of applied collaborative sport science research within professional team sports. European journal of sport science, 19(2), pp.147-155.

Mann, T., Lamberts, R.P. and Lambert, M.I. (2013). Methods of prescribing relative exercise intensity: physiological and practical considerations. *Sports medicine*, *43*, pp.613-625.

Mátrai, K.N.Z. (2016). Subjective and objective indicators in the research on health status. *Journal of Human Sport and Exercise*, *11*(1), pp.S207-S217.

McKay, A.K., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., Sheppard, J. and Burke, L.M. (2022). Defining Training and Performance Caliber: A Participant Classification Framework. *International journal of sports physiology and performance*, *17*(2), pp.317-331.

McLaren, S., Coutts, A. and Impellizzeri, F.M. (2022). Perception of effort and subjective monitoring. In French, D., Ronda, L.T., (eds) *NSCA's essentials of sport science*. Champaign, IL, USA: Human Kinetics., p. 231–54.

McLaren, S.J., Graham, M., Spears, I. and Weston, M. (2015). The sensitivity of differential ratings of perceived exertion as measures of internal load. *International Journal of Sports Physiology and Performance*, *11*(3), pp.404-406.

McLaren, S.J., Macpherson, T.W., Coutts, A.J., Hurst, C., Spears, I.R. and Weston, M. (2018a). The relationships between internal and external measures of training load and intensity in team sports: a meta-analysis. *Sports medicine*, *48*(3), pp.641-658.

McLaren, S.J., Smith, A., Bartlett, J.D., Spears, I.R. and Weston, M. (2018b). Differential training loads and individual fitness responses to pre-season in professional rugby union players. *Journal of sports sciences*, *36*(21), pp.2438-2446.

McLaren, S.J., Weston, M., Smith, A., Cramb, R. and Portas, M.D. (2016). Variability of physical performance and player match loads in professional rugby union. *Journal of Science and Medicine in Sport*, *19*(6), pp.493-497.

McLean, D.A. (1992). Analysis of the physical demands of international rugby union. *Journal of sports sciences*, *10*(3), pp.285-296.

McLellan, C.P., Coad, S., Marsh, D. and Lieschke, M. (2013). Performance analysis of super 15 rugby match-play using portable micro-technology. *J Athl Enhancement*, *2*(5), p.1000125.

McLellan, C.P., Lovell, D.I. and Gass, G.C. (2011). Performance analysis of elite rugby league match play using global positioning systems. *The Journal of Strength & Conditioning Research*, *25*(6), pp.1703-1710.

McNamee, M. (2004). Philosophy and the sciences of exercise, health and sport: Critical perspectives on research methods. London: Routledge.

Mohr, M. and Krustrup, P. (2014). Yo-Yo intermittent recovery test performances within an entire football league during a full season. *Journal of sports sciences*, *32*(4), pp.315-327.

Mokkink, L.B., Prinsen, C.A., Bouter, L.M., de Vet, H.C. and Terwee, C.B. (2016). The COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) and how to select an outcome measurement instrument. *Brazilian journal of physical therapy*, *20*, pp.105-113.

Montull, L., Slapšinskaitė-Dackevičienė, A., Kiely, J., Hristovski, R. and Balagué, N. (2022). Integrative Proposals of Sports Monitoring: Subjective Outperforms Objective Monitoring. *Sports Medicine-Open*, *8*(1), pp.1-10.

Mujika, I. (2010). Intense training: the key to optimal performance before and during the taper. *Scandinavian journal of medicine & science in sports*, *20*, pp.24-31.

Mujika, I. and Taipale, R.S. (2019). Sport science on women, women in sport science. *International journal of sports physiology and performance*, *14*(8), pp.1013-1014.

Nicholas, C.W. (1997). Anthropometric and physiological characteristics of rugby union football players. *Sports Medicine*, *23*(6), pp.375-396.

Nikolaidis, P.T. (2014). Age-predicted vs. measured maximal heart rate in young team sport athletes. *Nigerian medical journal: journal of the Nigeria Medical Association*, *55*(4), p.314.

Obling, K.H., Hansen, A.L.S., Overgaard, K., Normann, K., Sandbaek, A. and Maindal, H.T. (2015). Association between self-reported and objectively measured physical fitness level in a middle-aged population in primary care. *Preventive medicine reports*, *2*, pp.462-466.

Ooms, J. (2023). *Writexl: Export Data Frames to Excel 'Xlsx' Format*. https://CRAN.R-project.org/package=writexl.

Ortega, E., Villarejo, D. and Palao, J.M. (2009). Differences in game statistics between winning and losing rugby teams in the Six Nations Tournament. *Journal of sports science & medicine*, *8*(4), p.523.

Owen, A.L., Newton, M., Shovlin, A. and Malone, S. (2020b). The use of small-sided games as an aerobic fitness assessment supplement within elite level professional soccer. *Journal of Human Kinetics*, *71*, p.243.

Owen, C., Till, K., Weakley, J. and Jones, B. (2020a). Testing methods and physical qualities of male age grade rugby union players: A systematic review. *PLoS One*, *15*(6), p.e0233796.

Paradisis, G.P., Zacharogiannis, E., Mandila, D., Smirtiotou, A., Argeitaki, P. and Cooke, C.B. (2014). Multi-stage 20-m shuttle run fitness test, maximal oxygen uptake and velocity at maximal oxygen uptake. *Journal of human kinetics*, *41*, p.81.

Paul, L., Naughton, M., Jones, B., Davidow, D., Patel, A., Lambert, M. and Hendricks, S. (2022). Quantifying Collision Frequency and Intensity in Rugby Union and Rugby Sevens: A Systematic Review. *Sports medicine-open*, *8*(1), pp.1-38.

Pedersen, T.L. (2022). *Patchwork: The Composer of Plots*. https://CRAN.R-project.org/package=patchwork.

Petersen, C.B., Eriksen, L., Dahl-Petersen, I.K., Aadahl, M. and Tolstrup, J.S. (2021). Self-rated physical fitness and measured cardiorespiratory fitness, muscular strength, and body composition. *Scandinavian journal of medicine & science in sports*, *31*(5), pp.1086-1095.

Peterson, K.D. and Caldwell, A.R. (2019). mbir: magnitude-based inferences. *Journal of Open Source Software*, *4*(33), p.746. https://doi.org/10.21105/joss.00746.

Petrovic, A., Koprivica, V. and Bokan, B. (2017). Quantitative, qualitative and mixed research in sport science: a methodological report. *South African Journal for Research in Sport, Physical Education and Recreation*, *39*(2), pp.181-197.

Pisk, J. (2014). Sport science: ontological and methodological considerations. *Physical Culture and Sport. Studies and Research, 61*(1), pp.5-14.

Pollard, B.T., Turner, A.N., Eager, R., Cunningham, D.J., Cook, C.J., Hogben, P. and Kilduff, L.P. (2018). The ball in play demands of international rugby union. *Journal of science and medicine in sport*, *21*(10), pp.1090-1094.

Posit team. (2023). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. URL http://www.posit.co/.

Posthumus, L., Macgregor, C., Winwood, P., Darry, K., Driller, M. and Gill, N. (2020). Physical and fitness characteristics of elite professional rugby union players. *Sports*, *8*(6), p.85.

Quarrie, K.L. and Williams, S. (2001). Factors Associated with Pre-Season Fitness Attributes Of Rugby Players. *Science and football IV*, p.89.

Quarrie, K.L., Hopkins, W.G., Anthony, M.J. and Gill, N.D. (2013). Positional demands of international rugby union: evaluation of player actions and movements. *Journal of Science and Medicine in Sport*, *16*(4), pp.353-359.

Quarrie, K.L., Raftery, M., Blackie, J., Cook, C.J., Fuller, C.W., Gabbett, T.J., Gray, A.J., Gill, N., Hennessy, L., Kemp, S. and Lambert, M. (2017). Managing player load in professional rugby union: a review of current knowledge and practices. *British Journal of Sports Medicine*, *51*(5), pp.421-427.

R Core Team. (2022). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Rabbani, A., Kargarfard, M. and Twist, C. (2018). Reliability and validity of a submaximal warm-up test for monitoring training status in professional soccer players. *The Journal of Strength & Conditioning Research*, *32*(2), pp.326-333.

Randers, M.B., Mujika, I., Hewitt, A., Santisteban, J., Bischoff, R., Solano, R., Zubillaga, A., Peltola, E., Krustrup, P. and Mohr, M. (2010). Application of four different football match analysis systems: A comparative study. *Journal of sports sciences*, *28*(2), pp.171-182.

Read, D., Weaving, D., Phibbs, P., Darrall-Jones, J., Roe, G., Weakley, J., Hendricks, S., Till, K. and Jones, B. (2017). Movement and physical demands of school and university rugby union match-play in England. *BMJ open sport & exercise medicine*, *2*(1), p.e000147.

Read, D.B., Till, K., Beasley, G., Clarkson, M., Heyworth, R., Lee, J., Weakley, J.J., Phibbs, P.J., Roe, G.A., Darrall-Jones, J. and Jones, B. (2019). Maximum running intensities during English academy rugby union match-play. *Science and Medicine in Football*, *3*(1), pp.43-49.

Reardon, C., Tobin, D.P. and Delahunt, E. (2015). Application of individualised speed thresholds to interpret position specific running demands in elite professional rugby union: a GPS study. *PloS one*, *10*(7), p.e0133410.

Reardon, C., Tobin, D.P., Tierney, P. and Delahunt, E. (2017a). The worst case scenario: Locomotor and collision demands of the longest periods of gameplay in professional rugby union. *PLoS one*, *12*(5), p.e0177072.

