A Comparison of Body Composition Between Elite and Sub-elite Rugby Union Players: An Observational Study

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Harry Winham

A Comparison of Body Composition Between Elite and Sub-elite Rugby Union Players: An Observational Study

Abstract

Introduction: The assessment of body composition in athletes has become frequently used in practice as it is assumed to be an important determinant for athletic performance. Dual energy X-ray absorptiometry (DXA), a three-compartment model which assesses body composition in the form of bone mineral content, lean mass and fat mass, has quickly become the gold-standard measurement of body composition in athletic populations. The aim of this study was to compare body composition and anthropometric measurements between elite and national and development level rugby union players to examine if elite players possess more fat mass, muscle mass and bone content compared to national and development level players due to a higher participation level.

Methods: Demographic (age) and basic anthropometric data (stature, mass) were collected in 56 male rugby players (n=38 elite and n=18 national and development). Body composition outcomes were assessed from total-body less head (TBLH) DXA scans (Lunar iDXA, GE Healthcare (Madison, WI) taken during the preseason. The chosen significance level was p = 0.05 and the confidence interval was 95%. Two-way ANOVA tests were used to identify potential significance between the elite and national and developmental players as well as between the two positional groups (forwards and backs).

Results: The elite players were significantly older (24 vs 20 years; p=0.001) and displayed significantly greater amounts of trunk total mass (47.8 ± 6.8 vs 43.4 ± 4.8 kg; p = 0.005) compared to national and developmental players. Forwards possessed greater stature (190.1 ± 6.5 vs 180.3 ± 5.2 cm; p <0.001) and body mass (112.6 ± 15.3 vs 89.4 ± 8.2 kg; p<0.001) compared to backs. Forwards also have greater arm (14.3 ± 1.1 vs 11.7 ± 1.2 kg; p <0.001), leg (38.8 ± 3.5 vs 31.2 ± 3.4 kg; p <0.001), trunk (51.7 ± 4.7 vs 41.6 ± 3.7 kg; p <0.001) and TBLH (104.8 ± 8.1 vs 84.6 ± 8.0 kg; p <0.001) total mass. Forwards possessed greater lean mass in the arms (10.9 ± 1.5 kg; p <0.001), legs (28.5 ± 2.3 vs 24.2 ± 2.9 kg; p <0.001) trunk (36.6 ± 2.8 vs 32.8 ± 3.4 kg; p <0.001) and TBLH (76.2 ± 5.0 vs 66.5 ± 7.1 kg; p <0.001) regions. Forwards reported a greater difference in right leg (14.4 ± 1.1 vs 12.2 ± 15 kg; p <0.001) and left leg (14.1 ± 1.2 vs 11.9 ± 1.4 kg; p <0.001) lean mass. Forwards showed greater fat mass in the arms (18.5 ± 3.9 vs 14.7 ± 3.2 %; p <0.001), legs (21.7 ± 4.4 vs 17.4 ± 3.7 %; p <0.001), trunk (25.6 vs 6.2 vs 18.1 ± 4.5 %; p <0.001) and TBLH (23.2 ± 4.7 vs 17.4 ± 3.9 %; p <0.001) regions than backs. Forwards also reported greater TBLH bone mass (4.02 ± 0.44 vs 3.52 kg; p <0.001), BMD (1.56 vs 0.08 vs 1.46 ± 0.09 kg; p<0.001) and BMC (4.02 ± 0.44 vs 3.52 kg; p <0.001) than backs.

Conclusion: Elite players were older and possessed greater trunk total mass compared to the national and developmental players. The lack of differences in terms of body composition between the elite and national and developmental groups was likely due to the high level of performance of the national level players as many were close to making the transition to the elite level. In terms of playing position, forwards were greater in stature and possessed more body mass than backs. Forwards were found to have greater amounts of arms, legs, trunk and TBLH total mass, lean mass and fat mass compared to backs. Forwards also showed greater differences in right and left leg lean mass than backs and greater TBLH bone mass, TBLH bone mineral density and content. These findings indicate that playing position may be a greater determinant of body composition than playing level.

A Comparison of Body Composition Between Elite and National and Developmental Rugby Union Players: An Observational Study

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Masters of Science by Research

Supervisors: Dr Kathleen Di-Sebastiano and Mr Rob Cramb

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March 2023

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Declaration

The DXA scans in this study were collected as part of two larger studies. The elite players were recruited for DXA scans as part of another researcher's PHD study investigating fatigue and recovery responses in high performance rugby players. I aided in the recruitment of the development and national players to investigate the effects body composition has on performance within this cohort. My contribution to this project was comparing and analysing body composition between elite and development and national union players. All of the analysis and interpretation of the scans in this study is my own work.

Statement of copyright

Print name: Harry Winham

Signature: H. Winham

Date: 14.3.2023

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Chapter 1: Introduction

1.1 An introduction to body composition

Body composition has been referred to as the chemical or physical components which collectively make up an organism's mass (Stewart, 2010) and in a sporting context is concerned with the relative proportion of lean body mass and body fat mass within the body (Marriott and Grumstrup-Scott, 1992). The major components of body composition include fat mass, fat-free mass, total body fat, bone mineral content, bone mineral density and total body water (Siervogel *et al.*, 2003; Wells and Fewtrell, 2006). However, there are approximately forty body components, which are systematically categorised into five increasingly complex levels: i) atomic, ii) molecular, iii) cellular, iv) tissue system and v) whole body. This comprehensive 5 complex level model grants the convenience to clearly detailed body composition concepts and construct explicit body composition equations (Wang, 1997).

1.2 The importance of body composition in the general population

Body composition has been linked to a verity of health-related concerns including obesity, diabetes (Stefanaki *et al.*, 2018), cardiovascular disease and cancers (Kuriyan, 2018). Due to an increasing prevalence of obesity and lifestyle diseases there is a greater requirement for body composition assessment tools with enhanced precision and sensitivity (Kuriyan, 2018). There are various ways in which body composition can be assessed, including dual energy X-ray absorptiometry, skinfold anthropometry and bioelectrical impedance analysis (Kuriyan, 2018) each with their own strengths and limitations.

1.3 Body composition assessment for athletes

Beyond the general population, the measurement of body composition in athletes has become increasingly considered in practice, as the absolute and relative amounts of the body components are widely assumed to be an important determinant for athletic performance (Campa et al, 2021). In numerous sports athletes can gain an advantage through altering their body mass or body composition features. For example, gymnastics involves aesthetic and gravitational components, thereby, anthropometric characteristics may influence a gymnast's success (Bacciotti *et al.,* 2017). Furthermore, certain sports such as boxing and powerlifting are weight-classified, thus, athletes must maintain a certain body mass (Franchini *et al.,* 2012).

Beyond these more obvious examples, the aspects of body composition assumed important for sport performance vary, such as the amount of and distribution of body fat and lean mass. Lean mass is defined as the weight of the muscles, bones, tendons, ligaments and internal organs and is calculated by subtracting body fat from total body mass (Kravitz and Heyward, 1992; Frost *et al.,* 2014). Lean mass differs from fat-free mass as there is an essential amount of fat in the marrow of bones and internal organs, thereby, lean body mass involves a small percentage of essential fat (Kravitz and Heyward, 1992). Lean mass and fat-free mass are believed to be important health outcomes in athletes as lean mass may be linked with competitive success (Wells and Fewtrell, 2006; Sanchez-Munoz *et al.,* 2017). Lean mass is regarded to be an important determinant of performance in sports requiring high muscle strength or power (Garthe *et al.,* 2011), such as rugby union. Lean mass has a higher metabolic demand in comparison to fat mass and during exercise metabolic demands of lean mass can quickly increase in order to meet the energy requirements of the activity (Hepple, 2000). Additionally, fat mass has negative connotations regarding athletic performance such as hydrodynamic drag in swimmers and power-to-weight ratio (Sesbreno *et al.,* 2020).

1.4 Body composition for performance

While increased fat-free mass is generally assumed to be positive, increases in fat mass have been found to both benefit and hinder athletic performance (Hyatt and Kavazis, 2019). Gabbett (2005a) and Gorla and colleagues (2016) suggest that carrying excess body fat has a detrimental effect on performance. Body weight and the degree of excess body fat may impair performance variables including power-to-weight ratio (Meir, 2001), thermoregulation (Duthie *et al.,* 2003), endurance potential, speed and acceleration (Duthie, 2006). Where extra mass consists of fat rather than lean mass, the power-to-weight ratio is reduced and energy expenditure is increased during movement (Duthie *et al.*, 2003). Furthermore, enhanced lean mass and reduced fat mass can positively influence power-to-weight ratio, thereby improving the potential proliferate momentum, speed, strength and power (Bell *et al.,* 2005; McHugh *et al.,* 2021), thereby, a coach must consider the ideal anthropometry of the players according to their positional demands (Hansen *et al.,* 2011). A greater fat mass is linked with a greater reliance on carbohydrate metabolism (Higham et al, 2014), which may negatively impact thermoregulation (Selkirk and McLellan, 2001). Strategies to reduce the impact of thermoregulatory stress on rugby athletes includes weighing players before and after training and matches, implementing appropriate fluid intake and acclimatisation protocols and educating players on the role of fluid intake and its importance regarding recovery and performance (Gabbett *et al.,* 2008). Additionally, body composition may change during the competitive season. An increase in fat mass during the competitive season is believed to negatively impair performance by acting as theoretical ‘dead weight’ which increases energy expenditure during match-specific actions such as jumping and sprinting (Hartmann Nunes *et al.,* 2020).

1.5 Body composition in rugby

One such sport where the role of body composition is gaining more interest is rugby union, where body fat and fat-free mass are believed to be critical compartments of performance (Özkan *et al.,* 2012). The need to increase body mass, specifically fat-free mass, to gain a competitive advantage in rugby has become increasingly prevalent since professionalism was established in 1995 (Quarrie and Hopkins, 2007). Increased fat-free mass is associated with gains in muscle mass, which in turn increases the potential to produce force during performance, enhances strength, power, speed and endurance (Cormie *et al.,* 2007; Gorla *et al.,* 2016). Increases in lean mass has been found to improve impact forces during tackling (Pain *et al.,* 2008) as well as during scrums (Quarrie and Wilson, 2000). Conversely, low levels of fat mass may be beneficial in relation to rugby performance as the ability to accelerate may be hindered by additional fat mass (Till *et al.,* 2014). However, there is little understanding of how or if body composition may contribute to success at the highest elite levels of the sport.

1.6 Dual energy X-ray absorptiometry for body composition analysis

Due to its importance to performance, high-precision methods for body composition analysis are increasingly carried out in professional sport with the objective of monitoring acute changes in physiological status of athletes (Campa *et al.,* 2021). DXA is a quantitative imaging procedure traditionally used to measure bone mineral density and for the diagnosis of osteopenia and osteoporosis; however, newer applications include the assessments of lean and fat mass. During a DXA scan, low ionising radiation X-rays pass through the body, and the rate of energy attenuation can determine tissue type, density and mass (Shepherd *et al.,* 2017).

DXA utilises a three-compartment model (3-C) to analyse body composition in the form of bone mineral content, lean mass and fat mass (Harley *et al.,* 2011). DXA provides precise measurements of total soft tissue composition (Kutáč *et al.,* 2019) and can generate information for regional body segments. This method has become the “gold standard” for presenting information on three components of body composition: ‘fat mass’, ‘lean mass’, more accurately called ‘fat-free soft tissue’ and ‘bone mineral content’ and displays excellent reproducibility when following standardised protocols (Van Loan, 1998; Nana *et al.,* 2015; Keil *et al.,* 2016). The capability of this method to detect small changes (0.5%) (Stewart and Hannan, 2000) is important when examining athletes as the fluctuations in these compartments linked with physical training regularly led to violations of the assumptions of the traditional two-compartment model (fat and fat-free mass) (Sutton *et al.,* 2009; Shepherd *et al.,* 2017). In addition to the accurate detection of lean mass and fat mass, DXA has the ability to detect changes in bone mineral content over a competitive rugby season, which has not previously been found (Harley *et al.,* 2011). Within rugby union, body composition has typically been assessed through skinfolds given their portability and ease of use (Zemski *et al.,* 2019). However, the use of DXA has gained popularity and become more accessible within professional athletes and particularly professional rugby players (Barlow *et al.,* 2015; Morehen *et al.,* 2015; Nana *et al.,* 2015; Zemski *et al.,* 2015; Lees *et al.,* 2017), thereby demonstrating the relevance and importance of this study.

1.7 Rationale

Despite the recent interest in body composition and performance, several questions still remain, especially in regard to elite performance. In a complex game such as rugby, morphological characteristics and body composition are of critical importance, though their precise interaction with elite performance remains unclear (Silvestre *et al.,* 2006; Bjelica *et al.,* 2019).   The professional team within this study can be accurately defined as elite and the university level team can be considered a combination of national and development level player (McKay *et al.,* 2021). Developmental athletes are defined as individuals who train regularly (approximately three times per week) with a purpose to compete at a local level. National level athletes are referred to as individuals who compete at a national level and achievement of within around 20% of world-record performance. Elite level athletes are defined as highly skilled athletes and team-sport athletes competing at an international level and achieving within 7% of world-record performance. Rugby union performance is determined by a range of fitness metrics including speed, strength, power and aerobic fitness in order to perform efficiently and meet the physical demands of the sport (Smart *et al.,* 2014). Rugby union players all display varying levels of physical characteristics including anthropometric (stature and mass) and body composition (lean mass, fat mass and bone mass) in order to achieve sufficient levels of the desired aforementioned fitness qualities and to meet the specific positional demands of the sport (Brazier *et al.,* 2020). Also, there is a lack of clarity regarding the relationship between age and body composition in athletes (Nikolaidis and Karydis, 2011). A study by Manna and colleagues (2010) included 120 football players categorised into four age groups, under 16, under 19, under 23 and senior. Under 19 players reported a lower body fat percentage and higher fat free mass compared to the under 16 players, indicating a relationship between age and body composition across adolescence. Additionally, there is limited research directly comparing relationships between characteristics within professional rugby union forwards and backs, despite the varying performance demands of these positions (Posthumus *et al.*, 2020a). Thereby, this study will explore and compare body composition and anthropometric measurements between elite and national and developmental rugby union players as well as positional differences to fill these critical gaps in the literature.

1.8 Research aim and questions

This thesis aims to examine body composition within rugby union. This thesis will examine body composition assessed using DXA to measure lean mass, fat mass, bone mineral content and percentage body fat in elite level and developmental and national level rugby union athletes. It was hypothesised that elite level rugby players will possess significantly greater amounts of lean mass and smaller amounts of fat mass compared to national and developmental level athletes. Additionally, it was hypothesised that elite level rugby players would be significantly older, taller and heavier compared to national and developmental level players. In terms of playing position, it was hypothesised that forwards would demonstrate greater stature and levels of lean mass, fat mass, bone content compared to backs.