Reardon, C., Tobin, D.P., Tierney, P. and Delahunt, E. (2017b). Collision count in rugby union: a comparison of micro-technology and video analysis methods. *Journal of sports sciences*, *35*(20), pp.2028-2034.

Reilly, T. (1997). The physiology of rugby union football. *Biology of Sport*, *14*(2), pp.83-101.

Roberts, S.P., Trewartha, G., Higgitt, R.J., El-Abd, J. and Stokes, K.A. (2008). The physical demands of elite English rugby union. *Journal of sports sciences*, *26*(8), pp.825-833.

Rodríguez-Sánchez, F., Connor P.J. and Shaurita D.H. (2022). *Grateful: Facilitate Citation of r Packages*. https://github.com/Pakillo/grateful.

Ross, A., Gill, N., Cronin, J. and Malcata, R. (2015). The relationship between physical characteristics and match performance in rugby sevens. *European journal of sport science*, *15*(6), pp.565-571.

Rowell, A.E., Aughey, R.J., Clubb, J. and Cormack, S.J. (2018). A standardized small sided game can be used to monitor neuromuscular fatigue in professional A-league football players. *Frontiers in physiology*, *9*, p.1011.

Sandford, G.N., Allen, S.V., Kilding, A.E., Ross, A. and Laursen, P.B. (2019). Anaerobic speed reserve: a key component of elite male 800-m running. *International journal of sports physiology and performance*, *14*(4), pp.501-508.

Sandford, G.N., Laursen, P.B. and Buchheit, M. (2021). Anaerobic Speed/Power Reserve and Sport Performance: Scientific Basis, Current Applications and Future Directions. *Sports Medicine*, *51*(10), pp.2017-2028.

Saw, A.E., Main, L.C. and Gastin, P.B. (2016). Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *British journal of sports medicine*, *50*(5), pp.281-291.

Schneider, C., Hanakam, F., Wiewelhove, T., Döweling, A., Kellmann, M., Meyer, T., Pfeiffer, M. and Ferrauti, A. (2018). Heart rate monitoring in team sports—a conceptual framework for contextualizing heart rate measures for training and recovery prescription. *Frontiers in physiology*, p.639.

Schwellnus, M.P., Thomson, A., Derman, W., Jordaan, E., Readhead, C., Collins, R., Morris, I., Van der Linde, E. and Williams, A. (2014). More than 50% of players sustained a time-loss injury (> 1 day of lost training or playing time) during the 2012 Super Rugby Union Tournament: a prospective cohort study of 17 340 player-hours. *British journal of sports medicine*, *48*(17), pp.1306-1315.

Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English language teaching*, *5*(9), pp.9-16.

Scott, A.C., Roe, N., Coats, A.J. and Piepoli, M.F. (2003). Aerobic exercise physiology in a professional rugby union team. *International journal of cardiology*, *87*(2-3), pp.173-177.

Scott, T.J., McLaren, S.J., Caia, J. and Kelly, V.G. (2018). The reliability and usefulness of an individualised submaximal shuttle run test in elite rugby league players. *Science and Medicine in Football*, *2*(3), pp.184-190.

Scott, T.J., McLaren, S.J., Lovell, R., Scott, M.T. and Barrett, S. (2022). The reliability, validity and sensitivity of an individualised sub-maximal fitness test in elite rugby league athletes. *Journal of Sports Sciences*, *40*(8), pp.840-852.

Sheehan, A., Malone, S., Walters, A., Gabbett, T. and Collins, K. (2022). Match-play profile of elite rugby union, with special reference to repeated high-intensity effort activity (RHIE). *Sport Sciences for Health*, pp.1-10.

Shushan, T., Lovell, R., Buchheit, M., Scott, T.J., Barrett, S., Norris, D. and McLaren, S.J. (2023a). Submaximal Fitness Test in Team Sports: A Systematic Review and Meta-Analysis of Exercise Heart Rate Measurement Properties. *Sports Medicine-Open*, *9*(1), p.21.

Shushan, T., McLaren, S.J., Buchheit, M., Scott, T.J., Barrett, S. and Lovell, R. (2022). Submaximal fitness tests in team sports: a theoretical framework for evaluating physiological state. *Sports Medicine*, *52*(11), pp.2605-2626.

Shushan, T., Norris, D., McLaren, S.J., Buchheit, M., Scott, T.J., Barrett, S., Iacono, A.D. and Lovell, R. (2023b). A worldwide survey on the practices and perceptions of submaximal fitness tests in team sports. *International Journal of Sports Physiology and Performance*.

Smart, D., Hopkins, W.G., Quarrie, K.L. and Gill, N. (2014). The relationship between physical fitness and game behaviours in rugby union players. *European journal of sport science*, *14*(sup1), pp.S8-S17.

Smart, D.J., Hopkins, W.G. and Gill, N.D. (2013). Differences and changes in the physical characteristics of professional and amateur rugby union players. *The Journal of Strength & Conditioning Research*, *27*(11), pp.3033-3044.

Smith, M.F. (2010). *Research methods in sport.* Cornwall: Learning Matters.

Sparks, M. and Coetzee, B. (2013). The use of heart rates and graded maximal test values to determine rugby union game intensities. *The Journal of Strength & Conditioning Research*, *27*(2), pp.507-513.

Sporis, G., Jukic, I., Ostojic, S.M. and Milanovic, D. (2009). Fitness profiling in soccer: physical and physiologic characteristics of elite players. *The Journal of Strength & Conditioning Research*, *23*(7), pp.1947-1953.

Stenson, M.C., Fleming, J.K., Johnson, S.L., Caputo, J.L., Spillios, K.E. and Mel, A.E. (2022). Impact of COVID-19 on access to laboratories and human participants: exercise science faculty perspectives. *Advances in Physiology Education*, *46*(2), pp.211-218.

Swaby, R., Jones, P.A. and Comfort, P. (2016). Relationship between maximum aerobic speed performance and distance covered in rugby union games. *The Journal of Strength & Conditioning Research*, *30*(10), pp.2788-2793.

Tanaka, H., Monahan, K.D. and Seals, D.R. (2001). Age-predicted maximal heart rate revisited. *Journal of the american college of cardiology*, *37*(1), pp.153-156.

Taylor, J.B., Wright, A.A., Dischiavi, S.L., Townsend, M.A. and Marmon, A.R. (2017). Activity demands during multi-directional team sports: a systematic review. *Sports Medicine*, *47*(12), pp.2533-2551.

Tee, J.C. and Coopoo, Y. (2015). Movement and impact characteristics of South African professional rugby union players. *South African Journal of Sports Medicine*, *27*(2), pp.33-39.

Tee, J.C., Ashford, M. and Piggott, D. (2018). A tactical periodisation approach for rugby union. *Strength & Conditioning Journal*, *40*(5), pp.1-13.

Tee, J.C., Coopoo, Y. and Lambert, M. (2020). Pacing characteristics of whole and part-game players in professional rugby union. *European Journal of Sport Science*, *20*(6), pp.722-733.

Tee, J.C., Lambert, M.I. and Coopoo, Y. (2016). GPS comparison of training activities and game demands of professional rugby union. *International Journal of Sports Science & Coaching*, *11*(2), pp.200-211.

Tee, J.C., Lambert, M.I. and Coopoo, Y. (2017). Impact of fatigue on positional movements during professional rugby union match play. *International journal of sports physiology and performance*, *12*(4), pp.554-561.

Teece, A.R., Argus, C.K., Gill, N., Beaven, M., Dunican, I.C. and Driller, M.W. (2021). Sleep and performance during a preseason in elite rugby union athletes. *International journal of environmental research and public health*, *18*(9), p.4612.

The British Association of Sport and Exercise Sciences (BASES). (2021). *Code of Conduct.* Available at: https://www.bases.org.uk/imgs/code_of_conduct202.pdf (Accessed: 15/2/2022).

Thomas, J.R., Nelson, J.K. and Silverman, S.J. (2015). *Research methods in physical activity*. Human kinetics.

Thorpe, R.T., Atkinson, G., Drust, B. and Gregson, W. (2017). Monitoring Fatigue Status in Elite Team Sport Athletes: Implications for Practice. *International journal of sports physiology and performance*, *12*(2).

Thorpe, R.T., Strudwick, A.J., Buchheit, M., Atkinson, G., Drust, B. and Gregson, W. (2016). Tracking morning fatigue status across in-season training weeks in elite soccer players. *International journal of sports physiology and performance*, *11*(7), pp.947-952.

Thorpe, R.T., Strudwick, A.J., Buchheit, M., Atkinson, G., Drust, B. and Gregson, W. (2015). Monitoring fatigue during the in-season competitive phase in elite soccer players. *International journal of sports physiology and performance*, *10*(8), pp.958-964.

Tierney, P., Blake, C. and Delahunt, E. (2020). The relationship between collision metrics from micro-sensor technology and video-coded events in rugby union. *Scandinavian Journal of Medicine & Science in Sports*, *30*(11), pp.2193-2204.

Tierney, P., Blake, C. and Delahunt, E. (2021). Physical characteristics of different professional rugby union competition levels. *Journal of Science and Medicine in Sport*, *24*(12), pp.1267-1271.

Tierney, P., Tobin, D.P., Blake, C. and Delahunt, E. (2017). Attacking 22 entries in rugby union: running demands and differences between successful and unsuccessful entries. *Scandinavian Journal of Medicine & Science in Sports*, *27*(12), pp.1934-1941.

Till, K., Weakley, J., Read, D.B., Phibbs, P., Darrall-Jones, J., Roe, G., Chantler, S., Mellalieu, S., Hislop, M., Stokes, K. and Rock, A. (2020). Applied sport science for male age-grade rugby union in England. *Sports Medicine-Open*, *6*(1), pp.1-20.

Tucker, R., Lancaster, S., Davies, P., Street, G., Starling, L., De Coning, C. and Brown, J. (2021). Trends in player body mass at men's and women's Rugby World Cups: a plateau in body mass and differences in emerging rugby nations. *BMJ Open Sport & Exercise Medicine*, *7*(1), p.e000885.

Ungureanu, A.N., Brustio, P.R. and Lupo, C. (2020). Technical and tactical effectiveness is related to time-motion performance in elite rugby. *The Journal of Sports Medicine and Physical Fitness*, *61*(2), pp.167-174.

Vachon, A., Berryman, N., Mujika, I., Paquet, J.B. and Bosquet, L. (2021). Fitness determinants of repeated high-intensity effort ability in elite rugby union players. *International Journal of Sports Physiology and Performance*, *16*(8), pp.1103-1110.

Vahed, Y., Kraak, W. and Venter, R. (2016). Changes on the match profile of the South African Currie Cup tournament during 2007 and 2013. *International Journal of Sports Science & Coaching*, *11*(1), pp.85-97.

Van den Berg, P. and Malan, D.D.J. (2012). The effect of Experimental Law Variations on the Super 14 Rugby Union Tournaments science. *African Journal for Physical Health Education, Recreation and Dance*, *18*(3), pp.476-486.

van Rooyen, M., Rock, K., Prim, S. and Lambert, M. (2008). The quantification of contacts with impact during professional rugby matches. *International Journal of Performance Analysis in Sport*, *8*(1), pp.113-126.

Vanrenterghem, J., Nedergaard, N.J., Robinson, M.A. and Drust, B. (2017). Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sports medicine*, *47*, pp.2135-2142.

Varley, M.C., Fairweather, I.H. and Aughey, R.J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of sports sciences*, *30*(2), pp.121-127.

Wasserman, K. (1986). The anaerobic threshold: definition, physiological significance and identification. *Advances in cardiology*, *35*, pp.1-23.

Weakley, J., Black, G., McLaren, S., Scantlebury, S., Suchomel, T.J., McMahon, E., Watts, D. and Read, D.B. (2022). Testing and profiling athletes: recommendations for test selection, implementation, and maximizing information. *Strength & Conditioning Journal*, pp.10-1519.

West, S.W., Clubb, J., Torres-Ronda, L., Howells, D., Leng, E., Vescovi, J.D., Carmody, S., Posthumus, M., Dalen-Lorentsen, T. and Windt, J. (2021). More than a metric: how training load is used in elite sport for athlete management. *International Journal of Sports Medicine*, *42*(04), pp.300-306.

Weston, M., Siegler, J., Bahnert, A., McBrien, J. and Lovell, R. (2015). The application of differential ratings of perceived exertion to Australian Football League matches. *Journal of Science and Medicine in Sport*, *18*(6), pp.704-708.

Wheeler, K.W., Askew, C.D. and Sayers, M.G. (2010). Effective attacking strategies in rugby union. *European Journal of Sport Science*, *10*(4), pp.237-242.

Whitehead, S., Till, K., Weaving, D. and Jones, B. (2018). The use of microtechnology to quantify the peak match demands of the football codes: a systematic review. *Sports medicine*, *48*(11), pp.2549-2575.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K. and Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software, 4*(43): 1686. https://doi.org/10.21105/joss.01686.

Windt, J. and Gabbett, T.J. (2017). How do training and competition workloads relate to injury? The workload—injury aetiology model. *British Journal of Sports Medicine*, *51*(5), pp.428-435.

Windt, J., Gabbett, T.J., Ferris, D. and Khan, K.M. (2017). Training load--injury paradox: is greater preseason participation associated with lower in-season injury risk in elite rugby league players?. *British journal of sports medicine*, *51*(8), pp.645-650.

Windt, J., Hamilton, K., Cox, D.N., Zumbo, B.D. and Sporer, B.C. (2022). Capturing the 'expert's eye': A perspective on developing a better understanding and implementation of subjective performance evaluations in team sports. *Journal of Elite Sport Performance*, p.36710.

World Rugby Passport. (2022). *Rugby Ready*. Available at: https://passport.world.rugby/injury-prevention-and-risk-management/rugby-ready/the-lineout/ (Accessed: 27/5/2022).

World Rugby. (2018). *YEAR IN REVIEW 2018*. Available at: https://resources.world.rugby/worldrugby/document/2020/07/28/212ed9cf-cd61-4fa3-b9d4-9f0d5fb61116/P56-57-Participation-Map_v3.pdf (Accessed: 28/3/2022).

World Rugby. (2019). *Global Reach of Rugby 2019*. Available at: https://resources.world.rugby/worldrugby/document/2020/11/02/581254d9-5d92-4df9-b84b-f2af112d9b2a/Report-Global-Reach-of-Rugby-2019-EN-.pdf (Accessed: 28/3/2022).

World Rugby. (2022a). *The Game*. Available at: https://www.world.rugby/the-game/beginners-guide/game (Accessed: 28/3/2022).

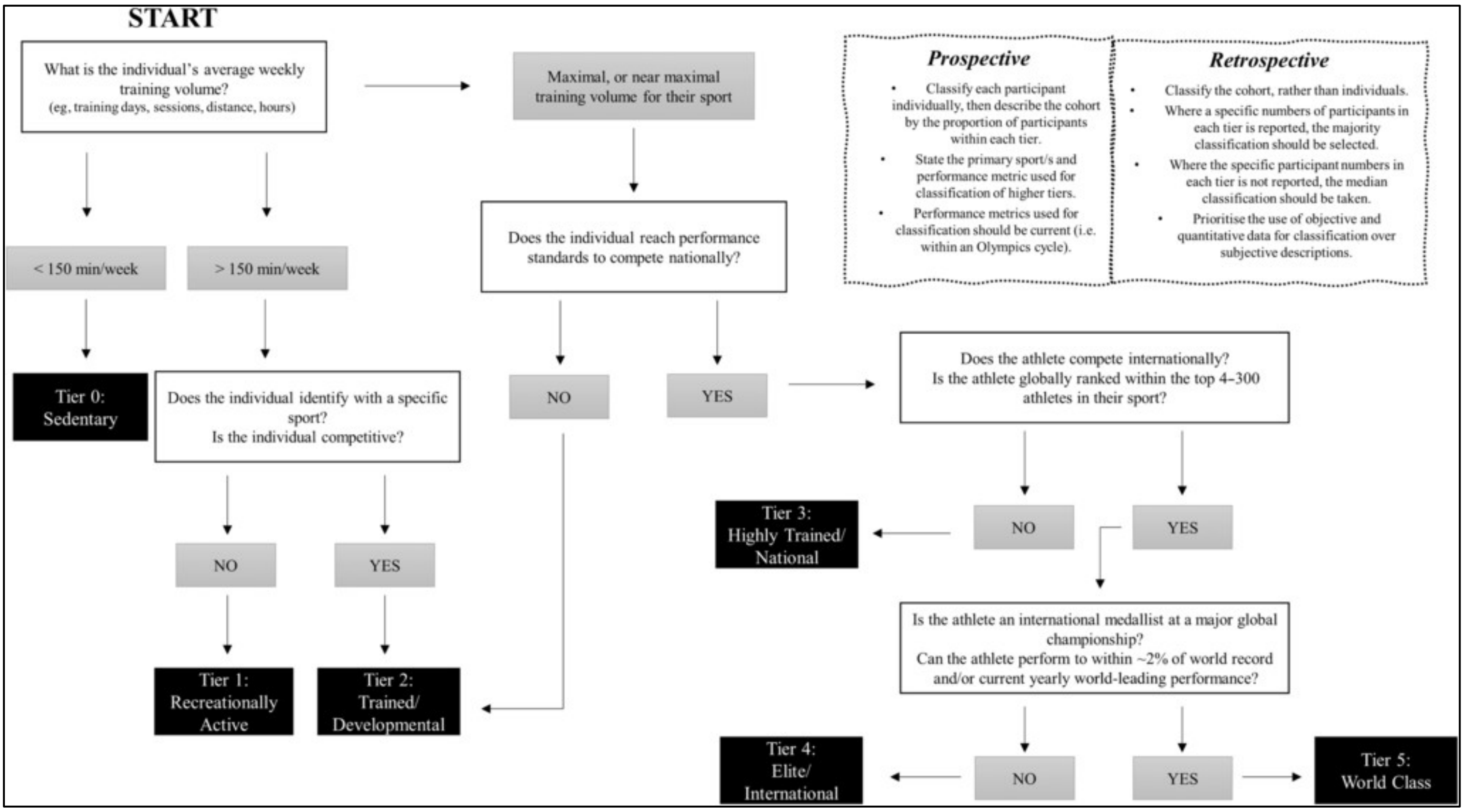
World Rugby. (2022b). *Membership and Growth*. Available at: https://www.world.rugby/organisation/about-us/membership-growth (Accessed: 25/5/2022).

Zamparo, P., Pavei, G., Nardello, F., Bartolini, D., Monte, A. and Minetti, A.E. (2016). Mechanical work and efficiency of 5+ 5 m shuttle running. *European journal of applied physiology*, *116*, pp.1911-1919.

Ziv, G. and Lidor, R. (2016). On-field performances of rugby union players—a review. *The Journal of Strength & Conditioning Research*, *30*(3), pp.881-892.