1. Do anthropometric measures (stature and body mass) differ between elite players and national and developmental players?
2. Does body composition (lean and fat mass) differ according to playing position?

This thesis will examine and compare anthropometric profiles and body composition in first team University male rugby union players (a combination of national and developmental level athletes) and first team professional rugby union players (elite level). Anthropometric measurements will consist of stature (cm) and body mass (kg). Body composition will be assessed through DXA and composes of measurements of lean mass and fat mass.

Chapter 2: Literature Review

2.1 Rugby union

Rugby union is a field-based contact sport involving 2 teams of 15 players played over a duration of two 40-minute halves. The objective is to advance the ball down the field into the opposition's territory to score a try (World Rugby, 2023). The ball is only permitted to be passed backwards, but it can be carried or kicked into the opposition's territory (Gissane *et al.,* 2002). The sport gained professional status in 1995 (Argus *et al.*, 2012; Hill *et al.*, 2018). Rugby continues to grow in popularity and it is played in 120 countries by 7.23 million players, of which 1.76 million are female (Viviers *et al.,* 2018). Furthermore, 4.91 million players are not registered with an official body and are therefore referred to as recreational players (World Rugby, 2022).

2.1.1 Competition structure in England

In the UK, there are three national leagues which make up the professional structure of rugby union and there are approximately 382,000 registered professional rugby union players within England (Last Word on Sports, 2020). The highest level of participation in rugby union is the Gallagher Premiership, also referred to as Premiership Rugby (https://www.premiershiprugby.com), consisting of the top 13 professional clubs in England, including the elite team (McKay *et al.*, 2021) in this study. The second-tier of rugby union is the Rugby Football Union (RFU) championship consisting of 12 professional clubs. The third tier of rugby union in England are the national leagues. Level three (National League 1) consists of 14 teams with the champions being promoted to the second tier RFU Championship and the bottom three teams relegated to level four. Level four (National League 2 East, National League 2 West and National League 2 North) consists of three leagues of 14 teams each. The three league champions are promoted, with the bottom two teams in each league relegated to their respective regional division.

Below professional status, in many parts of England, amateur rugby union is associated with fee-paying independent schools who historically have produced many of the national players. Although, presently it is often played at comprehensive and grammar schools. The Rugby Football Union (RFU) governs age-grade rugby in relation to participation within the game along with the identification and development of talented young amateur players. These identification and development programmes are delivered by fourteen regional academies typically aligned with professional rugby union clubs. Amateur players are often identified from community or school rugby and invited to train within a regional academy from around 15 years old, before potentially signing a professional contract at 18 (Till *et al.*, 2020). The British Universities and Colleges Sport (BUCS) is the national governing body for higher education sport in the UK. BUCS works with its member institutions, including the national/developmental (McKay *et al.*, 2021) team in this study, to get more students active and involved in competitive sport (British Universities and Colleges Sport, 2023).

2.1.2 Classifications of athlete performance levels

Sports science and sports medicine literature involving individuals ranging from ‘elite’ to ‘sedentary’ has evolved over time without clear terminology to categorise the training or experience status of an individual or group (McKay *et al.*, 2021). The term ‘elite’ is suggested to be one of the most over-used and ill-defined terms within sport science literature (McKay *et al.*, 2021). Recent work from McKay and colleagues (2021) established a participant classification framework including five tiers along with criteria for that classification. Tier 0 is defined as sedentary and encompasses approximately 46% of the global population. Individuals in this category do not meet the minimum activity guidelines. Tier 1 is defined as recreationally active and encompasses approximately 35 to 42% of the global population. Individuals in this category meet the World Health Organisation minimum activity guidelines (Bull *et al.,* 2020). Tier 2 is referred to as trained/developmental and includes approximately 12 to 19% of the global population. Individuals in this sector train regularly (approximately three times per week) with a purpose to compete at a local level. Tier 3 is known as highly trained/national level and involves approximately 0.014% of the global population. Individuals in this category compete at a national level and achievement of within around 20% of world-record performance. Tier 4 is the elite/international level and involves approximately 0.0025% of the global population. This includes highly skilled athletes and team-sport athletes competing at an international level and achieving within 7% of world-record performance. Tier 5 is world class and encompasses less than 0.00006% of the global population. This tier includes Olympic and/or world medallists displaying an exceptional skill level. Therefore, based on the aforementioned classifications, the professional team within this study can be accurately defined as elite and the university level team can be considered a combination of national and development level player.

2.1.2 Positional responsibilities

Within rugby union, players are categorised into two distinct positional groups, forwards (prop, hooker, lock, flanker and no. 8) and backs (scrum half, fly-half, centre, wing and full-back) (Delahunt *et al.,* 2013; Quarrie *et al.,* 2013). Within the forward and back units, players are required to perform match-specific tasks unique to that position (Delahunt *et al.,* 2013). Forwards are numbered 1 to 8 and are the primary drivers of the scrum as well as being responsible for high-intensity contact actions, such as mauls, lineouts and rucks (Quarrie *et al.,* 2013). A vital demand for forwards is to gain and retain possession of the ball and ensure they are available in attack by carrying the ball in close spaces (Delahunt *et al.,* 2013; Quarrie *et al.,* 2013). Backs are numbered 9 to 15 and consist of inside backs, midfield and outside backs (Watkins *et al.,* 2021). The primary role of the back unit is to evade defenders while carrying the ball in an open space, though they also have the responsibility of gaining possession of the ball in tackles and rucks (Delahunt *et al.,* 2013). Backs are required to be fast and agile in order to out-manoeuvre the opposition to create scoring opportunities from open spaces (Duthie *et al.,* 2003).

2.2 The physical demands of rugby union

There has been an increase in intensity of match-play and physical demands placed upon rugby union players over recent years (Virr *et al.,* 2014). Throughout an 80-minute match, the ball is typically in play for approximately 30 minutes, with the remaining time composing of injury time, conversions, penalty kicks or when the ball is out of play (Duthie *et al.,* 2003). Throughout competitive match play, players generally cover distances ranging from 90 to 100 metres per minute (Gabbett *et al.,* 2012) or 4,500 to 7,500 m per match, though distances differ among playing positions (Watkins *et al.,* 2021). The demands of rugby union are broadly defined by the high frequency of physical contacts, aerobic demands and repeated intermittent periods of high intensity activity (Posthumus *et al.,* 2020; Hamlin *et al.,* 2021). In order to execute these physiological demands, players require agility, speed, acceleration, endurance, muscle strength and power as well as rugby-specific skills (Higham *et al.,* 2013; Whitehead *et al.,* 2018; Read *et al.,* 2019). Table 1 provides an overview of examples of components of fitness which are critical to successful rugby performance.

Table 1: Components of fitness relevant to rugby union performance

Component	***Definition***	***Relevance to rugby union***
Agility	Agility has been defined as decision-making and anticipation of opponent's movements (Young *et al.*, 2002).	Agility is relevant in rugby union for attackers when outmanoeuvring defenders, advancing the ball forward and when aiming to maintain possession (Sayers, 1999; Young *et al.*, 2021). It is also critical for defenders to obtain developed agility to allow quick movements and precisely block attackers with the main aim of retrieving possession of the ball (Young *et al.*, 2021).
Aerobic and anaerobic demands	Aerobic and anaerobic power is referred to as repeated maximal or sub-maximal intensive activity which demands a high oxidative energy level (Ahsan and Ali, 2021).	Aerobic fitness and power are pivotal aspects of performance as rugby players cover approximately 4000 to 8000 m each match, of which 19% is covered at speeds of more than 5 m s^{-1}. This also includes frequent bouts of accelerating, decelerating and sprinting (Higham *et al.*, 2012; Suarez-Arrones *et al.*, 2012).
Muscle strength and power	Muscular strength has been defined as the ability to exert force on an external object or resistance (Suchomel *et al.*, 2016).	Muscular power is relevant to rugby as players are involved in numerous intense physical collisions and high velocity movements (Cronin and Hansen, 2005). Developed strength and power is critical in tackling, absorbing impacts and in evading an opponent (Johnston *et al.*, 2014). It can also lead to a reduction of injury risk (Redman *et al.*, 2021).
Speed	Speed is defined as the ability to move the body as quickly as possible over a set distance and relies heavily on a quick initial start and maintaining this speed over the given distance (Horicka *et al.*, 2014; Yu *et al.*, 2016).	Speed and acceleration are pivotal to competitive success across all levels of rugby union, although, positional demands influence a player's expression of force and velocity during match play (Watkins *et al.*, 2021). The stop-start nature of rugby union involves highly explosive sprints and high-intensity running, therefore it is vital for all players to maintain good acceleration and lower-limb explosive power as mean sprints range from 11 to 20 m during matches (Duthie *et al.*, 2005).

2.2.1 The demands of rugby union according to playing position

Specialist roles throughout match play determine the physiological demands of each position with forwards labelled as the ball winners and backs the ball carriers (Lindsay *et al.*, 2015). The match play of forwards typically involves close opposition contact, which requires high levels of strength and power to gain and retain possession of the ball (Swabi *et al.*, 2016). With forwards, as there are two distinct positions, the physical demands differ between positions. Front row forwards require greater body mass, while the second row requires tall, athletic players for jump height during line-outs (Duthie *et al.*, 2003). Forwards are often involved in a high number of physical collisions with the opposition to secure possession of the ball during line-outs, rucks, mauls and scrums. Forwards also engage in more high-intensity activity and bouts than backs (Roberts *et al.*, 2008). However, they are also required to be available in attack by carrying the ball in close quarters (Delahunt *et al.*, 2013). Forwards have been found to obtain greater absolute aerobic and anaerobic power and muscular strength (Zemski *et al.*, 2015). This is contrary to the other primary category of position in rugby, backs, whereas, backs tend to be faster and display greater agility and engage in more running than forwards (Delahunt *et al.*, 2013; Read *et al.*, 2019; Weaving *et al.*, 2019). Similar to forwards, inside backs experience high contact incidences with the opposition, therefore, they are required to display strength and power. However, most physical aspects for backs heavily emphasise speed and aerobic endurance, due to defensive demands and the need to evade the opposition (Brazier *et al.*, 2020). Therefore, backs spend more time in high-intensity running and sprinting than forwards, thus backs cover a greater distance compared to forwards (Roberts *et al.*, 2008).

Due to the physiological demands, it has been suggested that a specific body composition profile may be necessary for success at the various positions. Distinct anthropometric and body composition characteristics are necessary for certain positions in order to meet the physical demands of the sport (Duthie *et al.*, 2003). Sufficient amounts of body mass in terms of lean mass, fat mass and bone mass are vital in order to withstand the frequent and intense collisions during offensive and defensive match-play (Zemski *et al.,* 2015). Delahunt and colleagues (2013) state specific anthropometric profiles between forwards and backs are required to execute match-specific tasks effectively. Additionally, evidence suggests that the general classification of players into forwards and backs is fundamental as varying physiological attributes and skill sets are mandatory for each designated position (Cunniffe *et al.,* 2009; Coughlan *et al.,* 2011). Findings from the work of Delahunt and colleagues (2015) showed forwards to be statistically heavier (83.6 ± 10.5 vs 73.6 ± 6.6 kg) and taller (1.82 ± 7.1 vs 1.78 ± 5.6 m) compared to backs and forwards obtained a greater body fat percentage (18.4 ± 5.9 vs 14.3 ± 3.0 %). These statistics demonstrate that specific anthropometric profiles differ between forwards and backs due to the physical demands of their positions as forwards are involved in more physical collisions such as tackling and rucking, with a greater total-body mass and height being associated with competitive success (Sedeaud *et al.,* 2012). On the other hand, backs engage in more open space running and require high velocity multidirectional sprinting and agility, therefore, a lean body mass is required (Duthie *et al.,* 2003).

2.3 Body composition and performance in rugby

Previous research indicates a link between body composition and rugby performance (Posthumus *et al.,* 2020a). It has been suggested by Smart and colleagues (2014) that decreases in body fat percentage may improve work rate and the ability to repeatedly execute tasks in competition, additionally, it has been found that as playing level increases from semi-professional to professional, players are heavier, possess greater lean mass and lower body fat percentages, while displaying greater speed, strength and power (Smart *et al.,* 2013), Rugby athletes all obtain varying anthropometric and body composition measurements in order to reach the required levels of fitness and meet specific positional demands (Stoop *et al.,* 2019; Brazier *et al.,* 2020). This profile may be determined depending upon where in the programming cycle the player is. The long-term cyclical programming of training in rugby is comprised of three definitive phases; pre-season, in-season and off-season (Dobbin *et al.,* 2020). The pre-season and in-season phase focus on adaptation and between-match recovery, whereas, during the off-season a substantial reduction or complete breakdown of training may occur with the aim of promoting recovery and mental regeneration (Silva *et al.,* 2016). Short periods of recovery (1-3 weeks) have been found to have a positive effect on performance, though an extended off-season without frequent training may cause the loss of physiological and neuromuscular adaptation (Joo, 2018). This can negatively impair physical and anthropometric characteristics such as aerobic capacity, sprint ability, strength and power as well as body composition (Nirmalendran and Ingle, 2010; Koundourakis *et al.,* 2014). This means that body composition in athletes will be highly dependent on where in the season they are. Each phase of the training cycle may also have its own unique body composition profile.

The maintenance of increased lean mass and decreased fat mass throughout the competitive season is a primary intention for most players (Argus *et al.,* 2010). This is believed to be linked with health and performance benefits through the ergolytic effects of excessive body fat on the expenditure of energy and movement economy (Lees *et al.,* 2017). Increased lean mass is advantageous to contact sport athletes who are involved in high force collisions (Morehen *et al.,* 2020). Newtons second law of motion (force = mass x acceleration) demonstrates the importance of enhancing lean muscle mass as increases in body mass and lower body power can enhance acceleration and result in greater force production (Granacher *et al.*, 2016). A study by Lees and colleagues (2017) examined body composition changes among professional rugby players over a competitive rugby season using DXA. It was reported that body composition shifts were present as fat mass increased throughout the season and this was abetted with a decrease in lean mass from mid-season to the end of the season in backs and pre-season to end of season in forwards. Crucially, individual analysis highlighted a loss of lean mass was prevalent mid-end season, without regard to playing position, suggesting that fat mass gains preceded losses in lean mass. This may have been down to a decreased duration of gym-based training sessions and reduced competitive demands towards the end of the season, in contrast with the beginning of the season (Lees *et al.,* 2017), Similarly, Georgeson and colleagues (2012) concluded that body composition altered over a competitive season in professional male rugby players as they were found to lose lean mass and gain fat mass as the season progressed. Interestingly, whole body bone mineral density increased until mid-season and decreased thereafter. Furthermore, Gabbett (2005a) found a decrease in lean mass and increase in fat mass (+ 6.7%) in rugby players over the season. This may cause performance implications such as changes in speed, power, agility and strength of players due to a reduced power to body mass ratio and match specific activity. While the quantification of body fat has been the main focus of attention, many scientists and coaches working with elite athletes understand that the level and distribution of lean mass can be just as integral to athletic performance (Ackland *et al.*, 2012). As noted by Ackland and colleagues (2012), the association between the muscle cross-sectional area and the generation of force and power is widely accepted, thereby alterations in muscle size becomes a vital assessment parameter during the preparation phase for high level competition.