APPENDIX

Appendix 1. Participant Classification Framework for Defining Training and Performance Calibre of Athletes (from McKay et al., 2022).



Appendix 2. Departmental Ethical Approval

Ethical Approval: [redacted]

Ethics <[redacted]>
Mon 11/07/2022 13:51
To: SMITH, KIERAN R. <kieran.r.smith@durham.ac.uk>
Cc: SES-RESEARCHADMIN, S S. [redacted]

Please do not reply to this email.

Dear Kieran,

The following project has received ethical approval:

Project Title: *Body Composition and Performance in Sub-Elite Rugby Union Players: a Prospective Study;*
Start Date: *01 July 2022*;
End Date: *31 October 2022;*
Reference: [redacted]
Date of ethical approval: *11 July 2022*.

Please be aware that if you make any significant changes to the design, duration or delivery of your project, you should contact your department ethics representative for advice, as further consideration and approval may then be required.

If you have any queries regarding this approval or need anything further, please contact ses.researchadmin@durham.ac.uk

------

If you have any queries relating to the ethical review process, please contact your supervisor (where applicable) or departmental ethics representative in the first instance. If you have any queries relating to the online system, please contact research.policy@durham.ac.uk.

Appendix 3. Study Information Sheet

Durham University

Department of Sport and Exercise Sciences

Shaped by the past, creating the future

Participant Information Sheet

You are invited to take part in a research project. Before you decide if you would like to take part, please read this information sheet carefully. You can also ask the research team if you have any questions (please see contact details at the end of this sheet).

Title of Project: Body Composition and Performance in Sub-Elite Rugby Union Players: a Prospective Study

What is the purpose of the research?
The purpose of this study is to explore possible associations between body composition (e.g. lean mass and fat mass) and rugby union-specific performance. Throughout the sports science literature, there are frequent references to the importance of increasing lean mass and reducing fat mass, in order to optimise performance. However, there is a lack of evidence informing this. Athletes, particularly at the elite level, are under continuous pressure to achieve an 'optimal' body composition, but this is challenging given the lack of understanding about what this means. Therefore, this project seeks to provide an evidence-base to inform on the relationship between components of body composition and sports performance in rugby union.

Why have I been invited to take part?
You have been invited to take part in this study because you are a university high performance rugby union player aged over 18 years.

Do I have to take part?
Taking part in this study is completely optional and if you decide not to take part, you will not be treated any differently to those who decide to take part. You can request withdrawal of your data until data analysis is complete and ready for publication. You have the right to request the withdrawal of your identifiable data at any time.

What will be involved if I decide to take part in the research?
If you decide to take part, you will be asked to take part in performance testing and receive a measurement of your body composition, three times across the rugby union season (start of season-October, mid season-Jan and end of season-April).

Body Composition Test
Your body composition will be measured using multi-frequency bioelectrical impedance (MF-BIA). This will take less than one minute. You will be asked to stand on the MF-BIA platform and hold the hand grips during the test. A very small electric current will travel through your hands and feet to provide an estimate of your body composition, You will not feel this.

Speed: 40m Sprint Test
Your sprint performance will be measured over a distance of 40m using a reactive start sensor and timing gates set up every 5m up to 30m with the final gates at 40m. On the command 'go', you will be asked to perform at maximal effort throughout the 40m to the finish line.

Agility: Y-shaped test
This test will involve you sprinting 5m through the start gate, passing the trigger gate and cutting 45-degrees left or right depending on which reactive gate illuminates, then sprinting 5m to the finish line. The timing system will dictate which direction you will proceed after completing the first 5m of the course.

Aerobic Capacity: Bronco Test
Your aerobic capacity will be assessed using a common, submaximal, field-based test used in Rugby. The test will require you to progressively run to and back, to floor markers placed at 0 m, 20 m, 40 m and 60 m. 1

Durham University

Department of Sport and Exercise Sciences

Shaped by the past, creating the future

repetition = 1 run from 0m-60m-0m-40m-0m-20m-0m (total distance = 240m). This will then be repeated as fast as possible until achievement of five repetitions. Your heart rate will be monitored throughout the test and your time on completion will be recorded.

Strength and Power Testing

Bench Press:

The test will involve working under 3 different submaximal loading conditions (3 reps at 40% of 1 rep max, 3 reps at 60% of 1 rep max and 1 rep at 80% of 1 rep max). Once testing begins, you will be asked to lower the barbell down to your chest and then once the barbell has touched your chest, you can then proceed to push the barbell off your chest until you have locked your arms out to return to your starting position. During the movement the barbell is not to be bounced off your chest as it is a controlled movement, your feet will remain planted to the floor and glutes must be touching the bench at all times

Barbell Back squat:

You will be performing submaximal barbell back squats under 3 different loading conditions (3 reps at 40% of 1 rep max, 3 reps at 60% of 1 rep max and 1 rep at 80% of 1 rep max). You will be asked to place the bar on your trapezius and the bar will have to keep in constant contact with your shoulders whilst your feet are firmly planted on the floor during the whole movement. Once you are set, you will be told to back squat until your thighs are parallel with the floor (a knee angle of around 90°) and then begin to ascend back to a standing position

Countermovement Jump:

You will perform maximal countermovement jumps under 3 different loading conditions (0kg, 40kg, 60kg). Before each jump, you will be asked to stand up straight and still on the force plate with your hands placed on your hips for unloaded conditions and on the barbell (20kg) for loaded jumps; this hand position will remain the same during the entirety of the movement. At this point, you should initiate a downwards movement into a squatting position with a knee angle of about 90° (this will differ between athletes), followed instantly by a jump to your maximum height.

Drop Jump:

The test involves the performance of 1 jump starting from an elevated platform (Box) at a predetermined height from the ground ranging from 20 to 100 cm (no greater than Max CMJ height). You will be instructed to place your hands on your hips, step out from the box, and to jump as high and as fast as possible minimising time spent on the ground.

What are the benefits and risks of taking part?

The benefits of taking part in this research are to contribute to providing an evidence-base on the relationship between body composition and performance. There is very little evidence available currently, so this study is important to advance knowledge and will contribute to informing practice. You will also be able to receive your own individual results for all testing during the study. If you would like your results, please let the research team know.

The risks of taking part are very few outside of your normal high performance rugby activities. As with all exercise tests, there is a small risk of injury but the tests are routinely performed in rugby union and you will be supported through familiarisation prior to testing. You will also warm up prior to any testing and the tests will be supervised at all times.

What steps are being taken to mitigate the risk of COVID-19?

All government and University guidelines regarding Covid-19 will be adhered to. 2m social distancing will be observed, where possible, and the MF-BIA device will be sanitised between uses. You are asked to follow the University guidelines with regard to reducing the risk of Covid-19 on testing days. If you have any Covid19 symptoms, you should not attend testing and take a lateral flow test.

Durham University

Department of Sport and Exercise Sciences

Shaped by the past, creating the future

How will confidentiality be assured?
Your data will be anonymised using codes, and prior to data analysis all data will be held securely on a password protected computer/laptop and will not be shared outside of the research team. No personal data will be shared, and you will not be identified in any resultant outputs such as the student thesis or publications. Please see the Privacy Notice for further details.

What will happen to the results of the research?
The results of the research will be presented in MRes theses submitted to the Department of Sport and Exercise Sciences at Durham University, conference presentations, talks for sports practitioners and published research papers. No names (including club name) will be used in any output.

If you have any questions related to the project, please contact the lead researchers:

Kieran Smith
Email: kieran.r.smith@durham.ac.uk

Mark Christie
Email: mark.christie@durham.ac.uk

Harry Winham
Email: harry.m.winham@durham.ac.uk

Supervisor names: Dr Karen Hind, Dr Shaun McLaren, Mr Rob Cramb and Dr Katie Di Sebastiano.

Email: karen.hind@durham.ac.uk; shaun.mclaren@durham.ac.uk; r.k.cramb@durham.ac.uk; kathleen.di-sebastiano@durham.ac.uk

If you are happy with the answers to your questions, please complete and sign the Consent Form.

Appendix 4. Study Consent Form

Durham University

Department of Sport and Exercise Sciences

Shaped by the past, creating the future

Consent Form

Project title: Body Composition and Performance in Sub-Elite Rugby Union Players: a Prospective Study

Researcher(s): Kieran Smith, Mark Christie and Harry Winham.
Department: Sport and Exercise Sciences
Supervisor name: Dr Karen Hind
Supervisor contact details: karen.hind@durham.ac.uk

This form is to confirm that you understand what the purposes of the project, what is involved and that you are happy to take part. Please initial each box to indicate your agreement:

I confirm that I have read and understand the Information Sheet and the Privacy Notice for the above project.	
I have had sufficient time to consider the information and ask any questions I might have, and I am satisfied with the answers I have been given.	
I understand who will have access to provided personal data, how the data will be stored and what will happen to the data at the end of the project.	
I agree to follow the Covid-secure protocols	
I agree to take part in the above project, including: 1. Body Composition Test 2. Performance Testing	
I understand that my participation is entirely voluntary and that I am free to withdraw at any time without giving a reason.	

Participant's Signature______________________________ Date_____________

(NAME IN BLOCK LETTERS)____

Researcher's Signature_____________________________ Date_____________

(NAME IN BLOCK LETTERS)____

Appendix 5. University Privacy Policy

Privacy Notice

Durham University

PART 1 – GENERIC PRIVACY NOTICE

Durham University has a responsibility under data protection legislation to provide individuals with information about how we process their personal data. We do this in a number of ways, one of which is the publication of privacy notices. Organisations variously call them a privacy statement, a fair processing notice or a privacy policy.

To ensure that we process your personal data fairly and lawfully we are required to inform you:

- Why we collect your data
- How it will be used
- Who it will be shared with

We will also explain what rights you have to control how we use your information and how to inform us about your wishes. Durham University will make the Privacy Notice available via the website and at the point we request personal data.

Our privacy notices comprise two parts – a generic part (ie common to all of our privacy notices) and a part tailored to the specific processing activity being undertaken.

Data Controller

The Data Controller is Durham University. If you would like more information about how the University uses your personal data, please see the University's Information Governance webpages or contact Information Governance Unit:

Telephone: (0191 33) 46246 or 46103

E-mail: information.governance@durham.ac.uk

Information Governance Unit also coordinate response to individuals asserting their rights under the legislation. Please contact the Unit in the first instance.

Data Protection Officer

The Data Protection Officer is responsible for advising the University on compliance with Data Protection legislation and monitoring its performance against it. If you have any concerns regarding the way in which the University is processing your personal data, please contact the Data Protection Officer:

Jennifer Sewel
University Secretary
Telephone: (0191 33) 46144
E-mail: university.secretary@durham.ac.uk

Your rights in relation to your personal data

Privacy notices and/or consent
You have the right to be provided with information about how and why we process your personal data. Where you have the choice to determine how your personal data will be used, we will ask you for consent. Where you do not have a choice (for example, where we have a legal obligation to process the personal data), we will provide you with a privacy notice. A privacy notice is a verbal or written statement that explains how we use personal data.

Whenever you give your consent for the processing of your personal data, you receive the right to withdraw that consent at any time. Where withdrawal of consent will have an impact on the services we are able to provide, this will be explained to you, so that you can determine whether it is the right decision for you.

Accessing your personal data
You have the right to be told whether we are processing your personal data and, if so, to be given a copy of it. This is known as the right of subject access. You can find out more about this right on the University's Subject Access Requests webpage.

Right to rectification
If you believe that personal data we hold about you is inaccurate, please contact us and we will investigate. You can also request that we complete any incomplete data.

Once we have determined what we are going to do, we will contact you to let you know.

Right to erasure
You can ask us to erase your personal data in any of the following circumstances:

- We no longer need the personal data for the purpose it was originally collected
- You withdraw your consent and there is no other legal basis for the processing
- You object to the processing and there are no overriding legitimate grounds for the processing
- The personal data have been unlawfully processed
- The personal data have to be erased for compliance with a legal obligation
- The personal data have been collected in relation to the offer of information society services (information society services are online services such as banking or social media sites).

Once we have determined whether we will erase the personal data, we will contact you to let you know.

Right to restriction of processing
You can ask us to restrict the processing of your personal data in the following circumstances:

- You believe that the data is inaccurate and you want us to restrict processing until we determine whether it is indeed inaccurate
- The processing is unlawful and you want us to restrict processing rather than erase it
- We no longer need the data for the purpose we originally collected it but you need it in order to establish, exercise or defend a legal claim and
- You have objected to the processing and you want us to restrict processing until we determine whether our legitimate interests in processing the data override your objection.

Once we have determined how we propose to restrict processing of the data, we will contact you to discuss and, where possible, agree this with you.

Retention

The University keeps personal data for as long as it is needed for the purpose for which it was originally collected. Most of these time periods are set out in the University Records Retention Schedule.

Making a complaint

If you are unsatisfied with the way in which we process your personal data, we ask that you let us know so that we can try and put things right. If we are not able to resolve issues to your satisfaction, you can refer the matter to the Information Commissioner's Office (ICO). The ICO can be contacted at:

Information Commissioner's Office Wycliffe House Water Lane Wilmslow Cheshire SK9 5AF

Telephone: 0303 123 1113

Website: Information Commissioner's Office

PART 2 – PROJECT-SPECIFIC PRIVACY NOTICE

Project Title: Body Composition and Performance in Sub-Elite Rugby Union Players: a Prospective Study

This section of the Privacy Notice provides you with information that you need to know before you provide personal data to the University for the particular purpose(s) stated below.

Type(s) of personal data collected and held by the researcher and method of collection:

Personal data will be collected through the process of obtaining consent, including your age, sex, number of years playing rugby and physical data (body composition and performance data).

At no point will individuals be identified in the academic theses, publications or for any other means outside of the members of the named research team.

Lawful Basis

Collection and use of personal data is carried out under the University's public task, which includes teaching, learning and research.

How personal data is stored:

All personal data will be held securely and strictly confidential to the research team. Data in electronic form will be stored on a password-protected computer. Hardcopies (e.g., consent forms) will be scanned electronically and shredded. Data will not be available to anyone outside the research team.

How personal data is processed:

Identifiable data will be kept separate from data analysis spreadsheets, you will be assigned a participant code for data analysis.

Withdrawal of data

You can request withdrawal of your data until data analysis is complete and ready for publication. You have the right to request the withdrawal of your identifiable data at any time.

Who the researcher shares personal data with:

The only individual with access to identifiable data will be the named researchers.

How long personal data is held by the researcher:

The consent form containing your personal identifiable data will be held from the end of the project for 2 years.

How to object to the processing of your personal data for this project:

If you have any concerns regarding the processing of your personal data, or you wish to withdraw your data from the project, please contact the primary supervisor, Dr. Karen Hind (karen.hind@durham.ac.uk).

Appendix 6. Study Debriefing Sheet

Durham University

Department of Sport and Exercise Sciences

Shaped by the past, creating the future

Debriefing Sheet

Project title: Body Composition and Performance in Sub-Elite Rugby Union Players: A Prospective Study

Thank you for taking part in this study. The purpose of this project was to provide an evidence base to inform if there is a relationship between components of body composition and sports performance in rugby union. Consequently, this may provide practitioners such as S&C coaches and sports scientists, with a greater understanding of how to help athletes achieve optimal body composition, and the effect this may have on sports performance.

Now data collection has concluded, the data you have provided has been automatically anonymised and the data which identifies you is stored separately. Should you wish to voluntarily withdraw from the study, all data related to you will be responsibly destroyed and you will be omitted from the study. Please note voluntary withdrawal may be requested up until data analysis has been completed, after this point, it will not be possible to distinguish individual data.

Once data analysis is complete, your anonymised data will be presented in Masters of Research theses submitted to the Department of Sport and Exercise Sciences at Durham University. The findings may also be presented at a conference, as a conference abstract and published in a sports science/physiology journal. No names (including club names) will be used in any output. Additionally, group findings will be presented to Team Durham RFC coaching staff. At no point will your individual data become available to anyone outside the research team.

Shortly you will receive your testing report from your final body composition and performance testing sessions. If you would like further information about the study or would like to know about the research team's findings, when all the data have been collated and analysed, then please contact the lead researchers using the contact details below.

If you have any further questions related to the project, please contact the lead researchers:

Kieran Smith
Email: kieran.r.smith@durham.ac.uk

Mark Christie
Email: mark.christie@durham.ac.uk

Harry Winham
Email: harry.m.winham@durham.ac.uk

Supervisors: Dr Karen Hind, Dr Shaun McLaren, Mr Rob Cramb and Dr Katie Di Sebastiano.

Email: karen.hind@durham.ac.uk; shaun.mclaren@durham.ac.uk; r.k.cramb@durham.ac.uk; kathleen.di-sebastiano@durham.ac.uk

Appendix 7. Athlete Rating of Perceived Fitness (RPF) Scale

RATING OF PERCEIVED FITNESS

Name:	
Position:	Prop, Hooker, Lock, Back Row, Scrum Half, Fly Half, Centre, Winger, Full Back

This is a rating scale concerning your self-appraisal of your aerobic fitness. The term "aerobic fitness" is meant by your overall endurance capacity, as measured by your performance in the Bronco test.

Use the scale below to rate yourself in relation to your aerobic fitness 'right now' against the rest of your team. Put simply, think about where you would rank yourself in the Bronco test compared to everybody else at this moment in time. Try to appraise your capacity as objectively as possible. Do not underestimate or overestimate your ability.

The rating scale consists of 13 steps ranging from extremely low to high capacity. Together with rating values from 1 to 13, you will find verbal anchors explaining the meaning of each value. If you think your capacity is slightly below the average, choose 4, 5, or 6 according to how much below you think you are. If you think you are much below the average, use 2 or 3. Mark a 1 if you think your capacity is extremely low. If you think your capacity is above average rate yourself in a corresponding way. Select the appropriate answer below:

1	Extremely low
2	
3	Much Below Average
4	
5	Slightly Below Average
6	
7	Average
8	
9	Slightly Above Average
10	
11	Much Above Average
12	
13	Extremely High

Scale modified from Borg, Skinner, and Bar-Or (1972).

Borg, G., Skinner, J.S., and Bar-Or, O. (1972). *Self-appraisal of physical performance capacity*. Reports from the Institute of Applied Psychology, the University of Stockholm, No.32.

Appendix 8. RPF Scale Online Form

RATING OF PERCEIVED FITNESS

* Required

1
Name *
First Name & Surname

Enter your answer

2
Position *

Select your answer

3
RATING OF PERCEIVED FITNESS

This is a rating scale concerning your self-appraisal of your aerobic fitness. The term "aerobic fitness" is meant by your overall endurance capacity, as measured by your performance in the Bronco test.