Throughout a competitive season the main goal for players is to maintain improvements in strength, power and lean mass from the pre-season phase (Baker, 2001), though this is suggested to be difficult as conditioning volume during the season is reduced (Argus *et al.,* 2009). Performance over a season has been found to change as the work of Argus and colleagues (2009) examined alterations in strength and power over the season. Bench press and box squat one repetition maximum was assessed among professional rugby players and a trivial decrease in bench press strength (-1.7kg) was found, while a slight increase in box squat strength (16 kg) was evident from the start to the end of the season. Additionally, bench throw power decreased (-40 W), as did jump squat power (-175 W) throughout the season. Although body composition and performance alter over a competitive season, strength and power has been shown to be consistent throughout a playing career in rugby union players (Appleby *et al.,* 2012). Although, Barr and colleagues (2014) indicate a window for adaption exists in in developing sprint momentum and speed. This window is perhaps greater for athletes in their late teens and early twenties, compared to athletes in their late twenties. Therefore, the development of sprint momentum and speed should be of critical importance for this age group. However, research conducted by Stodden and Galitski (2010) reported that the development of speed is far more restricted when compared to strength in American university football players. This is believed to be the case as speed peaks early as a physical ability in contact field-sport players, though sprint momentum may continue to develop over time as athletes gain muscle mass (Appleby *et al.,* 2012).

2.4 The measurement of body composition in elite sport

Body composition is often carried out in professional sport for the purpose of monitoring acute alterations in physiological status, using a range of methods, in order to analyse individual levels of body mass, lean tissue mass and fat mass with high level precision (Ellis, 2000; Harley *et al.,* 2011; Hind *et al.,* 2011). The measurement of body composition is routine practice across sport (Kasper *et al.,* 2021). Body composition has typically been measured utilising skinfold measurements which is an accessible and robust method used in rugby union (Ackland *et al.,* 2012; Zemski *et al.,* 2018; Zemski *et al.,* 2019). However, surface anthropometry measurements are inadequate to precisely quantify changes in fat mass and fat free mass (Silva *et al.,* 2009; Zemski *et al.,* 2018). Due to this restraint, body composition assessments are being completed by other accurate methods such as DXA, bioelectrical impedance analysis and air displacement plethysmography (e.g. BodPod) (Duren *et al.,* 2008; Zemski *et al.,* 2019; Posthumus *et al.,* 2020a; Kasper *et al.,* 2021).

2.4.1 Skinfold/surface anthropometry

Skinfold anthropometry involves the use of a caliper to measure a double fold of gripped skin over a range of sites to identify an overall measurement of subcutaneous adiposity (Kasper *et al.,* 2021). Skinfold analysis is an example of a two-compartment (2-C) model of body composition and has been found to significantly overestimate body fat percentage among elite rugby players. Particularly, when utilising the Durnin and Womersley (1974) four-site (biceps, triceps, subscapular, suprailiac) and Jackson and Pollock (1978) seven-site equation in comparison to DXA, a three-compartment (3-C) reference model of body composition assessment (Harley *et al.,* 2009). Additionally, other 2-C models, including the Jackson and Pollock (1978) three-site skinfold equation, when utilising the Brozek (1963) or Siri (1961) equations to convert body density to body fat percentage have been reported to significantly underestimate body fat percentage within this population (Harley *et al.,* 2009). It is widely accepted that skinfold-based regression equations are not an effective or accurate method of measuring and monitoring body composition in rugby union (Zemski *et al.,* 2018), nor changes among athletes generally (Silva *et al.,* 2009). However, according to Zemski and colleagues (2019), skinfolds are a useful proxy in identifying the direction of changes in fat mass when compared to DXA, although they do not have the ability to precisely estimate the magnitude of changes. This method is also unable to quantify lean mass; therefore, practitioners today opt to utilise only the sum of skinfolds rather than the accompanying regression equations. This is likely the case as there are currently over one hundred equations to estimate body fat percentage from skinfold thickness and they have not been validated when tracking regular alterations in body composition (Silva *et al.,* 2009). In addition, these equations are established across varying populations, using different protocols and frequently display intra-practitioner and criterion variability and reliability issues (Kasper *et al.,* 2021).

2.4.2 Bioelectrical impedance analysis (BIA)

BIA is typically used within general populations for body composition assessment given the speed, portability and lower cost in comparison to other methods (Kasper *et al.,* 2021). This technique calculates the fat-free mass of participants using the known electrical resistance of body tissues (Delaney *et al.,* 2016). Bioelectrical impedance analysis estimates body fat mass and lean body mass by regulating a weak alternating electrical current which flow at different speeds depending on tissue type (Ramos-Álvarez *et al.,* 2021). This current is easily conducted by tissues rich in water and electrolytes including muscles and blood, and is impeded in spaces filled with air, bone and fat (Mulasi *et al.,* 2015). Suggested by Kyle and colleagues (2004) factors including food and fluid intake and physical activity may impact total body water and thereby BIA outcomes. This method may not provide the reliability of other methods as the water content of cells highly influences the measures (Moon, 2013). Furthermore, this method has also demonstrated limited use among groups of athletes who had undergone alterations in body composition, body weight or body-fluid volume (Lukaski, 2013). This is due to limited athlete-specific equations and a lack of knowledge regarding predictive equations used by BIA manufactures to estimate fat-free mass and/or fat mass (de la Cruz Marcos *et al.,* 2021). This method may also be problematic when examining team-sport athletes as body composition has been found to significantly alter as a training programme progresses, therefore other methods may be more effective (Morgan and Callister, 2011). Additionally, there is limited research among athletic populations regarding the validation of BIA methods to examine fat mass and fat free mass, with conflicting findings in comparison to reference methodologies like DXA. An underestimation of fat mass and overestimation of fat free mass has been found in the literature (Hartmann *et al.,* 2020; Syed-Abdul *et al.,* 2021).

2.4.3 Air displacement plethysmography

Air displacement plethysmography (ADP) is a substitute for hydrostatic weighing and shows greater practicality in applied sport, whereby rather than water, air is used to measure body density (Kasper *et al.,* 2021). A common example of ADP is the BodPod. This apparatus uses Poisson's Law to compute air displacement and converts this into a volumetric calculation. Isothermal air, the air trapped near the skin, hair, clothing and lungs, is then calculated by inbuilt systems or generated through a prediction formula and combined to measure a corrected body volume and composition (Higgins *et al.,* 2001; Kasper *et al.,* 2021). While ADP has been found to have high levels of reliability, this method is insufficiently sensitive when identifying in-competition changes in an athletes' body composition (Kasper *et al.,* 2021) and is sensitive to pressure, temperature alterations and clothing (Higgins *et al.,* 2001; Peeters and Claessens, 2011). ADP has been reported to overestimate percentage body fat by at least 1.28% when compared to hydro-densitometry (Gibby *et al.,* 2017) and ADP diverges at the extremes of the BMI spectrum, which may cause concern among certain athletic populations (Lowry and Tomiyama, 2015). Furthermore, ADP is unable to differentiate fat mass distribution, thereby, in an applied sport context, this method is not widely used (Kasper *et al.,* 2021).

2.4.4 Dual-energy X-ray absorptiometry

DXA is growing in popularity and is becoming more accessible as a method of monitoring body composition among athletes (Nana *et al.,* 2015). Given that DXA can quantify regional and whole-body tissue, its use is beneficial in rugby as it can estimate nutritional requirements and monitor injury rehabilitation (Ackland *et al.,* 2012). DXA utilises two X-ray intensities which assess bone mineral and soft tissue masses separately and is more accurate and faster to examine compared to other imaging methods such as computed tomography and magnetic resonance imaging (Seabolt *et al.,* 2015; Hind *et al.,* 2018; Kutáč *et al.,* 2019). Over the past few decades, DXA has become the most distinguished method of body composition assessment through total body scans (Thurlow *et al.,* 2018). DXA provides a 3-compartment model to assess body composition in terms of bone mineral content, fat mass and lean mass at total body and regional level, to a high level of precision (Milanese *et al.,* 2012; Barlow *et al.,* 2015; Thurlow *et al.,* 2018).

DXA models are either fan beam or pencil beam. Fan beams use a wider X-ray beam which results in a shorter scan time and greater image resolution (Ackland *et al.,* 2012). With the pencil beam, X-ray passes through a narrow collimator and the data is gained by a rectilinear pattern separated by millimetres over the participant’s longitudinal axis (Pludowski *et al.,* 2010). Scans allow for a rapid assessment of body composition as they are completed in approximately 6.5 or 12.5 minutes, depending on the scan mode (Thurlow *et al.,* 2018). However, DXA is a costlier and less accessible method of assessment compared to others such as skinfolds, although it has been reported to be able to identifying changes in body composition among highly trained athletes (Bilsborough *et al.*, 2014; Farley *et al.*, 2020). DXA has been found to show accurate estimations of body composition when compared to the 4-C model which is more demanding in assessing body composition of young adults varying in race, gender, body size, body fatness, athletic size and musculoskeletal development (Van Der Ploeg *et al.*, 2003; Milanese *et al.*, 2012). Additionally, the 4-C model can be more time consuming and expensive, though it is accepted as a reference method for body composition analysis (Van Der Ploeg *et al.*, 2003).

The advantages of DXA according to Nana and colleagues (2015) include the ability to assess regional body composition, speed of acquisition and is a non-intrusive method. The low radiation dose, which is typically reported to be around 2-6 μSv depending on the scan mode, makes DXA suitable for longitudinal monitoring but it is recommended to leave at least 6 weeks between scans (Thurlow *et al.*, 2017; Hind, 2022). On the other hand, DXA can be more expensive than other methods, is non-portable and requires a trained and certified technician. Furthermore, the manufacturers' body composition estimation algorithms are not developed from athletes and it is not possible to directly compare results between different DXA machines unless cross calibration is performed (Nana *et al.*, 2015).

2.4.5 Precision

DXA precision is the capability of the same system and operator to achieve the same result when assessing an individual at multiple points over a short time period (Baim *et al.*, 2005). In addition to operator precision, precision can vary by the size of the athlete (Barlow *et al.*, 2015). Precision error is calculated as the root-mean-square standard deviation (RMS-SD) or % coefficient of variation. When precision error is objectified, least significant change (LSC) is calculated as:

$$\text{RMS-SD} \times 2.77 = \text{LSC}$$

The LSC is the minimum change between two measurements required for 95% confidence than a change has developed (Hangartner *et al.*, 2013; Hind, 2022). A study by Barlow and colleagues (2015) assessing elite male rugby players reported DXA to provide a lean mass precision (%CV) of 1.6% (LSC 4.5%) and fat mass precision of 2.3% (LSC 6.4%). Precision has been reported to be lower for BIA measurements of body composition among elite athletes (Bilsborough *et al.,* 2014).

Precision of body composition methods can be influenced by biological and technical error (Vescovi *et al.,* 2002; Hind *et al.,* 2018). Biological error is typically derived from food and fluid intake or physical exercise prior to assessment (Kerr *et al.*, 2017). Technical error can be a result of level of technical expertise, equipment calibration, positioning and clothing (Marfell-Jones *et al.,* 2012; Hind, 2022). Limiting precision error is vital during scanning, thereby, there is a requirement to include standardised pre-scan protocols which aid in minimising biological and technical error (Hind *et al.,* 2018).

Table 2 below summarises the findings from Farley and colleagues (2020) who reported precision error from different body composition methods. Their conclusions show greater precision error for fat mass compared to lean mass measurements across all measurement types. Additionally, there was variation in precision between methods, with greater precision for DXA and skinfolds, conveying high test-retest reliability and accuracy.

Table 2: A comparison of precision error of different body composition assessment methods (Farley *et al.*, 2020, p10)

	Fat mass		***Lean mass***	
Method	%CV	LSC	%CV	LSC
DXA	1.5	4.2	0.5	1.3
Skinfolds	1.0	2.9	0.2	0.4
Bodpod	2.5	6.9	0.5	1.3
BIA	5.2	14.4	0.6	1.6

%CV = percentage coefficient of variation, LSC = least significant change

2.5 Rugby union player physique and body composition

Due to the intense nature of rugby union, players are required to demonstrate highly developed physical qualities which closely align with their body composition (Geeson-Brown *et al.*, 2020). At the elite level, players demonstrate superior muscular strength, speed and power compared to sub-elite players (Gabbett *et al.*, 2011) which may be improved by altering body composition, such as enhancing fat free mass (Taber *et al.*, 2019). It is widely suggested that an increase in body fat negatively impacts performance (Hyatt and Kavazis, 2019) as greater levels of fat mass have been associated with a lower power to weight ratio and limit in acceleration ability (Darrall-Jones *et al.*, 2016), while an increase in fat-free mass has been associated with increases in strength, speed and explosiveness (Anding and Oliver, 2015).

2.5.1 The need for body composition assessment in rugby

Since the year 2000, changes in rugby union have resulted in a faster and more attractive match play (Owen *et al.,* 2015), which in turn has altered the demands of each playing position (Quarrie and Hopkins, 2007). Therefore, a preference for taller and heavier players with enhanced physical performance characteristics has appeared (Sedeaud *et al.,* 2012; Lombard *et al.,* 2015). While the direct impact of body composition on performance in sport is still unclear, there is evidence for higher lean mass and lower fat mass at the elite level (Jones *et al.,* 2015). Accordingly, lean mass has found to be related to performance outcomes in athletes involved in high force production sports (Stöggl *et al.,* 2010). Increases in lean mass have been associated with improvements in lower body speed and power in rugby players (Waldron *et al.,* 2014). Stated by Smart and colleagues (2014), an ideal body composition should promote lean mass while reducing fat mass to support the development of speed, power and aerobic capacity. Furthermore, practitioners are likely to desire lower levels of fat mass and the maintenance of sufficient muscle mass compatible with the demands of the sport (Suarez-Arrones *et al.,* 2018). In practice, there is a frequent need to estimate absolute measures of lean mass and fat mass, an example being in the development and assessment of dietary and training interventions (Zemski *et al.,* 2018).