Use the scale below to rate yourself in relation to your aerobic fitness 'right now' against the rest of your team. Put simply, think about where you would rank yourself in the Bronco test compared to everybody else at this moment in time. Try to appraise your capacity as objectively as possible. Do not underestimate or overestimate your ability.

The rating scale consists of 13 steps ranging from extremely low to high capacity. Together with rating values from 1 to 13, you will find verbal anchors explaining the meaning of each value. If you think your capacity is slightly below the average, choose 4, 5, or 6 according to how much below you think you are. If you think you are much below the average, use 2 or 3. Mark a 1 if you think your capacity is extremely low. If you think your capacity is above average rate yourself in a corresponding way. Select the appropriate answer below:
*

1	Extremely low
2	
3	Much Below Average
4	
5	Slightly Below Average
6	
7	Average
8	
9	Slightly Above Average
10	
11	Much Above Average
12	
13	Extremely High

Select your answer

Submit

Never give out your password. Report abuse

Appendix 9. R, RStudio, Packages and Computational Environment Versions

```
R version 4.2.2 (2022-10-31) -- "Innocent and Trusting"
Copyright (C) 2022 The R Foundation for Statistical Computing
Platform: aarch64-apple-darwin20 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

  Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> # Packages -----------------------------------------------------------
> library(readxl)
> library(tidyverse)
──          Attaching          core          tidyverse          packages
────────────────────────────────────────────────────────────────────────
────────────────────────────────────────────────────────────────────────
──── tidyverse 2.0.0 ──
✔ dplyr     1.1.1     ✔ readr     2.1.4
✔ forcats   1.0.0     ✔ stringr   1.5.0
✔ ggplot2   3.4.2     ✔ tibble    3.2.1
✔ lubridate 1.9.2     ✔ tidyr     1.3.0
✔ purrr     1.0.1
──                                                             Conflicts
────────────────────────────────────────────────────────────────────────
────────────────────────────────────────────────────────────────────────
────────────────────── tidyverse_conflicts() ──
✖ dplyr::filter() masks stats::filter()
✖ dplyr::lag()    masks stats::lag()
ℹ Use the conflicted package to force all conflicts to become errors
> library(writexl)
> library(mbir)
> library(modelsummary)
`modelsummary` has built-in support to draw text-only (markdown) tables. To
generate tables in other formats, you must install one or more of these
libraries:

install.packages(c(
    "kableExtra",
    "gt",
    "flextable",
    "huxtable",
    "DT"
```

```
))

  Alternatively, you can set markdown as the default table format to silence
this alert:

config_modelsummary(factory_default = "markdown")

> library(olsrr)

Attaching package: ‘olsrr’

The following object is masked from ‘package:datasets’:

    rivers

> library(grateful)
> # R, packages used, RStudio and environment ---------------------------
> # R, packages & package versions
> # RStudio
> RStudio.Version()
$citation

To cite RStudio in publications use:

  Posit team (2023). RStudio: Integrated Development Environment for R.
Posit Software, PBC, Boston, MA. URL http://www.posit.co/.

A BibTeX entry for LaTeX users is

  @Manual{,
    title = {RStudio: Integrated Development Environment for R},
    author = {{Posit team}},
    organization = {Posit Software, PBC},
    address = {Boston, MA},
    year = {2023},
    url = {http://www.posit.co/},
  }


$mode
[1] "desktop"

$version
[1] ‘2023.3.0.386’

$long_version
[1] "2023.03.0+386"

$release_name
[1] "Cherry Blossom"

>
> # environment
> sessionInfo()
```

```
R version 4.2.2 (2022-10-31)
Platform: aarch64-apple-darwin20 (64-bit)
Running under: macOS Ventura 13.3.1

Matrix products: default
LAPACK:                    /Library/Frameworks/R.framework/Versions/4.2-arm64/Resources/lib/libRlapack.dylib

locale:
[1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8

attached base packages:
[1] stats     graphics  grDevices utils     datasets  methods   base

other attached packages:
 [1] grateful_0.1.11     olsrr_0.5.3         modelsummary_1.4.0 mbir_1.3.5
writexl_1.4.2       lubridate_1.9.2     forcats_1.0.0       stringr_1.5.0
dplyr_1.1.1         purrr_1.0.1
[11] readr_2.1.4        tidyr_1.3.0         tibble_3.2.1        ggplot2_3.4.2
tidyverse_2.0.0     readxl_1.4.2

loaded via a namespace (and not attached):
 [1] Rcpp_1.0.10        cellranger_1.1.0  pillar_1.9.0       compiler_4.2.2
tools_4.2.2         goftest_1.2-3      digest_0.6.31      lifecycle_1.0.3
gtable_0.3.3       timechange_0.2.0  pkgconfig_2.0.3
[12] rlang_1.1.0        cli_3.6.1          rstudioapi_0.14    xfun_0.38
fastmap_1.1.1       gridExtra_2.3      knitr_1.42          withr_2.5.0
generics_0.1.3     vctrs_0.6.1        hms_1.1.3
[23] nortest_1.0-4     grid_4.2.2         tidyselect_1.2.0  data.table_1.14.8
glue_1.6.2          R6_2.5.1           fansi_1.0.4         carData_3.0-5
car_3.1-2           tzdb_0.3.0         magrittr_2.0.3
[34] htmltools_0.5.5    tables_0.9.17      scales_1.2.1        abind_1.4-5
insight_0.19.1      colorspace_2.1-0   utf8_1.2.3          stringi_1.7.12
munsell_0.5.0
ℹ Use the conflicted package to force all conflicts to become errors
> library(writexl)
> library(mbir)
> library(patchwork)
> library(modelsummary)
> library(olsrr)

Attaching package: ‘olsrr’

The following object is masked from ‘package:datasets’:

    rivers

> library(grateful)
>
```

Appendix 10. Statistical Analysis R Script

```r
# load packages ----------------------------------------------------------
library(readxl)
library(tidyverse)
library(writexl)
library(mbir)
library(patchwork)
library(modelsummary)
library(olsrr)
library(grateful)


# set working directory and load data ------------------------------------
setwd("/Users/kieransmith/R Working Directory/MSc Statistical Analysis")
data <- read_excel("studydata.xlsx")

View(data)

# data quick look
summary(data)


# correct order of positional groups and positions -----------------------
data$positionalgroup <-
  factor(data$positionalgroup, levels = c("Forward", "Back"))
data$position <-
  factor(
    data$position,
    levels = c(
      "Front Row",
      "Second Row",
      "Back Row",
      "Half Back",
      "Centre",
      "Back Three"
    )
  )


# check normality --------------------------------------------------------
# visual inspection
# histograms
par(mfrow = c(3, 3))
hist(data$age, main = "Histogram of age", prob = TRUE)
lines(density(data$age),
      col = "steelblue",
      lwd = 2)
hist(data$height, main = "Histogram of height", prob = TRUE)
lines(density(data$height),
      col = "steelblue",
      lwd = 2)
hist(data$bodymass, main = "Histogram of bodymass", prob = TRUE)
```

```
lines(density(data$bodymass),
      col = "steelblue",
      lwd = 2)
hist(data$RPF, main = "Histogram of RPF", prob = TRUE)
lines(density(data$RPF, na.rm = T),
      col = "steelblue",
      lwd = 2)
hist(data$HRex, main = "Histogram of HRex", prob = TRUE)
lines(density(data$HRex),
      col = "steelblue",
      lwd = 2)
hist(data$HRR, main = "Histogram of HRR", prob = TRUE)
lines(density(data$HRR),
      col = "steelblue",
      lwd = 2)
hist(data$broncoHRavg, main = "Histogram of broncoHRavg", prob = TRUE)
lines(density(data$broncoHRavg),
      col = "steelblue",
      lwd = 2)
hist(data$broncoHRpeak, main = "Histogram of broncoHRpeak", prob = TRUE)
lines(density(data$broncoHRpeak),
      col = "steelblue",
      lwd = 2)
hist(data$totaltime, main = "Histogram of totaltime", prob = TRUE)
lines(density(data$totaltime),
      col = "steelblue",
      lwd = 2)

# ///export plots using plots panel///

# q-q plots
par(mfrow = c(3, 3))
qqnorm(data$age,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of age")
qqline(data$age, col = "steelblue", lwd = 2)
qqnorm(data$height,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of height")
qqline(data$height, col = "steelblue", lwd = 2)
qqnorm(data$bodymass,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of bodymass")
qqline(data$bodymass, col = "steelblue", lwd = 2)
qqnorm(data$RPF,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of RPF")
qqline(data$RPF, col = "steelblue", lwd = 2)
qqnorm(data$HRex,
       pch = 1,
```

```
       frame = FALSE,
       main = "Q-Q plot of HRex")
qqline(data$HRex, col = "steelblue", lwd = 2)
qqnorm(data$HRR,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of HRR")
qqline(data$HRR, col = "steelblue", lwd = 2)
qqnorm(data$broncoHRavg,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of broncoHRavg")
qqline(data$broncoHRavg, col = "steelblue", lwd = 2)
qqnorm(data$broncoHRpeak,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of broncoHRpeak")
qqline(data$broncoHRpeak, col = "steelblue", lwd = 2)
qqnorm(data$totaltime,
       pch = 1,
       frame = FALSE,
       main = "Q-Q plot of totaltime")
qqline(data$totaltime, col = "steelblue", lwd = 2)

# ///export plots using plots panel///

# shapiro-wilk normality tests
swt1 <- shapiro.test(data$age)
swt2 <- shapiro.test(data$height)
swt3 <- shapiro.test(data$bodymass)
swt4 <- shapiro.test(data$RPF)
swt5 <- shapiro.test(data$HRex)
swt6 <- shapiro.test(data$HRR)
swt7 <- shapiro.test(data$broncoHRavg)
swt8 <- shapiro.test(data$broncoHRpeak)
swt9 <- shapiro.test(data$totaltime)
swtests <-
  as.data.frame(rbind(swt1, swt2, swt3, swt4, swt5, swt6, swt7, swt8, swt9
))
swtests <- swtests [, c(4, 2, 1, 3), ]
swtests <- apply(swtests,2,as.character)

View(swtests)

# export as .csv
write.csv(swtests, "shapiro wilk results.csv", row.names = TRUE)


# participant characteristics -----------------------------------------
# all players
allparchar <-
  data %>%                                                 # select data
  summarise(across(
    .cols = c(age, height, bodymass),                   # select columns
```

```
    .fns = list(                               # select summary statistics
      n = ~ n(),
      mean = mean,
      sd = sd,
      min = min,
      max = max
    )
  )) %>%
  mutate(positionalgroup = "All", .before = age_n)     # add rowname "All"

# filtered by positional group
posparchardata <-
  data %>%                                                      # select data
  group_by(positionalgroup) %>%                # group by positional group
  summarise(across(
    .cols = c(age, height, bodymass),                        # select columns
    .fns = list(                               # select summary statistics
      n = ~ n(),
      mean = mean,
      sd = sd,
      min = min,
      max = max
    )
  ))

# combine as 1 df
parcharacteristics <- allparchar %>%
  full_join(posparchardata) %>%
  mutate_if(is.numeric, round, 2) %>%
  mutate(across(
    c(
      'age_mean',
      'age_sd',
      'age_min',
      'age_max'
    ),
    round,
    1
  ))

View(parcharacteristics)

# export as .xlsx
write_xlsx(x = parcharacteristics,
           path = "participant characteristics.xlsx",
           col_names = TRUE)


# descriptive statistics ---------------------------------------------------
# 1st paragraph descriptive position data
sumpos <- as.data.frame(summary(data$position))

# export as .csv
write.csv(sumpos, "descriptive position data.csv", row.names = TRUE)
```

```
# all descriptive statistics
# all players
alldesstats <-
  data %>%                                              # select data
  summarise(across(
    .cols = c(                                       # select columns
      completiontime,
      RPF,
      estHRmax,
      HRex,
      `HRex%HRmax`,
      HRR,
      `HRR%HRmax`,
      totaltime,
      bcorMAS,
      broncoHRavg,
      `HRavg%HRmax`,
      broncoHRpeak
    ),
    .fns = list(                          # select summary statistics
      mean = mean,
      sd = sd,
      min = min,
      max = max
    ),
    na.rm = TRUE
  )) %>%                                          # add rowname "All"
  mutate(positionalgroup = "All", .before = completiontime_mean)

# filtered by positional group
posdesstats <-
  data %>%                                              # select data
  group_by(positionalgroup) %>%         # group by positional group
  summarise(across(
    .cols = c(                                       # select columns
      completiontime,
      RPF,
      estHRmax,
      HRex,
      `HRex%HRmax`,
      HRR,
      `HRR%HRmax`,
      totaltime,
      bcorMAS,
      broncoHRavg,
      `HRavg%HRmax`,
      broncoHRpeak
    ),
    .fns = list(                          # select summary statistics
      mean = mean,
      sd = sd,
      min = min,
      max = max
```

```
    ),
    na.rm = TRUE
  ))

# combine as 1 df
desstats <- alldesstats %>%
  full_join(posdesstats) %>%
  mutate_if(is.numeric, round, 2) %>%
  mutate(across(
    c(
      'RPF_mean',
      'RPF_sd',
      'RPF_min',
      'RPF_max',
      'estHRmax_mean',
      'estHRmax_sd',
      'estHRmax_min',
      'estHRmax_max',
      'HRex_mean',
      'HRex_sd',
      'HRex_min',
      'HRex_max',
      'HRR_mean',
      'HRR_sd',
      'HRR_min',
      'HRR_max',
      'broncoHRavg_mean',
      'broncoHRavg_sd',
      'broncoHRavg_min',
      'broncoHRavg_max',
      'broncoHRpeak_mean',
      'broncoHRpeak_sd',
      'broncoHRpeak_min',
      'broncoHRpeak_max'
    ),
    round,
    1
  ))

View(desstats)

# export as .xlsx
write_xlsx(x = desstats,
           path = "descriptive statistics.xlsx",
           col_names = TRUE)

# t-tests
ttest1 <-
  t.test(
    RPF ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
```

```
ttest2 <-
  t.test(
    estHRmax ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest3 <-
  t.test(
    HRex ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest4 <-
  t.test(
    `HRex%HRmax` ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest5 <-
  t.test(
    HRR ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest6 <-
  t.test(
    `HRR%HRmax` ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest7 <-
  t.test(
    totaltime ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest8 <-
  t.test(
    bcorMAS ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest9 <-
  t.test(
    broncoHRavg ~ positionalgroup,
    data = data,
    var.equal = TRUE,
```

```
    conf.level = 0.9
  )
ttest10 <-
  t.test(
    `HRavg%HRmax` ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )
ttest11 <-
  t.test(
    broncoHRpeak ~ positionalgroup,
    data = data,
    var.equal = TRUE,
    conf.level = 0.9
  )

ttests <-
  as.data.frame(
    rbind(
      ttest1,
      ttest2,
      ttest3,
      ttest4,
      ttest5,
      ttest6,
      ttest7,
      ttest8,
      ttest9,
      ttest10,
      ttest11
    )
  )
ttests <- apply(ttests, 2, as.character)

# export as .csv
write.csv(ttests, "descriptive stats ttests.csv", row.names = TRUE)

# Magnitude-Based Inferences
mbi1 <-
  smd(es = -2.448917, p = 0.0007443, df = 34)                       # RPF
mbi2 <-
  smd(es = 0.2269, p = 0.3637, df = 45)                        # estHRmax
mbi3 <-
  smd(es = 3.4052, p = 0.1714, df = 45)                            # HRex
mbi4 <-
  smd(es = 1.67254, p = 0.2033, df = 45)                     # HRex%HRmax
mbi5 <-
  smd(es = -0.20696, p = 0.9418, df = 45)                           # HRR
mbi6 <-
  smd(es = -0.12951, p = 0.9308, df = 45)                     # HRR%HRmax
mbi7 <-
  smd(es = 34.4231, p = 3.256e-08, df = 45)                   # totaltime
mbi8 <-
```

```
  smd(es = -0.505321, p = 2.01e-08, df = 45)                     # bcorMAS
mbi9 <-
  smd(es = 2.1483, p = 0.3539, df = 45)                      # broncoHRavg
mbi10 <-
  smd(es = 1.0105, p = 0.4135, df = 45)                      # HRavg%HRmax
mbi11 <-
  smd(es = -0.326, p = 0.8776, df = 45)                      # broncoHRpea
k

mbis <-
  as.data.frame(rbind(mbi1, mbi2, mbi3, mbi4, mbi5, mbi6, mbi7, mbi8, mbi9
, mbi10, mbi11))
mbis <- apply(mbis, 2, as.character)

# export as .csv
write.csv(mbis, "descriptive stats mbis.csv", row.names = TRUE)

# appendix MAS table for discussion ------------------------------------
# all players
allmasdata <-
  data %>%                                                   # select data
  summarise(across(
    .cols = c(MAS, bcorMAS, corMAS),                      # select columns
    .fns = list(                               # select summary statistics
      mean = mean,
      sd = sd,
      min = min,
      max = max
    )
  )) %>%
  mutate(positionalgroup = "All", .before = MAS_mean)  # add rowname "All"

# filtered by positional group
posmasdata <-
  data %>%                                                   # select data
  group_by(positionalgroup) %>%                # group by positional group
  summarise(across(
    .cols = c(MAS, bcorMAS, corMAS),                      # select columns
    .fns = list(                               # select summary statistics
      mean = mean,
      sd = sd,
      min = min,
      max = max
    )
  ))

# combine as 1 table
masdata <- allmasdata %>%
  full_join(posmasdata) %>%
  mutate_if(is.numeric, round, 2)

View(masdata)

# export as .xlsx
```

```
write_xlsx(x = masdata,
           path = "appendix mas data.xlsx",
           col_names = TRUE)


# plots ---------------------------------------------------------------------------
# RPF and MAS
# define x and y
x1 <- data$RPF
y1 <- data$bcorMAS

# plot design
plot1 <-
  data %>% ggplot(aes(x = x1, y = y1, linetype = "Linear prediction with \
n90% confidence interval",)) +
  geom_point (alpha = 0.7, size = 10, aes(colour = position)) +
  geom_smooth(
    method = "lm",
    level = 0.90,
    linewidth = 2.5,
    colour = "dodgerblue4",
    fill = "grey",
    se = TRUE
  ) +
  theme_minimal() +
  scale_color_hue(h = c(0, 240)) +
  scale_x_continuous(breaks = c(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)
) +

  # title, subtitle, caption, x and y axis labels, text & legend
  theme(
    plot.margin = margin(10, 20, 0, 10),
    text = element_text(family = "Helvetica"),
    plot.title = element_text(size = 30, face = "bold"),
    plot.subtitle = element_text(size = 24,),
    plot.caption = element_text(size = 20,),
    axis.title.x = element_text(size = 20, face = "bold"),
    axis.title.y = element_text(size = 20, face = "bold"),
    axis.text = element_text(size = 20,),
    legend.title = element_text(size = 20, face = "bold"),
    legend.text = element_text(size = 20),
    legend.position = "bottom",
    legend.background = element_rect(fill = "gray95", colour = "gray95")
  ) +
  labs(
    title = "RPF and MAS",
    subtitle = "Linear model of relationship between RPF and MAS.",
    caption = "",
    x = "RPF (AU)",
    y = "MAS (m•s⁻¹)",
    linetype = "Trend Line",
    colour = "Position"
  )
```

```
# print plot
plot1

# export plot
ggsave("RPF and MAS.png", bg = 'white')

# SMFT HRex and MAS
# define x and y
x2 <- data$HRex
y2 <- data$bcorMAS

# plot design
plot2 <-
  data %>% ggplot(aes(x = x2, y = y2, linetype = "Linear prediction with \
n90% confidence interval",)) +
  geom_point (alpha = 0.7, size = 10, aes(colour = position)) +
  geom_smooth(
    method = "lm",
    level = 0.90,
    linewidth = 2.5,
    colour = "dodgerblue4",
    fill = "grey",
    se = TRUE
  ) +
  theme_minimal() +
  scale_color_hue(h = c(0, 240)) +

  # title, subtitle, caption, x and y axis labels, text & legend
  theme(
    plot.margin = margin(10, 20, 0, 10),
    text = element_text(family = "Helvetica"),
    plot.title = element_text(size = 30, face = "bold"),
    plot.subtitle = element_text(size = 24,),
    plot.caption = element_text(size = 20,),
    axis.title.x = element_text(size = 20, face = "bold"),
    axis.title.y = element_text(size = 20, face = "bold"),
    axis.text = element_text(size = 20,),
    legend.title = element_text(size = 20, face = "bold"),
    legend.text = element_text(size = 20),
    legend.position = "bottom",
    legend.background = element_rect(fill = "gray95", colour = "gray95")
  ) +
  labs(
    title = "SMFT HRex and MAS",
    subtitle = "Linear model of relationship between SMFT HRex and MAS.",
    caption = "",
    x = "HRex (b•min⁻¹)",
    y = "MAS (m•s⁻¹)",
    linetype = "Trend Line",
    colour = "Position"
  )

# print plot
plot2
```

```
# export plot
ggsave("SMFT HRex and MAS.png", bg = 'white')

# RPF and SMFT HRex
# define x and y
x3 <- data$RPF
y3 <- data$HRex

# plot design
plot3 <-
  data %>% ggplot(aes(x = x3, y = y3, linetype = "Linear prediction with \
n90% confidence interval",)) +
  geom_point (alpha = 0.7, size = 10, aes(colour = position)) +
  geom_smooth(
    method = "lm",
    level = 0.90,
    linewidth = 2.5,
    colour = "dodgerblue4",
    fill = "grey",
    se = TRUE
  ) +
  theme_minimal() +
  scale_color_hue(h = c(0, 240)) +
  scale_x_continuous(breaks = c(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)
) +

  # title, subtitle, caption, x and y axis labels, text & legend
  theme(
    plot.margin = margin(10, 20, 0, 10),
    text = element_text(family = "Helvetica"),
    plot.title = element_text(size = 30, face = "bold"),
    plot.subtitle = element_text(size = 24,),
    plot.caption = element_text(size = 20,),
    axis.title.x = element_text(size = 20, face = "bold"),
    axis.title.y = element_text(size = 20, face = "bold"),
    axis.text = element_text(size = 20,),
    legend.title = element_text(size = 20, face = "bold"),
    legend.text = element_text(size = 20),
    legend.position = "bottom",
    legend.background = element_rect(fill = "gray95", colour = "gray95")
  ) +
  labs(
    title = "RPF and SMFT HRex",
    subtitle = "Linear model of relationship between RPF and SMFT HRex.",
    caption = "",
    x = "RPF (AU)",
    y = "HRex (b•min⁻¹)",
    linetype = "Trend Line",
    colour = "Position"
  )

# print plot
plot3
```

```
# export plot
ggsave("RPF and SMFT HRex.png", bg = 'white')

# multi panel plot
plot1 + plot2 + plot3 + plot_layout(guides = "collect") + plot_annotation(
tag_levels = "A") &
  theme(plot.tag = element_text(size = 30, face = "bold"),
        legend.position = 'bottom')

# ///export plot using plots panel///


# pearson's product-moment correlation coefficients ---------------------
# HRex & MAS
cor1 <-
  cor.test(
    data$HRex,
    data$bcorMAS,
    use = "pairwise.complete.obs",
    method = "pearson",
    conf.level = 0.9
  )

# RPF & MAS
cor2 <-
  cor.test(
    data$RPF,
    data$bcorMAS,
    use = "pairwise.complete.obs",
    method = "pearson",
    conf.level = 0.9
  )

# RPF & HRex
cor3 <-
  cor.test(
    data$RPF,
    data$HRex,
    use = "pairwise.complete.obs",
    method = "pearson",
    conf.level = 0.9
  )

cortests <- as.data.frame(rbind(cor1, cor2, cor3))
cortests <- cortests [, c(8, 4, 9, 1, 2, 3, 5, 6, 7), ]
cortests <- apply(cortests, 2, as.character)

View(cortests)

# export as .csv
write.csv(cortests, "pearsons correlations.csv", row.names = TRUE)

# Magnitude-Based Inferences
```

```
mbicor1 <- corr(r = -0.2520266, n = 47)                        # HRex & MAS
mbicor2 <- corr(r = 0.5759148, n = 36)                          # RPF & MAS
mbicor3 <- corr(r = -0.1913176, n = 36)                        # RPF & HRex

cormbis <-
  as.data.frame(rbind(mbicor1, mbicor2, mbicor3))
cormbis <- apply(cormbis, 2, as.character)

# export as .csv
write.csv(cormbis, "pearsons correlations mbis.csv", row.names = TRUE)

# linear regression models ----------------------------------------------
# create lm models
lmmodels <- list(
  "HRex and MAS" = lm(data$bcorMAS ~ data$HRex),
  "RPF and MAS" = lm(data$bcorMAS ~ data$RPF),
  "RPF and HRex" = lm(data$HRex ~ data$RPF)
)

# summarise models
modelsummary(lmmodels, statistic = c("SE = {std.error}"))

# export as .csv
modelsummary(lmmodels, output = "linear regression models.csv")
capture.output(summary(lm(data$bcorMAS ~ data$HRex)), file = "HRex and MAS
SEE.csv")
capture.output(summary(lm(data$bcorMAS ~ data$RPF)), file = "RPF and MAS S
EE.csv")
capture.output(summary(lm(data$HRex ~ data$RPF)), file = "RPF and HRex SEE
.csv")


# multiple linear regression model --------------------------------------
# create multiple lm model
mlrmodel <- lm(data$bcorMAS ~ data$RPF + data$HRex)

# summarise model
modelsummary(mlrmodel, statistic = c("SE = {std.error}"))

# export as .csv
modelsummary(mlrmodel, output = "multiple linear regression model.csv")
capture.output(summary(mlrmodel), file = "mlr SEE.csv")

# diagnostics - tolerance and variance inflation factor (VIF)
ols_coll_diag(mlrmodel)

# export as .csv
diagmlr <- ols_coll_diag(mlrmodel)
capture.output(diagmlr, file = "multiple linear regression model diagnosti
cs.csv")


# cite R, packages used, RStudio and environment -------------------------
# R, packages & package versions
```

```
cite_packages(cite.tidyverse = TRUE, out.format = "docx") # creates .docx
with table of packages, versions and in-text citations; formatted paragrap
h and full refs

# RStudio
RStudio.Version()

# environment
sessionInfo()
```