2.5.2 Physique and structure

Table 3: Physique and stature of elite rugby players

Study	***Performance level***	***Position***	***Age (years)***	***Methods***	***Body composition***				
					Body mass (kg)	***Stature (m)***	***Body fat %***	***Fat mass (kg)***	***Lean mass (kg)***
Till et al (2016)	Professional European Super league	Forwards (n=36)	26.3 ± 4.9	DXA	100.4 ± 7.8	1.84 ± 5.6	17.2 ± 3.7	15.4 ± 3.2	76.9 ± 5.1
		Backs (n=27)	26.0 ± 4.3		91.3 ± 8.6	1.81 ± 5.9	15.2 ± 3.4	12.6 ± 2.8	71.3 ± 4.5
Lees et al (2016)	Professional English Premiership (pre-season)	Forwards (n=20)	25.5 ± 4.7	DXA	110 ± 7.6	1.86 ± 7.1	-	26.4 ± 4.9	85.3 ± 5.3

		Backs (n=15)	26.1 ± 4.5		92.5 ± 6.3	1.83 ± 4.0	-	13.4 ± 3.2	74.7 ± 5.7
La Monica et al (2016)	American championship	Forwards (n=13)	Both groups (20.2 ± 1.6)	Skinfold analysis	90.5 ± 12.4	1.8 ± 0.1	12.6 ± 4.2	-	-
		Backs (n=12)			73.7 ± 7.1	1.8 ± 0.1	8.8 ± 2.1	-	-
Zemski et al (2018)	Australian national squad	Forwards (n=23)	26.5 ± 3.4	DXA	112.4 ± 7.3	1.91 ± 7.1	-	17.4 ± 4.0	96.5 ± 6.3
		Backs (n=16)	24.7 ± 2.3		92.2 ± 6.6	1.82 ± 5.4	-	10.8 ± 2.2	82.8 ± 5.9
Posthumus et al (2020a)	New Zealand Super Rugby Championship	Forwards (n=23)	27.2 ± 2.8	DXA	116.5 ± 10.1	1.90 ± 5.9	17.8 ± 2.4	21.1 ± 4.5	92.3 ± 5.7

		Backs (n=16)	25.7 ± 3.8		95.9 ± 9.4	1.83 ± 7.5	14.8 ± 1.2	14.3 ± 1.8	78.5 ± 7.9
Ramos-Álvarez et al (2021)	Spanish national league	Forwards (n=32)	22.4 ± 4.5	BIA	100.1 ± 11.2	1..82 ± 0.05	21.0 ± 7.7	21.1 ± 8.7	73.1 ± 19.8
		Backs (n=33)	20.6 ± 2.1		80.1 ± 8.7	1.78 ± 0.07	16.4 ± 7.4	12.4 ± 5.7	57.0 ± 26.0
Hamlin et al (2021)	Professional	Forwards (n=10)	19.2 ± 0.8	Skinfold analysis	104.3 ± 5.4	1.87 ± 8.8	-	-	-
		Backs (n=14)	18.8 ± 0.7		86.9 ± 7.9	1.83 ± 7.3	-	-	-

As shown by Table 3, forwards are typically significantly taller and heavier than backs and tend to have greater total fat and lean mass. This is believed to be due to the greater number of collisions and lower running demands (Zemski *et al.,* 2015; Weaving *et al.,* 2019; Brazier *et al.,* 2020). However, backs have been found to show a greater percentage lean mass (84.5 ± 85.8 %) compared to forwards (81.0 ± 82.6 %) as well as a lower percentage fat mass (10.0 ± 11.4 vs. 13.4 ± 15.0 %) (Zemski *et al.,* 2015). Accordingly, research conducted by Fontana and colleagues (2015) involving 362 professional rugby players, compared forwards and backs anthropometrically. Forwards were found to be heavier (106.1 ± 1 vs. 87.9 ± 9.1 kg) and taller (1.86 ± 0.07 vs. 1.80 ± 0.06 m) in comparison to backs. Forwards also demonstrated a greater body fat percentage (19.1 ± 5.9 vs. 12.4 ± 4.6 %) and fat free mass (85.5 ± 7.3 vs. 76.8 ± 6.9 kg) compared to backs.

2.5.3 Body mass

A greater body mass has been deemed to be a predictor of success in rugby (Austin *et al.,* 2011). Stated by Darrall-Jones and colleagues (2015), age-grade rugby players' stature and body mass are higher in forwards compared to backs (Darrall-Jones *et al.,* 2016). A sufficient quantity of body mass in terms of fat mass, lean mass and bone mass are believed to be crucial in order to withstand the intensity and frequency of collisions during defensive and offensive match-play (Zemski *et al.,* 2015). The significance of anthropometrics on team success in professional rugby union has been examined (Barr *et al.,* 2014). From this it has been suggested that possessing larger players, in particular, heavier forwards and taller backs, typically results in greater team success in World Cup competition (Posthumus *et al.,* 2020a). According to Brazier and colleagues (2020), if the extra body mass comprises fat rather than lean tissue, this can reduce a player's power-to-weight ratio and acceleration in the horizontal and vertical planes is reduced. Excess body fat has been found to negatively affect rugby performance as it has been reported to negatively impair tackling ability among senior semi-professional male rugby players (Gabbett *et al.*, 2011). Additionally, negative correlations have been reported between increased body mass and critical physical traits such as speed and aerobic performance (Darrall-Jones *et al.,* 2016; Lees *et al.,* 2017). Suggested by Smart and colleagues (2014), decreasing body fat percentage may enhance work rate and ability to repeatedly execute actions in competition. However, given that forwards are involved in more tackles and collisions per game, it may be hypothesised that larger body mass is beneficial in the advancement of greater impact forces related to these actions (Gabbett *et al.*, 2008). With backs, attaining an efficient lean-to-fat mass ratio is beneficial to support players to be quicker and more agile to create scoring opportunities (Posthumus *et al.,* 2020a). It has also been suggested that forwards benefit from a higher body fat percentage as it may aid in protection of impact injuries, although there is no significant research to refute or support this (Gabbett *et al.,* 2008). Forwards are involved in 60% more high acceleration and deceleration impacts than backs (Cunniffe *et al.,* 2009), while showing a lower risk of injury (Gabbett *et al.,* 2010). Additionally, the greater body mass obtained by forwards has been associated with greater scrummaging force (Quarrie and Wilson, 2000) as it adds momentum to contact actions (Brazier *et al.,* 2018).

Data indicates that the body mass of elite male rugby players has altered over the past century and is greater than athletes competing in non-contact sports and the average body mass of the general UK population (Olds, 2001; Fuller *et al.,* 2013; Sedeaud *et al.*, 2013; Fontana *et al.,* 2015; Hill *et al.,* 2018; Casserly *et al.,* 2019). The past 25 years has shown that the average body mass of rugby players has risen at a rate twice that of the previous 75 years (Austin *et al.,* 2011). This has been attributed to greater attention regarding athletes' evaluation and development including improved equipment and facilities and specialised training (Fontana *et al.,* 2015). The mass of rugby players has increased dramatically since the sport became professional in 1995 (Hill *et al.,* 2018). Research from Hill and colleagues (2018) examined the mass of rugby players from 1955 to 2015. A 24.3% increase in average player mass from 1955 to 2015 (84.8 kg to 105.4 kg) has been reported (Hill *et al.,* 2018). A small 5% increase in mass was reported between 1955 to 1995, however, a large increase of 20% was found from 1995 to 2015. More specifically, the mass of forwards has steadily increased between 1955 to 2015, though that of backs has mainly increased since 1995 (Hill *et al.,* 2018; Pontaga *et al.,* 2019). This is likely due to rugby gaining professional status (Tucker *et al.,* 2021). An investigation conducted by Tucker and colleagues (2021) examined elite men's rugby player mass between 1991 and 2019. A 9.7% increase was reported from 1991 to 2019 (103 kg to 113 kg), though this increase occurred primarily up to 2011. All rugby players display various levels of physical characteristics, including height and body mass in order to achieve desired levels of the required aforementioned aspects of fitness and to meet the positional demands of the sport (Stoop *et al.,* 2019; Brazier *et al.,* 2020).

2.5.4 Stature

It has been stated that elite level rugby union players demonstrate greater stature compared to sub-elite players (Smart *et al.,* 2013). The stature of elite rugby union players has increased similar to that of the general public over the last century (Olds, 2001). According to Sedeaud and colleagues (2012), during every rugby union World Cup between 1897 and 2007, backs in the quarter-finals, semi-finals and finals winning team were taller than backs of other teams and similar findings were reported for forwards. Similarly, Sedeaud *et al.,* (2013) compared the stature of elite French rugby union players in the 1988-1989 and 2008-2009 seasons. Both forwards and backs were found to be taller by a mean of 2.9 and 5.4 cm respectively. Similarly, Fuller and colleagues (2013) reported changes in English Premiership rugby union players during 2002 to 2011. Significant increases in stature were found in forwards (~1.3 cm) and backs (~1.4 cm) over this time period. These findings mirror the widely accepted assumption that taller players are more likely to progress from the sub-elite to the elite level (Stoop *et al.*, 2018). As stated by Olds (2001), teams with taller players tend to win a greater number of matches, thereby this anthropometric advantage is critical in rugby union. As height cannot be influenced through training, it is uniquely a matter of directional selection (Sedeaud *et al.*, 2013).

Table 4: Physique and stature according to playing position (Watkins *et al.*, 2021)

Study	***Performance level***	***Position***	***Body mass (kg)***	***Stature (m)***	***Age (y)***
Watkins et al (2021)	**International**	All positions	107.3 ± 14.0	1.85 ± 0.07	27.3 ± 3.6
		Tight-5 forwards	120.4 ± 9.8	1.87 ± 0.07	28.1 ± 2.7
		Loose forwards	109.5 ± 4.8	1.90 ± 0.04	26.2 ± 3.9
		Inside backs	88.6 ± 8.4	1.77 ± 0.05	27.8 ± 4.1
		Midbacks	99.0 ± 6.5	1.82 ± 0.05	26.0 ± 4.0
		Outside backs	102.8 ± 5.9	1.87 ± 0.05	27.1 ± 4.5
	Professional	All positions	107.9 ± 10.8	1.88 ± 0.06	23.3 ± 3.1
		Tight-5 forwards	115.9 ± 5.3	1.89 ± 0.07	23.8 ± 3.6
		Loose forwards	109.6 ± 6.1	1.91 ± 0.02	23.1 ± 2.7
		Inside backs	91.5 ± 7.4	1.81 ± 0.02	23.8 ± 3.9
		Midbacks	98.0 ± 6.8	1.83 ± 0.06	22.6 ± 2.1
		Outside backs	101.2 ± 6.2	1.91 ± 0.03	22.0 ± 1.9

Club	All positions	102.7 ± 14.0	1.84 ± 0.07	20.1 ± 2.7
	Tight-5 forwards	115.1 ± 10.4	1.86 ± 0.07	19.8 ± 2.1
	Loose forwards	109.0 ± 7.3	1.89 ± 0.05	20.2 ± 3.0
	Inside backs	87.5 ± 7.7	1.78 ± 0.05	20.9 ± 3.6
	Midbacks	100.5 ± 10.2	1.83 ± 0.05	20.4 ± 2.4
	Outside backs	90.4 ± 7.2	1.81 ± 0.04	19.5 ± 2.5

Table 4 presents the findings from Watkins and colleagues (2021). This study compared the anthropometric profiles of 176 male rugby union players across different participation levels; international, professional and club. Echoing the work of Van Den Berg and colleagues (2021), it can be inferred that forwards are heavier and taller compared to backs. In term of playing position, across each participation level, tight-5 forwards demonstrate the greatest body mass, followed closely by loose forwards. Inside backs are typically found to demonstrate the lowest body mass across each level. Overall, this data supports the work of Smart and colleagues (2013), demonstrating as participation level increases, height and mass also increase.

2.6 Current practice of body composition assessment in high performance sport

Insight and quantifying body composition in athletes has become an integral aspect of research for the best part of a decade (Ackland *et al.*, 2012). Even with advancements in assessment techniques over the years, there is no universally endorsed measurement technique (Ackland *et al.*, 2012; Kasper *et al.*, 2021). The decision of body composition method typically depends of the intended purpose of what the data is to be used for and which method is available (Ackland *et al.*, 2012). In relation to high performance sport, the measurement of body composition may be utilised to define a performance or criteria for selection, examine the effectiveness of a dietary intervention or monitor the health of an athlete (Ackland *et al.*, 2012). Over the years, many methods have been developed in order to gain a greater understanding of the assessment and evaluation of body composition in sport (Kasper *et al.*, 2021). Nevertheless, the accuracy, reliability and validity of some of these techniques can be debatable as methods are often chosen based on expense, portability, safety or invasiveness, rather than most suitable for the required assessment (Kasper *et al.*, 2021).

2.6.1 Body composition in elite and development/national rugby players

There is a growing demand in understanding rugby players across all competitive levels including the elite and sub-elite level (Fontana *et al.,* 2015). Since the introduction of professionalism in rugby union, a greater emphasis on the physical development of players has been present with Old and colleagues (2001) reporting that professional players are significantly more mesomorphic compared to amateur players. Numerous studies have examined the physical make up and characteristics of elite, adolescent and amateur rugby players (Durandt *et al.,* 2006). However, there is very limited research comparing body composition between elite and sub-elite rugby athletes, especially using DXA (Till *et al.,* 2016), further demonstrating the importance of this project. Body composition assessment in professional rugby is often utilised routinely as a monitoring procedure to enhance competitive performance and monitor training (Harley *et al.,* 2011). It is widely accepted that as participation level increases from semi-professional to professional, players have been found to be heavier, taller, have a greater lean mass and lower body fat percentage, while demonstrating greater speed, strength and power (Smart *et al.,* 2013; Posthumus *et al.,* 2020a). For example, Quarrie and colleagues (1995) suggested that senior club players obtain greater mass, height, speed, strength and aerobic fitness compared to their lower-level age group counterparts. The differing physical demands of rugby union and its numerous playing positions requiring specific height characteristics with evident differences in height between forwards and backs (Gabbett *et al.,* 2008). While numerous studies have reported the physical characteristics of professional rugby union players and have suggested that body composition with ideal amounts of lean mass and fat mass are vital for performance (Higham *et al.,* 2014; Zemski *et al.,* 2015; Lees *et al.,* 2017), there are few studies comparing composition between elite rugby union forwards and backs (Posthumus *et al.,* 2020a), which is a pivotal focus of this thesis.

Recent findings indicate that differences in body composition may be present between senior and junior players (Till *et al.*, 2016), and between elite and sub-elite players (Smart *et al.,* 2013; Jones *et al.,* 2015). This is supported by the work of Geeson-Brown and colleagues (2020) who found senior elite rugby players displayed a lower percentage of fat mass compared to junior elite and senior sub-elite players. Interestingly, absolute fat mass did not differ between standard of competition or age in rugby for either group. Additionally, as negligible differences in absolute fat mass was present between age and standard, a greater level of fat free mass in senior elite may cause a reduced percentage of fat mass to overall mass (Geeson-Brown *et al.,* 2020).

Research published by Till and colleagues (2016) assessed and compared the anthropometric profiles and body composition of senior professional rugby players and sub-elite academy players using DXA. It was found that the professional players were taller (183.2 ± 5.8 vs. 179.2 ± 5.7 cm) and heavier (96.5 ± 9.3 vs. 86.5 ± 9.0 kg) than academy players. In terms of body composition, professional players obtained a lower body fat percentage (16.3 ± 3.7 vs. 18.0 ± 3.7 %), greater total lean mass ($p<0.001$) than academy players. Regionally, academy players demonstrated significantly greater fat mass at the legs compared to elite players ($p<0.001$).

In addition, a study from Jones and colleagues (2015) compared the body composition and anthropometric profile of professional and semi-professional rugby players using DXA. The data indicated that professional forwards and backs displayed a greater stature (184.3 ± 3.2 and 181.3 ± 6.1 vs. 182.3 ± 5.9 and 180.1 ± 7.1 cm, respectively) and body mass (99.8 ± 8.1 and 90.2 ± 9.1 vs. 98.4 ± 8.4 and 90.8 ± 8.7 kg, respectively). Furthermore, professional forwards and backs demonstrated less total fat mass (16.8 ± 4.2 and 12.7 ± 3.4 vs. 20.1 ± 4.4

and 18.2 ± 4.5 kg, respectively) and greater lean mass (78.5 ± 6.4 and 73.2 ± 7.9 vs. 73.9 ± 7.6 and 68.6 ± 5.7 kg, respectively) compared to semi-professional players.

2.6.2 Implications of body composition evaluation in high performance sports

There is a growing area of research examining the broader implications of body composition in high-performance sport for health. For example, a large proportion of elite rugby union athletes are categorised as overweight or obese according to BMI classifications, which has potential health implications in non-athletic populations. However, BMI is not accurate for estimating fat mass in athletic populations (Ackland *et al.,* 2012; Dunican *et al.,* 2019). It has been releveled that the topography of body fat, or the location of the fat depots, is a more effective predictor of cardiometabolic implications than the overall amount of fat mass (Tchernof and Despres, 2013).

Visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) are contributors to not only obesity but differ in their structural composition, functional significance and metabolic activity (Neeland *et al.,* 2013). VAT is found surrounding internal organs and has been defined as a hormonally active component of total body fat with unique biochemical characteristics which affect numerous normal and pathological processes in the human body (Shuster *et al.,* 2012). SAT is the adipose tissue located just beneath the skin (Mittal, 2019), and potentially has fewer health implications associated with adverse cardiometabolic risk factors (Liu *et al.,* 2010). Due to the size of rugby union players and the relationship between greater VAT and cardiometabolic complication in ‘supersized’ athletes, further research into VAT and other markers of cardiometabolic disease in rugby union is necessary (Zemski *et al.,* 2019). There is limited knowledge on VAT in rugby players and it is unclear if players with increases in body fat percentage over a season have concomitant increases in VAT (McHugh *et al.,* 2021).

This may be due to a recent increase in player size. At the 2015 World Cup, average body mass for forwards was 111.4 kg and the average mass for backs was 91.5 kg (Fuller *et al.*, 2017), compared to 2019 World Cup forwards who reported an average mass of 114 kg, with the lightest forward being 80 kg and the heaviest 153 kg (RugbyPass, 2019).

Increases in body mass, especially recently, are of interest due to performance and player welfare concerns (Tucker *et al.*, 2021). Given the frequency of contact in rugby, collisions involving larger players, or a potential mismatch may enhance risk of injury as larger players can produce greater force which enables them to 'win' collisions (Tierney *et al.*, 2018). This has been suggested to be contributing factor threatening participation, with suggestions to reduce player size for safety reasons (Tucker *et al.*, 2021). Increases in player mass may bring potential performance implications. Increasing body mass beyond a certain point may negatively impact acceleration, speed, endurance and agility (Tucker *et al.*, 2021). Moreover, an increase in player mass may expose potential health implications. It has recently been found that athletes who purposefully maximise their lean and/or fat mass in order to enhance performance have been shown to display signs of elevated cardiometabolic disease risk and greater levels of VAT compared to non-heavyweight athletes (Guo *et al.*, 2013; Murata *et al.*, 2016). While athletes are generally deemed a 'healthy population' with training and match play providing health benefits, risk factors such as high BMI and hypertension have been found in rugby athletes (McHugh *et al.*, 2021).

2.7 Gaps in the knowledge

Future research may assess different methods for maintaining lean mass while limiting increases in fat mass throughout a season (Posthumus *et al.*, 2020a). It has been reported that professional rugby union players display increases in lean mass and decreases in fat mass during pre-season phases and appear to increase body mass, lean mass and strength over consecutive seasons. However, players may be able to enhance performance further by limiting reductions in lean mass and increases in fat mass throughout a competitive season (Appleby *et al.,* 2012; Bradley *et al.,* 2015; Zemski *et al.,* 2019). While there has been recent work dedicated to body composition and performance, morphological characteristics and body composition especially in elite populations remain uncertain (Bjelica *et al.,* 2019). Also, there is limited research directly comparing relationships between characteristics within professional rugby union forwards and backs, despite the varying performance demands of these positions (Posthumus *et al.,* 2020a). Findings from Smart et al (2013) and Jones et al (2015) suggest body composition differences exist between elite and sub-elite players, although the magnitude and consistency of these observations has not been evaluated (Geeson-Brown *et al.,* 2020). A deeper insight of these differences may provide knowledge regarding the physical characteristics of rugby players and may guide the development of specific body composition goals as players transition between sub-elite and elite playing standards (Geeson-Brown *et al.,* 2020). While there are limited studies examining the anthropometric and physical characteristics of rugby union players (Darrall-Jones *et al.,* 2015), previous research regarding body composition assessment of rugby union players is often limited by small samples sizes or the inclusion of only one club for data analysis (Geeson-Brown *et al.,* 2020). Thereby, this study aims to compare body composition and anthropometric measurements between elite and national and development rugby union players from two different clubs as well as positional differences to fill these critical gaps in the literature.

Chapter 3: Methodology

3.1 Ontological approach and study design

This study involved the collection of precise, objective measurements which are controlled by the researcher and can be replicated by others (Gratton and Jones, 2014). This approach has numerous strengths including knowledge of precision of the methods used, control and objectivity in the interpretation of the data. The statistical analysis of the data removes the requirement for further intuitive interpretation, potentially resulting in clear-cut interpretations (Gratton and Jones, 2014).

The study design was observational and cross-sectional, which meant that participants were tested at one time point. The strengths of cross-sectional study designs are lower attrition rates, preliminary evidence for planning a future advanced study and depending on the sampling strategy employed and the representativeness of the sample, random samples can be taken from the population to enable the findings to be generalised to the wider population (Gratton and Jones, 2014; Wang and Cheng, 2020).

3.2 Study sample and recruitment

3.2.1 Study sampling methods

The study sample used in this study was non-probability purposive sampling (Smith, 2010; Gratton and Jones, 2014). Non-probability sampling is where the probability that a subject is selected is unknown however this may result in selection bias (Acharya *et al.,* 2013). Purposive sampling is frequently used and the selection is based on a degree of judgement or arbitrary ideas of the researcher(s) seeking a kind of ‘representative’ sample (Vehovar *et al.,* 2016). This sample is often selected on the basis of the convenience of the researcher (Acharya *et al.,* 2013).

In the case of this study, the recruitment of the national and development players was possible through contact with the first team coach. The recruitment of the elite rugby union athletes was possible through another ongoing study of professional rugby players. This sample also involves subjects being included based on them meeting the inclusion criteria of the study. This is advantageous as it eliminates the need to list all the population elements, required criteria and it is the most commonly used sample (Acharya *et al.,* 2013). However, this sample is limited as variability and bias cannot be controlled or measured; therefore, data from the study cannot be applied beyond the sample (Acharya *et al.,* 2013).

3.2.2 Inclusion and exclusion criteria

In relation to the elite participants, the inclusion criteria were players achieving within 7% of world-record performance highly proficient in skills required to perform the sport (McKay *et al.,* 2021), representing a professional club participating in Premiership Rugby, England’s highest division of rugby union. The exclusion criteria for this population was currently or recently injured within the last three months.

Regarding the national and development participants, the inclusion criteria were first team highly skilled and trained males representing a University’s team. A number of participants had been offered and were currently discussing professional contracts and had participated in international competition. Furthermore, this was an all-male population due to convenience and the coach allowing the men’s team to partake in testing. However, future research is warranted focusing on female rugby union as there is currently limited knowledge regarding this population and physical qualities by playing position (Jones *et al.,* 2016; Curtis *et al.,* 2021). Similarly, currently injured or recently injured (in the last three months) players were excluded from testing. Likewise, any player with metal plates on their skeleton was excluded to ensure accurate measurements of body composition. Also, only total body less head scans were used to ensure reliable outcomes regarding a player's body composition. Thereby, one player was removed from analysis as their scan was total body. The total number of national and development participants was 18 and the total number of elite participants was 38. Thereby, based on the eligibility criteria, the final sample size for the observational study was 56.

3.3 Ethical approval

The study was reviewed and approved by the Durham University Ethics Committee and the NHS REC for the use of ionising radiation from DXA. The approval number for the NHS ethics was 2/NE/0036 IRAS Reference: 308072. The approval number for the elite player's and national level player's DXA scans was SPORT-2022-05-28T09_56_39-hwhs25.

The key ethical considerations were as follows:

All participants were informed of the nature of the study, how the data would be collected, used and distributed (Gratton and Jones, 2014). It was ensured that all participants were given and understood all the vital information in order to allow them to make a fully informed decision to take part or not (Gratton and Jones, 2014). This is referred to as 'informed consent' (Berg and Latin, 2008). Each participant was provided with an information sheet and gave written consent to have their body mass measured and were made aware of how the data would be used and who would have access to it. All participants provided written informed consent prior to participating in the study.

3.3.1 Confidentiality

All participants were informed as to who would have access to the data from the study. This was only those closely associated to the research and no one could access it without authorisation (Gratton and Jones, 2014). The hard copies of data were stored securely in a locked filing cabinet, known only to those close to the study. Digital data was stored in password secured files. Anonymity is vital to prevent the identification of individuals in the study (Gratton and Jones, 2014), this was ensured by providing each subject a number.

3.4 DXA radiation

DXA does expose the patient and operator to ionizing radiation, however the dose is very minute to both (Shepherd *et al.*, 2018). The effective dose to an adult from a typical bone density scan is around 7 µSv depending on the manufacturer, model and scan mode used. The total body scan brings a lower effective dose of around 3.0 µSv. It is beneficial to compare these values to the natural background radiation dose in the UK which is approximately 7.3 µSv daily (2.7 mSv annually) (Public Health England, 2011). While the dose of radiation from DXA is limited, all laboratories or centres executing DXA scans are required follow the regulations set out in the Ionising Radiation Regulations 2017 (IRR17) (Health and Safety Executive, 2018) and the Ionising Radiation for Medical Exposure Regulations (IRMER) (Department of Health and Social Care, 2018). Furthermore, all operators must have received IRMER-specific training. DXA scans utilised for human participant research require ethical approval from an NHS Research Ethics Committee where the input from a Medical Imaging Expert and a Clinical Radiation Expert is required (Hind, 2022).

3.5 Body composition assessment protocol

Body composition was assessed using fan beam dual energy X-ray absorptiometry (Lunar iDXA, GE Healthcare (Madison, WI). All national and development scans took place over two days during the pre-season phase of the 2022/23 season and the elite scans were completed over a 3-week period during the 2022/23 preseason. This was the case due to a greater number of elite participants and schedule conflicts. The scan protocol was identical for every participant in this study. Each player was advised to arrive at their chosen time slot in appropriate clothing and in a fasted and euhydrated condition. Once they completed the consent form, shoes were removed and their mass was taken using scales and recorded to the nearest 0.1 kg and their stature was taken using a stadiometer and recorded to the nearest 0.1 cm. The DXA scanner was calibrated according to the manufacturer's guidelines using a standard calibration block. Trained DXA investigators were present at all times to conduct the scans. The participant was then positioned on the scanning bed. The participants' body was positioned lying flat on their back with a 1 cm air space between their upper leg and hand (Hind, 2022). A band was positioned around their ankles and they were instructed to apply pressure on it to ensure this air space. Their toes were pointed up and the scans only began once their body was inside the scan boundaries which were lined out on the scanning bed. Once they were in the correct position the scan began. Scans are completed in approximately 6.5 or 12.5 minutes, depending on the scan mode (Thurlow *et al.*, 2018). Though in the case of this study as the standard scan mode was used, scans typically lasted between 6.5 and 7.5 minutes. Upon completion of the scan their results in terms of bone content, lean mass and body fat percentage were briefly explained to them.

3.5.1 Standardisation

Participants were given detailed explanations of the DXA process, how to prepare, and the nature of the data collection method. A pre-DXA screening questionnaire was provided covering all contraindications and gathers other important information including the reason for the scan and any internal artefacts such as metal plates and rods, that may jeopardise scan quality. This was important as providing a pre-DXA screening questionnaire and information can improve compliance, decrease potential anxiety in participants and is vital for data acquisition (Licata and Williams, 2014).