Appendix 11. Correction of MAS

Buchheit (2008) proposed correcting MAS by 0.7 s for every 180º COD in shuttle-based tests in a sample of young Basketball and Handball players. Given that rugby players possess a larger anthropometrical profile and body mass is considered to negatively affect COD ability in rugby union players, unpublished data has suggested correcting MAS by 1 s for each of the 29 turns in a 1.2SRT to attain a closer calculation of MAS (Owen et al., 2020a; Baker and Heaney, 2015). Consequently, in the present study, time to turn was measured using video recordings of the test and confirmed as 1 s. 1 s Corrected MAS was then determined by subtracting 29 s from the total time taken to complete the 1.2SRT before dividing by 1200m. Table 6 summarises MAS data from the study with current corrective equations applied.

Table 6. Descriptive statistics for MAS calculated using the traditional equation and corrective equations: 0.7 s correction (Buchheit, 2008) and 1 s correction (Baker and Heaney, 2015) (mean ± SD) (min–max).

Positional Group:	**MAS (m•s⁻¹):**	**0.7 s Corrected MAS (m•s⁻¹):**	**1 s Corrected MAS (m•s⁻¹):**
All (n = 47)	3.97 ± 0.31 (3.38 – 4.51)	4.26 ± 0.36 (3.59 – 4.88)	4.40 ± 0.38 (3.68 – 5.06)
Forward (n = 26)	3.77 ± 0.27 (3.38 – 4.43)	4.03 ± 0.31 (3.59 – 4.79)	4.16 ± 0.33 (3.68 – 4.96)
Back (n = 21)	4.21 ± 0.14 (4.01 – 4.51)	4.54 ± 0.16 (4.31 – 4.88)	4.69 ± 0.17 (4.44 – 5.06)

Given the range of scores achieved within and between positional groups when using different correction factors (Table 6), the agreement between the 1.2SRT and a gold-standard assessment such as a laboratory-graded exercise test should be conducted to assess the influence of accounting for COD and potential development of a corrected equation.