All participants were made aware of the potential risks such as the involvement of radiation from DXA. Standardisation of the DXA scans was addressed through ensuring confounding variables such as meal and fluid consumption, clothing, exercise and hydration were standardised. Biological variation reflected in changes to mass and lean mass due to food consumption may occur from food or fluid consumption too close to a scan (Nana *et al.*, 2012). To eliminate this, participants were encouraged to report in an overnight fasted state of 8-hours. If this is not possible, the suggested content of consumption should be no more than 500g (Kerr *et al.*, 2017). Biological variation can also arise from hydration status, thereby, participants were euhydrated and advised to consume 1 to 2 glasses of water with each meal the day before the scan. Changes in hydration level may result in either decreases (dehydrated) or increases (over hydrated) in lean mass. Variable hydration of soft tissue may also affect fat estimation (Pietrobelli *et al.*, 1998). Additionally, prior to the scan, athletes were encouraged to empty their bladder. Exercise is an important factor as it can affect tissue hydration, fluid shifts to regional compartments and shifts in blood volume. Therefore, athletes were encouraged to report in well rested, undertaken no exercise the morning of the scan and no intense exercise since midday the previous day (Hind, 2022). Technical error is also a risk and may arise from metal on clothing presenting as bone mass. Therefore, this risk was reduced by informing participants to wear lightweight clothing with no metal for their scan and all jewellery containing metal was removed.

3.5.2 Technology

The X-ray source generates the X-ray beams containing photons which are discharged through electromagnetic energy (Hind, 2022). As these photons pass through the body, there is differential attenuation depending on the density of the tissues. The extent of attenuation is dependent upon the energy of the photons and the thickness of the tissue (Prado and Heymsfield, 2014). Bone measurement is based upon the assumption that the body is made up of two compartments, soft tissue and bone. Bone has a greater density than soft tissue, thereby, the photon energies are attenuated less (Toombs *et al.*, 2012). To image either tissue, the two energy beams are subtracted, either subtracting the soft tissue and image the bone, or subtracting the bone and image the soft tissue (Hind, 2022). In order to differentiate lean and fat tissue, bone is subtracted and the ratio of the two photon energies is linearly associated to the proportion of fat in the soft tissue (Laskey, 1996). This results in lean tissue mass, fat mass and bone mineral. Technological advancements have resulted in a shift from pencil beam to narrow fan beam densitometers and a greater number of detectors providing an enhanced resolution. This has resulted in greater image quality and reduced scan times (Hind, 2022).

3.5.3 Scanning

Regarding the physical characteristics of some athletes in this study, the possibility of exceeding the scan boundaries was considered. There are two available options depending on system and software for tall athletes exceeding the scan boundaries. The most recent Encore software (version 18) from GE provides a new total body-less head (TBLH) scan which begins at the level of the mandible (Hind, 2022). This was used to ensure a consistent protocol for all athletes as the composition of the head is unlikely to alter, though this does not offer absolute body composition. The second option offers a combination of two partial scans, one of the head and one of the body (Silva *et al.*, 2013).

In the current study, TBLH scans are used over the Silva method as TBLH allows the researcher to quantify the magnitude and quality of full-body mass distribution (Kutáč *et al.,* 2019). Furthermore, when assessing body composition, it is more desirable to scan the entire body

(Shepherd *et al.,* 2018). Total body scan reports include total and regional (arms, legs and trunk) estimates of total mass, fat mass, fat-free mass (compromising of lean mass and bone mass), lean mass, bone mineral content and bone mineral density. Further detailed knowledge includes regional and tissue percent fat mass, appendicular lean mass index and fat mass index (Hind, 2022).

Hands were placed in the mid prone position allowing 1 cm of air space between the hand and the upper leg. This position is recommended by the International Society for Clinical Densitometry (ISCD) and the National Health and Nutrition Examination Survey (NHANES) 2011 protocol (National Health and Nutrition Examination Survey, 2011; Thurlow *et al.,* 2018) as consistency of positioning can influence precision error. This position also reduces the scan width allowing the participant to fit within the scan boundaries. Nana and colleagues (2012) also recommend this position and state that the use of foam positioning aids may be beneficial in maintaining consistent placement. This is vital as alterations of hand position may influence total bone mineral density, arm bone and fat mass and precision (Thurlow *et al.,* 2018). Additionally, this position is of use for broader athletes, though consideration is required so that the hand does not overlap the upper leg.

3.6 Quality assurance

The accuracy and performance of DXA may be affected by alterations in instrument performance which can suddenly occur (calibration shift) or gradually (calibration drift) (Lewiecki *et al.,* 2016). Therefore, it is critical to have a calibration and quality assurance protocol in place to identify any performance alterations (Hind, 2022). This typically involves daily scanning of a calibration block and weekly scanning of a phantom (Standardised object with known bone mineral density content). In the case of this study, a quality assurance test was completed and passed at the start of each testing day. Testing cannot take place if this test is failed. It is important that attention is given to shifts or drifts in calibration which exceed 1.5% (Lewiecki *et al.,* 2016).

3.7 Limitations

Regarding the elite DXA phase scans, two players had metal plates on their skeleton. One player had a metal plate in their arm and another had metal plates in their leg. These players were removed from analysis as this study has a specific focus on body composition measurements and metal plates would affect the results. During the scanning phase, two players were recorded as female. These players were also removed from analysis as the population of this study was all-male. This mistake was down to human error as a large number of players were scanned in the same day. Finally, one player had a total body scan, therefore their head was included in the scan. This player was removed as this study utilised the TBLH scan mode.

3.8 Statistical analysis

Statistical analysis was conducted using the software programs Microsoft Excel (Version 16.16) and IBM Statistics (Version 28, SPSS Inc, US). Data was found to be normally distributed, thereby presented as the mean and standard deviation of the specific variable. Comparisons in body composition measurements between 56 elite and national and developmental players was conducted using two-way ANOVA tests using Tukey post hoc analysis. Group effect sizes are also reported within the tables. Two-way ANOVA tests were used to identify potential significant differences between the elite and national and developmental cohorts as well as the two positional groups (forwards and backs). The chosen significance level was $p<0.05$ and the confidence interval was 95%.

Chapter 4: Results

4.1 Descriptive statistics

The total study sample was comprised of 56 male participants (n=38 elite and n=18 national and development). Players were divided into their respected playing position (forward or back). All players were scanned using standard mode and TBLH scans.

Elite rugby union players were older (24 vs 20 years) when compared to the national and developmental cohort. Forwards were reported to be taller (190 .1 ± 6.5 vs 180.3 ± 5.2 cm) and heavier (112.6 ± 15.3 vs 89.4 ± 8.2 kg) in comparison to backs. Please see table 5 for full descriptive statistics for the whole cohort and positional groups.

Table 5: Descriptive statistics elite vs national/development, forwards vs backs

	Stature			*Mass*			*Age*		
	Sig.	Effect size	Average (cm)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (years)
Level	0.704	0.003		0.043	0.075		<0.001*	0.202	
Elite (n=38)			185.6 ± 7.4			103.5 ± 17.9			24
N/D (n=18)			183.6 ± 7.4			93.9 ± 11.7			20
Position	<0.001*	0.392		<0.001*	0.424		0.599	0.005	
Forward (n=26)			190.1 ± 6.5			112.6 ± 15.3			24
Back (n=30)			180.3 ± 5.2			89.4 ± 8.2			22

*Level * position*	0.532	0.007		0.422	0.012		0.702	0.003	
Elite forwards (n=19)			190.3 ± 6.9			115.2 ± 16.9			25
Elite backs (n=19)			181.2 v 4.6			91.4 ± 7.8			24
N/D forwards (n=7)			190.4 ± 5.5			105.3 ± 4.8			20
N/D backs (n=11)			179.2 ± 6.1			86.7 ± 8.3			20

N = number of participants, ± = standard deviation, N/D = national and developmental athletes, * indicates significant difference between forwards and backs

4.2 Total mass

Elite rugby union athletes reported a greater trunk total mass (47.8 ± 6.8 vs 43.4 ± 4.8 kg) compared to national and developmental athletes. Forwards displayed greater arms (14.3 ± 1.1 vs 11.7 ± 1.2), legs (38.8 ± 3.5 vs 31.2 ± 3.4 kg), trunk (51.7 ± 4.7 vs 41.6 ± 3.7 kg) and TBLH (104.8 ± 8.1 vs 84.6 ± 8.0 kg) total mass compared to the backs. Please see table 6 for full total mass statistics.

Table 6: Total mass elite vs national/development, forwards vs backs

	Arms total mass			*Legs total mass*			*Trunk total mass*			*TBLH total mass*		
	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)
Level	0.009	0.121		0.154	0.038		0.005*	0.141		0.013	0.110	
Elite (n=38)			13.3 ± 1.8			35.6 ± 5.0			47.8 ± 6.8			96.7 ± 13.1
N/D (n=18)			12.1 ± 1.4			33.1 ± 5.2			43.4 ± 4.8			88.7 ± 11.2
Position	<0.001*	0.477		<0.001*	0.518		<0.001*	0.542		<0.001*	0.575	
Forward (n=26)			14.3 ± 1.1			38.8 ± 3.5			51.7 ± 4.7			104.8 ± 8.1
Back (n=30)			11.7 ± 1.2			31.2 ± 3.4			41.6 ± 3.7			84.6 ± 8.0
*Level * Position*	0.304	0.020		0.724	0.002		0.234	0.027		0.543	0.007	
Elite forwards (n=19)			14.6 ± 1.0			39.1 ± 3.7			52.9 ± 4.8			106.7 ± 8.4

Elite Backs (n=19)	11.9 ± 1.3	31.8 ± 3.1	42.4 ± 3.7	86.2 ± 7.7
N/D forwards (n=7)	13.3 ± 1.3	38.0 ± 2.8	48.1 ± 1.7	99.5 ± 4.4
N/D backs (n=11)	11.3 ± 1.1	30.0 ± 3.9	40.3 ± 3.6	81.8 ± 82

N = number of participants, ± = standard deviation, N/D = national and developmental athletes, * indicates significant difference between forwards and backs

4.3 Lean mass

Table 7 demonstrates that forwards possessed greater arms (10.9 ± 1.5 vs 9.4 ± 1.1 kg), legs (28.5 ± 2.3 vs 24.2 ± 3.7 kg), trunk (36.6 ± 2.8 vs 32.8 ± 3.4 kg) and TBLH (76.2 ± 5.0 vs 66.5 ± 7.1 kg) lean mass than backs. Please see table 7 for full lean mass statistics.

Table 7: Lean mass elite vs national/development, forwards vs backs

	Arms lean mass			*Legs lean mass*			*Trunk lean mass*			*TBLH lean mass*		
	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)
Level	0.117	0.046		0.420	0.012		0.361	0.016		0.288	0.021	
Elite (n=38)			10.3 ± 1.2			26.6 ± 3.2			35.0 ± 3.5			72.0 ± 7.5
N/D (n=18)			9.7 ± 1.1			25.4 ± 3.7			33.8 ± 3.9			69.0 ± 8.3
Position	<0.001*	0.306		<0.001*	0.373		<0.001*	0.212		<0.001*	0.330	
Forward (n=26)			10.9 ± 1.5			28.5 ± 2.3			36.6 ± 2.8			76.2 ± 5.0
Back (n=30)			9.4 ± 1.1			24.2 ± 2.9			32.8 ± 3.4			66.5 ± 7.1
*Level * Position*	0.619	0.005		0.702	0.003		0.488	0.009		0.788	0.001	
Elite forwards (n=19)			11.1 ± 0.8			28.6 ± 2.3			37.0 ± 2.6			76.8 ± 4.8

Elite Backs (n=19)	9.5 ± 1.1	24.5 ± 2.7	32.9 ± 3.1	67.0 ± 6.7
N/D forwards (n=7)	10.5 ± 0.8	28.3 ± 2.3	35.5 ± 3.0	74.4 ± 5.5
N/D backs (n=11)	9.2 ± 1.0	23.6 ± 3.2	32.7 ± 4.1	65.5 ± 8.0

N = number of participants, ± = standard deviation, N/D = national and developmental athletes, * indicates significant difference between forwards and backs

4.4 Fat mass

Forwards displayed greater arms (18.5 ± 3.9 vs 14.7 ± 3.2 %), legs (21.7 ± 4.4 vs 17.4 ± 3.7 %), trunk (25.6 ± 6.2 vs 18.1 ± 4.5 %) and TBLH (23.2 ± 4.7 VS 17.4 ± 3.9 %) fat mass compared to backs. Please see tables 8 and 9 for full fat mass statistics.

Table 8: VAT and SAT mass elite vs national/development, forwards vs backs

	VAT mass			*SAT mass*		
	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)
Level	0.018	0.102		0.222	0.028	
Elite (n=38)			0.542 ± 0.37			1.117 ± 0.61
N/D (n=18)			0.291 ± 0.13			0.872 ± 0.53
Position	0.097	0.052		0.028	0.090	
Forward (n=26)			0.542 ± 0.37			1.278 ± 0.54
Back (n=30)			0.391 ± 0.29			0.901 ± 0.61
*Level * Position*	0.411	0.013		0.294	0.021	
Elite forwards (n=19)			0.582 ± 0.42			1.28 ± 0.60

Elite backs (n=19)	0.50 ± 0.31	1.59 ± 0.76
N/D forwards (n=7)	0.43 ± 0.13	1.24 ± 0.60
N/D backs (n=11)	0.20 ± 0.09	0.64 ± 0.33

N = number of participants, ± = standard deviation, N/D = national and developmental athletes, * indicates significant difference between forwards and backs, VAT = visceral adipose tissue, SAT = subcutaneous adipose tissue

Table 9: Fat mass elite vs national/development, forwards vs backs

	Arms fat mass			*Legs fat mass*			*Trunk fat mass*			*TBLH fat mass*		
	Sig.	Effect size	Average (%)	Sig.	Effect size	Average (%)	Sig.	Effect size	Average (%)	Sig.	Effect size	Average (%)
Level	0.078	0.058		0.267	0.023		0.028	0.088		0.050	0.071	
Elite (n=38)			17.2 ± 4.0			20.0 ± 4.6			23.0 ± 6.1			21.1 ± 4.9
N/D (n=18)			15.0 ± 3.8			18.1 ± 4.2			18.7 ± 6.7			18.0 ± 5.2
Position	0.002*	0.167		<0.001*	0.189		<0.001*	0.288		<0.001*	0.275	
Forward (n=26)			18.5 ± 3.9			21.7 ± 4.4			25.6 ± 6.2			23.2 ± 4.7
Back (n=30)			14.7 ± 3.2			17.4 ± 3.7			18.1 ± 4.5			17.4 ± 3.9
*Level * Position*	0.463	0.010		0.882	0.000		0.849	0.001		0.875	0.000	
Elite forwards (n=19)			19.4 ± 3.7			22.4 ± 4.4			27.0 ± 5.8			24.3 ± 4.4

Elite Backs (n=19)	15.1 ± 3.1	18.0 ± 3.6	19.3 ± 3.8	18.2 ± 3.5
N/D forwards (n=7)	16.6 ± 4.2	20.8 ± 3.4	22.9 ± 7.0	21.3 ± 5.0
N/D backs (n=11)	14.0 ± 3.4	16.4 ± 3.8	16.0 ± 5.1	15.9 ± 4.3

N = number of participants, ± = standard deviation, N/D = national and developmental athletes, * indicates significant difference between forwards and backs

4.5 Bone analysis

Forwards reported greater bone mass (4.02 ± 0.31 vs 3.39 ± 0.36 kg), bone mineral density (1.56 ± 0.08 vs 1.46 ± 0.07 kg) and bone mineral content (4.01 ± 0.31 vs 3.39 ± 0.36 kg) compared to backs. Please see table 10 for full bone content statistics.

Table 10: Bone content elite vs national/development, forwards vs backs

	TBLH bone mass			*TBLH BMD*			*TBLH BMC*		
	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)
Level	0.116	0.046		0.298	0.020		0.116	0.0046	
Elite (n=38)			3.77 ± 0.44			1.52 ± 0.08			3.77 ± 0.44
N/D (n=18)			3.52 ± 0.47			1.48 ± 0.09			3.52 ± 0.47
Position	<0.001*	0.437		<0.001*	0.242		<0.001*	0.437	
Forward (n=26)			4.02 ± 0.31			1.56 ± 0.08			4.02 ± 0.31
			3.39 ± 0.36			1.46 ± 0.07			3.39 ± 0.36

N/D (n=30)									
*Level * Position*	0.642	0.004		0.542	0.007		0l642	0.004	
Elite forwards (n=19)			4.05 ± 0.31			1.57 ± 0.8			4.05 ± 0.31
Elite backs (n=19)			3.46 ± 0.36			1.48 ± 0.7			3.46 ± 0.36
N/D forwards (n=7)			3.94 ± 0.30			1.55 ± 0.9			3.94 ± 0.32
N/D backs (n=11)			3.26 ± 0.35			1.44 ± 0.7			3.26 ± 0.35

TBLH = total body less head, BMD = bone mineral density, BMC = bone mineral content, N = number of participants, ± = standard deviation, N/D = national and development athletes, * indicates significant difference between forwards and backs

4.6 Asymmetrical differences

Forwards were found to show greater differences in right leg lean mass (14.4 ± 1.1 vs 12.2 ± 1.5 kg) and left leg lean mass (14.1 ± 1.2 vs 11.9 ± 1.4 kg). However, the differences in lean mass across both limbs was not different between the two positional groups. Please see table 11 for full asymmetrical statistics.

Table 11: Differences in lean mass in lower body elite vs national/development, forwards vs backs

	Right leg lean mass			*Left leg lean mass*			*Legs diff lean mass*		
	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)	Sig.	Effect size	Average (kg)
Level	0.279	0.022		0.609	0.005		0.211	0.029	
Elite (n=38)			13.4 ± 1.6			13.1 ± 1.6			3.18 ± 0.43
N/D (n=18)			12.7 ± 1.8			12.6 ± 1.8			4.55 ± 0.31
Position	<0.001*	0.376		<0.001*	0.355		0.997	0.000	
Forward (n=26)			14.4 ± 1.1			14.1 ± 1.2			3.31 ± 0.46
Backs (n=30)			12.2 ± 1.5			11.9 ± 1.4			3.89 ± 0.34
*Level * Position*	0.568	0.006		0.851	0.001		0.349	0.017	
Elite forwards (n=19)			14.4 ± 1.1			14.2 ± 1.2			0.26 ± 0.4
Elite backs (n=19)			12.4 ± 1.3			12.0 ± 1.4			0.37 ± 0.3

N/D forwards (n=7)	14.2 ± 1.0	14.0 ± 1.4	0.52 ± 0.3
N/D backs (n=11)	11.8 ± 1.6	11.8 ± 1.6	0.41 ± 0.3

N = number of participants, ± = standard deviation, N/D = national and development athletes, * indicates significant difference between forwards and backs

5.0 Discussion

5.1 Summary of major findings

The purpose of this study was to examine anthropometric and body composition differences between elite and national and developmental rugby union players as well to examine potential positional differences within these groups. It was hypothesised that the elite level players would demonstrate significantly greater lean mass and lower fat mass than national and development level players as these features of body composition have been associated with performance. However, the differences in lean mass were not of significance and elite rugby union players possessed greater amounts of fat mass compared to their national and developmental counterparts. Furthermore, significant differences in body composition measures were hypothesized between forwards and backs. Significant differences in stature, mass, total mass, lean mass, fat mass, bone analysis and differences in lean mass across both limbs was found between all forwards and backs. The main significant differences between the elite and national and developmental groups observed in the current study was elite players were significantly older and displayed greater trunk total mass.

5.2 Anthropometry and total mass

It was hypothesised that elite rugby union player would be significantly older, taller and heavier compared to national and development level players; however, elite players were only found to be significantly older than national and developmental players. The elite athletes did report greater trunk total mass compared to national and developmental players. These hypotheses were aligned with the current trend in rugby towards taller and heavier players (Lombard *et al.*, 2015). A clear increase in player size over the past decades has been present (Austin *et al.*, 2011) and teams that include larger players, such as heavier forwards and taller backs, have greater success in test matches and World Cup competitions (Barr *et al.,* 2014). Hamlin and colleagues (2021) and Till and colleagues (2016) also found elite rugby union players to display greater height and mass than sub-elite players. Both studies reported positional differences between elite and amateur players, elite forwards and backs were taller, heavier and older compared to their sub-elite counterparts. Table 10 presents key studies regarding anthropometric differences in elite and sub-elite rugby union players according to playing position over the past 12 years. The existing literature demonstrates elite rugby forwards and backs demonstrate greater mass, height and age than their sub-elite counterpart. This is believed to be the case as sub-elite players are still maturing and growing and are in a developmental phase of life (Till *et al.,* 2016). In the current study, the national and development players were shorter and lighter compared to the elite players; however, they were also younger than the elite players. These differences maybe present as the national and development athletes were still developing, suggesting that with some additional training they may be capable of making the step to elite status. The current study supports the notion of forwards possessing greater anthropometric measurements compared to backs (Hill *et al.,* 2018). Positional differences were reported as forwards showed greater stature and mass compared to backs.

Stature and body mass have been found to increase with age due to normal processes related to maturation and growth (Malina *et al.,* 2004; Till *et al.,* 2020). These anthropometric characteristics have been shown to increase with age in both elite (Waldron *et al.*, 2014) and sub-elite rugby players (Gabbett, 2009), with further differences demonstrated in elite cohorts compared to sub-elite (Till *et al.*, 2011). As the competitive level increases so does the demands of the game in terms of technical ability and physical structure (Sedeaud *et al.,* 2014). Total mass has been found to increase as playing level increases resulting in heavier athletes with greater lean masses and lower body fat percentages (Smart *et al.*, 2013). Total body mass has been suggested to continue to develop into early adulthood (Malina *et al.*, 2004), especially when combined with more frequent resistance training and nutritional intervention such as those experienced by a rugby player from an academy developmental programme (Till *et al.*, 2014).

Development programmes are commonly found within rugby union to support the development and transition of young rugby athletes to make the step to senior professional athletes (Till *et al.,* 2017). These programmes aim to support young athletes through the growth and maturation process while developing their playing skills. The physical development of young rugby athletes is of importance to coaches and player development staff in advancing players to meet the intense and increasing physical demands of elite rugby (Johnston *et al.,* 2014). A clear understanding of potential factors influencing the development of physical characteristics such as height and weight, during this period is vital for optimising long-term development in young rugby athletes (Till *et al.,* 2017).

There were significant differences in total mass between elite and national and developmental players in the current study as elite players demonstrated greater mass in the trunk region. It is believed that elite players possess greater total body mass compared to sub-elite players due to increased training and match demands (Quarrie and Hopkins, 2007). Training demands between the elite and sub-elite level can be drastically different as elite players may be exposed to a greater frequency, intensity and volume of training (Tee *et al.*, 2016). However, high-level players obtain a greater work: recovery ratio which enables greater training routine improvement compared to sub-elite players (van Rooyen *et al.*, 2014).

Beyond the differences in training, these differences in total mass may aid in explaining why elite players are elite. Athletes that are genetically heavier may have a greater chance of reaching elite status, though whether this is due to performance advantage or coaches' preferences for heavier players remain unknown. It has been suggested by the work of Sedeaud and colleagues (2012) that teams with heavier backs have greater Rugby World Cup success. This may be the case as possessing greater mass is advantageous in tackling, rucking and competing for the ball. The recruitment of heavier players may also be desirable as players possessing greater mass are able to generate more momentum and force production which is perceived to be vital in match situations involving tacking, scrummaging and aggressive contact (Hill *et al.,* 2018; Chiwaridzo *et al.,* 2019). Research indicates that muscular strength and power significantly impacts team selection (Gabbett and Seibold, 2013) as well as differentiating between playing standard (Jones *et al.,* 2018). These findings may also encourage coaching staff to recruit heavier players, which may further shift the desirable body composition for elite rugby players. Anthropometric characteristics such as height and body mass are deemed as desirable qualities in the selection process for coaches (Chiwaridzo *et al.,* 2019), and may influence which players are selected for elite participation.

It was hypothesised that forwards would possess a greater stature and mass compared to backs. Positional differences were reported as forwards reported greater stature and mass compared to backs. In terms of total mass and playing position, forwards were found to demonstrate larger amounts of total mass in each region. Forwards occupied greater total mass in the arms, legs, trunk and TBLH compared to backs. Table 10 provides a comparison of body composition in elite and sub-elite forwards and backs between recently published literature and the current study. The findings from this current project align with relevant literature (table 10), demonstrating that forwards possess greater body composition measurements compared to backs. Forwards are frequently found to obtain a greater body mass compared to backs (Fontana *et al.*, 2015). The findings from this current study echo the work of Vaz *et al.*, 2014; Zemski *et al.*, 2015; and Posthumus *et al.*, 2020 who reported forwards show a greater body mass compared to backs. Additionally, conclusions from Posthumus and colleagues (2020) found forwards to possess a significantly greater total body mass in comparison to backs (116.5 ± 10.1 vs 95.9 ± 9.4 kg). This is the case as forwards are involved in a high number of physical collisions with the opposition to secure possession of the ball during line-outs and scrums and a greater total-body mass is associated with competitive success (Roberts *et al.*, 2008; Sedeaud *et al.*, 2012). It has been suggested that teams with larger and heavier players have greater success (Smart *et al.*, 2011).

Table 12: Anthropometrics in elite level and national level rugby union forwards and backs

Study	***Position***		***Body composition***	
		Age (years)	***Body mass (kg)***	***Stature (cm)***
Hamlin et al (2021)	**Elite forwards (n=10)**	19.2 ± 0.8	104.3 ± 5.4	187.5 ± 8.8
	Elite backs (n=14)	18.8 ± 0.7	86.9 ± 7.9	183.9 ± 7.3
	Sub-elite forwards (n=36)	18.8 ± 1.6	99.7 ± 10.2	186 ± 5.9
	Sub-elite backs (n=23)	18.6 ± 0.6	82.3 ± 6.7	180.4 ± 4.7
Till et al (2016)	**Elite forwards (n=36)**	26.3 ± 4.9	100.4 ± 7.8	184.4 ± 5.6
	Elite backs (n=27)	26.0 ± 4.3	91.3 ± 8.6	181.7 ± 5.9
	Sub-elite forwards (n=19)	18.2 ± 1.1	89.9 ± 8.8	179.7 ± 5.2
	Sub-elite backs (n=15)	18.1 ± 1.1	82.1 ± 7.5	178.5 ± 6.4

Gabbett et al (2009)	**Elite forwards (n=16)**	15.9 ± 0.4	87.0± 11.1	180.9 ± 6.7
	Elite backs (n=12)	16.0 ± 0.2	74.9 ± 7.6	178.8 ± 5.5
	Sub-elite forwards (n=19)	15.8 ± 0.7	88.9 ± 7.2	113.6 ± 21.9
	Sub-elite backs (n=17)	16.1 ± 0.7	69.2 ± 12.2	176.4 ± 7.4
Current study	**Forwards**	24	112.6 ± 17.9	190.1 ± 6.5
	Backs	20	89.4 ± 8.2	180.3 ± 5.2

5.3 Body composition

5.3.1 Lean mass and fat mass

The results from this study found no difference in terms of lean mass and fat mass between elite and national and developmental rugby union players. This was an unexpected conclusion as it was hypothesised elite players would demonstrate significantly greater levels of lean mass in line with existing literature. For example, Till and colleagues (2016) reported a significant difference between elite and sub-elite players in terms of lean mass (74.6 ± 0.8 vs 71.8 ± 1.0 kg, $p<0.001$). According to Fontana *et al* (2015), lean mass is the single most significant predictor of level classification (elite vs sub-elite) when all other attributes are constant. A greater lean mass in elite players was expected as this population is exposed to increased training and match demands and obtain greater musculoskeletal maturity (Gabbett, 2013). However, no difference in lean mass between elite and national and developmental players in the current study may have been due to both cohorts being involved in regular intense training and match competition. Both the elite and national and development athletes in this study are involved in weekly competitive fixtures in the Gallagher Premiership and BUCS respectively. Furthermore, many of the national players in this study were close to transitioning to the elite level, thereby, differences may be less pronounced compared to other national and developmental groups. Due to a combination of national and developmental athletes, the differences between the two cohorts were not as clear as hypothesised. This was because the national level players demonstrated similar body composition measurements to the elite players, though not every player was at the national level. Thereby, the developmental players showed some differences. Age may also play a significant role in the lack of difference conclusions drawn by Till and colleagues (2016) and the current study. The national and developmental players in the current study were older (20 years) compared to the sub-elite population in the Till *et al* (2016) study (18 years). As with total mass, aging is associated with greater lean mass (McHugh *et al.,* 2021) and the national and developmental population in this study have greater physical maturity and experience. There were also fewer national and developmental players in this study compared to elite players (national and development = 18 vs elite = 38), which may have influenced the ability to detect differences between the groups.

In relation to lean mass and playing position, it was hypothesised that forwards would possess greater amounts of lean mass compared to backs due to the demands of the positions. Forwards demonstrated greater arms, legs, trunk and TBLH lean mass compared to backs. These findings support the work of Geeson-Brown and colleagues (2020) who reported that rugby union forwards displayed significantly higher lean mass scores compared to backs (91.1 ± 4.9 vs 79.2 ± 4.5 kg). Forwards frequently report greater lean mass scores as an increase in lean mass and subsequent increase in overall mass results in a greater impact force during tackles (Till *et al.,* 2015). Also, an increase in momentum due to a greater lean mass is believed to enhance ball carrying due to the increased ability to overcome opposing defenders (Geeson-Brown *et al.,* 2020). While an increased mass has been found to be beneficial during collisions, the frequent collisions forwards experience in a match and training may hinder lean mass accrual due to an elevated metabolic rate for up to 72 hours post collision-based activity (Costello *et al.,* 2018). The lower mass of backs is critical for this position as backs are involved in a greater amount of free-running and are required to be more agile and quicker than forwards in order to evade the opposition (Jones *et al.,* 2015). Backs are required to obtain the ball from forwards and accelerate from scrums and mauls and carry the ball down field to create scoring chances (La Monica *et al.,* 2016). Forwards also displayed a greater difference in right leg and left lean mass compared to backs. This may be attributed to the greater running demands placed upon backs (Lees *et al.,* 2017).

In relation to percentage body fat (% fat), this study found no differences between elite and national and developmental rugby union players. Interestingly, these findings are in contrast to the work of Till and colleagues (2016) who reported elite players showed lower amounts of fat mass (14.1 ± 0.8 vs 17.1 ± 1.2 kg) compared to sub-elite players. In sub-elite populations, lower fat mass may indicate these players are still developing musculoskeletal characteristics and physically maturing (Till *et al.*, 2016). Additionally, unlike this study, Till and colleagues (2016) found sub-elite rugby union players displayed greater amounts of arms fat mass (1.78 ± 0.1 vs 1.54 ± 0.9 kg), legs fat mass (6.2 ± 0.4 vs 4.6 ± 0.2 kg) and trunk fat mass (8.1 ± 0.7 vs 7.0 ± 0.5 kg) compared to elite players. A lower body fat percentage has been reported to be beneficial for rugby performance (Till *et al.*,2010), as the ability to accelerate may be hindered by additional fat mass (Till *et al.*, 2014). However, the increased movement requirements of elite rugby performance may demand professional players to possess sufficient levels of fat mass in order to meet the demands of the match and protect against fracture (Till *et al.*, 2016).

This highlights a vital consideration of the development of academy players into professional players. A primary purpose of an academy programme is to develop the physical qualities of young players in order to meet the increasing training and match demands at higher levels (Gabbett, 2013), therefore, an understanding and evaluation of differences in anthropometric and body composition of this population is valuable (Till *et al.*, 2016). Gradual increments in lean mass and bone content while controlling fat mass is a critical consideration when working with sub-elite academy players, particularly within the lower limbs (Till *et al.*, 2016). This indicates that it may be advisable for academy and sub-elite rugby players to be monitored for optimal development as an appropriate body fat percentage is vital for performance, though optimum scores are unknown (Till *et al.*, 2017). It has been suggested that a relatively large fat mass, which acts as a physical buffer, may protect against in the high forces transferred during contact (Geeson-Brown *et al.*, 2020). Additionally, when other attributes remain constant, a greater body mass enables more momentum which is beneficial during tackling and contesting for the ball (Meir *et al.,* 2003). However, while a greater body mass is associated with protection against impacts in forwards, this greater body fat component may result in increased physiological demands on players required to support this mass during match play (O'Connor, 1996). This suggest that there may be an optimal amount of fat which will provide enough protection and support the development of momentum, but not significantly hinder player performance. However, this exact level is unknown. This presents an interesting avenue for future research.

In terms of fat mass and playing position, it was hypothesised that forwards would display greater amounts of fat mass compared to backs due to the nature of the position. Forwards reported greater arms, legs, trunk and TBLH fat mass compared to backs. This is in accordance with conclusions from Geeson-Brown and colleagues (2020) who found forwards possessed a greater percentage fat mass compared to backs (15.3 ± 2.4 vs 11.4 ± 1.8 %). Additionally, Smart and colleagues (2013) found forwards to be heavier and possess a greater body fat percentage compared to backs (12.7 ± 2.9 vs 9.4 ± 2.3 %). This greater fat mass is suggested to be beneficial to forwards as they are involved in more collisions compared to backs (Geeson-Brown *et al.,* 2020). A greater fat mass may also be advantageous in acting as a protective barrier during contact actions such as scrums and rucks (Lindsay *et al.,* 2015). According to Escrivá and colleagues (2021), in order to execute their position-specific actions such as advancing the ball forward (Duthie *et al.,* 2003), backs should be lighter and leaner compared to forwards and avoid possessing excess fat. This is critical for efficient performance for backs as they are required to obtain a greater aerobic capacity due to them spending more time in high-intensity running and covering greater distances compared to forwards (Cahill *et al.,* 2013).

5.4 Bone analysis

This study showed no differences were present in terms of bone mass, bone mineral density or bone mineral content between elite and national and developmental players. This contradicts existing literature, for example, Till and colleagues (2016) reported professional rugby players possessed greater levels of bone mineral content (4313 ± 71 vs 4081 ± 101 g) compared to sub-elite players. Differences in bone content between elite and sub-elite rugby union players is suggested to be due to sub-elite players still naturally developing as bone content may continue to increase into a player’s early 20’s (Mølgaard *et al.,* 1997). Within this current study all rugby players (elite and national/development) displayed high levels of bone mass due to nature of the sport, frequent collisions and strength training (Till *et al.*, 2016). Athletes from high impact sports including rugby union display greater bone density compared to non-athletes (Hind *et al.,* 2015). Many rugby athletes, particularly those involved in high levels of competition such as those in the current study, begin participation in the sport at a young age when bone is highly responsive to mechanical loading (Ginty *et al.*, 2005). Additionally, participation in rugby has been found to improve axial and appendicular bone mass and increase bone turnover (Elloumi *et al.*, 2009), therefore, it is likely this contributed to the high bone mineral content observed in the current study.

While no differences were found between status, differences in bone mass, bone mineral density and bone mineral content was reported between forwards and backs. It was hypothesised that forwards would show greater amounts of bone content compared to backs due to their enhanced exposure to collision-based actions (Geeson-Brown *et al.,* 2020).

Forwards displayed greater bone mass, bone density and content compared to backs. This echoes the findings of Elloumi and colleagues (2006) who reported forwards possessed greater bone area, bone mineral content and bone mineral density compared to backs. Long-term rugby participation, particularly starting at a pubertal age, is associated with a greater bone mass, bone mineral content and bone mineral density at all skeletal sites, except the head (Elloumi *et al.,* 2006). A greater bone mineral content is desirable as it may limit the risk of skeletal fractures (Turner and Robling, 2003). Additionally, an increased lean mass is related with a greater bone mineral content due to a greater torque acting upon the bone (Vuori, 2001). While Till and colleagues (2016) reported elite rugby players possessed greater levels of bone mineral content, it has been suggested that a limit may exist to the amount of lean mass and rugby training can influence bone mineral content (Geeson-Brown *et al.,* 2020).

5.5 The effects of training season on body composition

In the current study, all scans were complete during the pre-season, which may have a significant influence on body composition. Lees and colleagues (2016) investigated longitudinal body composition of elite rugby union players over one competitive season. In their study, 35 professional players were scanned using DXA during pre-season (August), mid-season (January) and end of season (May). From mid-season to the end of the season, a significant loss of lean mass was found ($p < 0.018$). It was reported that 17 players showed a reduction in lean mass and 21 players gained fat mass from pre-season to end of season. Also, there was significant increases in total body bone mineral content throughout the season ($p < 0.05$) (Lees *et al.,* 2016). Longitudinal research may be useful to determine the extent and time period of body composition shifts, and in relation to injury especially in forwards progressing from academy to the elite level who are susceptible to injury (Lees *et al.,* 2016). The original intent of this project was to examine body composition over the course of the season; however, several challenges including logistical considerations as well as the challenges of collecting physiological data during a global pandemic prevented this from occurring. However, results may have differed if DXA scans had been completed at another time during the season. Thus, the timing of body composition assessment may influence the ability to compare studies.

5.6 Study limitations

There are several limitations within this study, the first being the relatively small sample size and the limited number of teams involves (1 elite, 1 national/development). As a result, players were grouped only by primary position (forwards and backs) and limited conclusions were able to be drawn about the potential implications of position on body composition. Future research with a potentially larger sample may further classify forwards (hooker, prop, second-row and loose forward) and backs (winger, full-back, half-back and centre). This would be advantageous due to the unique demands of these specific positions within the team (Jones *et al.,* 2015).

The study population was also homogeneous in regard to ethnicity, with the majority population of this study identifying as white with few players identifying as black, thereby, a more diverse group may yield different results. The findings of this study may not be generalisable beyond a white population. There was a lack of significant differences between the elite and sub-elite groups in terms of body composition. This was likely the case as many of the national athletes were almost ready to make the step up to the elite status. Therefore, future studies may benefit from recruiting amateur players with less experience and skill sets as this will allow for a greater talent difference between elite and development populations which may yield greater differences.

Regarding the use of DXA for body composition analysis, this method is not without its limitations. Food and fluid intake and physical activity can influence DXA measurements. These factors can cause a substantial increase in typical error of DXA estimates of total and regional lean mass, thereby the potential of under or over reporting exists (Nana *et al.,* 2012). These factors were controlled as best as possible in this study by providing participants with scanning protocols in advance of their scan appointment, but are subject to human error.

Furthermore, the original aim of this study was to scan the participants at three points over their competitive season. Scans were planned to take place pre-season, mid-season and end of season. This would have allowed for the chance to analyse and identify potential changes in body composition over a season. However, due to scheduling issues and information not getting to participants regarding scanning protocols, only one scan phase was possible, which was August pre-season 2022. It is also important to note that the results from this study should not be generalised as there are potential differences in training and competitive demands as well as recovery between clubs.

5.7 Future directions for research

Future work may report the ethnic background of players which may influence body composition (Jones *et al.,* 2015). A more diverse population may have yielded different findings as Polynesian player have frequently been reported to show greater levels of lean mass and lower fat mass compared to Caucasian players (Rush *et al.,* 2009). To date, no study has examined differences in physique adaptation to training by ethnicity in rugby union (Zemski *et al.,* 2019). The recruitment of differentiating ethnicities in future research may enable further insight into the role ethnicity plays in training adaptations not only during a season, but post-season in the absence of the training stimulus, where previously significant compromises in body composition have been found in other elite contact team sport cohorts (Bilsborough *et al.,* 2017).

Future studies may also gain an advantage from examining body composition changes across multiple clubs in order to limit potential recruitment bias (Jones *et al.*, 2015; Lees *et al.,* 2016). According to Till and colleagues (2016), future research is required to evaluate longitudinal changes in body composition in order to gain a greater understanding of the development process and the individual effects of lean and fat mass on performance, health and career longevity in rugby union. According to Hind (2022), follow-up DXA scans are beneficial in the examination of the effects of injury rehabilitation, training programmes and nutrition intervention.

6.0 Conclusions

This study aimed to compare anthropometric and body composition measurements between elite and a combination of national and developmental level rugby union players. It was hypothesised that the elite cohort would demonstrate greater levels of lean mass and smaller amounts of fat mass compared to national and developmental level athletes. It was also hypothesised that elite level athletes would be older, taller and heavier compared to national and developmental players. Regarding playing position, it was hypothesised that forwards would demonstrate greater stature and levels of lean mass, fat mass and bone content compared to backs.

This study found elite rugby union players were older and displayed greater amounts of trunk total mass compared to national and developmental players. With reference to question 1 of this study, no differences were found in terms of stature and mass between elite and national and developmental players. Furthermore, no significant differences were reported in terms of lean and fat mass between elite and national and developmental players. This was likely the case as many of the national level players were close to making the transition to the elite level.

In relation to playing position and question 2 of this study, forwards were greater in stature and possessed more mass than backs. Forwards were found to have greater amounts of arms, legs, trunk and TBLH total mass, lean mass and fat mass compared to backs. Forwards also showed greater differences in right and left leg lean mass than backs and greater TBLH bone mass, TBLH bone mineral density and content. These findings indicate that playing position may be a greater determinant of body composition than playing level. Significant differences in terms of body composition were reported between the positional groups (forwards and backs) while only differences in age and trunk total mass were found between the elite and national and developmental players. The lack of significant difference between the elite and national and developmental groups in the current study may be attributed to the relatively high level of performance of many players in the national and development group recruited for this work. Therefore, future research may benefit from involving players from lower tiers of participation with less playing experience.

References

Ackland, T.R., Lohman, T.G., Sundgot-Borgen, J., Maughan, R.J., Meyer, N.L., Stewart, A.D. and Müller, W. (2012). Current status of body composition assessment in sport. *Sports Medicine.* 42, (3), 227-249.

Ahsan, M. and Ali, M.F. (2021). Determining the dynamic balance, maximal aerobic capacity, and anaerobic power output of university soccer and rugby players: A cross-sectional comparative study. *Journal of Human Movement and Sports Sciences.* 9, (6), 1486-1492.

Anding, R. and Oliver, J.M. (2015). Football player body composition: Importance of monitoring for performance and health. *Sports Science Exchange.* 28, (145), 1-8.

Appleby, B., Newton, R.U. and Cormie, P. (2012). Changes in strength over a 2-year period in professional rugby union players. *The Journal of Strength and Conditioning Research.* 26, (9), 2538-2546.

Archarya, A.S., Prakash, A., Saxena, P. and Nigam, A. (2013). Sampling: Why and how of it. *Indian Journal of Medical Specialties.* 4, (2), 330-333.

Argus, C.K., Gill, N., Keogh, J., Hopkins, W.G. and Beaven, C.M. (2010). Effects of a short-term pre-season training programme on the body composition and anaerobic performance of professional rugby union players. *Journal of Sports Sciences.* 28, (6), 679-686.

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

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

Austin, D.J., Gabbett, T.J. and Jenkins, D.J. (2011a). The physical demands of Super 14 rugby union. *Journal of Science and Medicine in Sport.* 14, (3), 259-263.

Bacciotti, S., Baxter-Jones, A., Gaya, A. and Maia, J. (2017). The physique of elite female artistic gymnasts: a systematic review. *Journal of Human Kinetics.* 58, 247-259.

Baim, S., Wilson, C.R., Lewiecki, E.M., Luckey, M.M., Downs Jr, R.W. and Lentle, B.C. (2005). Precision assessment and radiation safety for dual-energy X-ray absorptiometry: position paper of the International Society for Clinical Densitometry. *Journal of Clinical Densitometry.* 8, (4), 371-378.

Baker, D. (2001). The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *Journal of Strength and Conditioning Research.* 15, (2), 172-177.

Barlow, M.J., Oldroyd, B., Smith, D., Lees, M.J., Brightmore, A, Till, K., Jones, B. and Hind, K. (2015). Precision error in dual-energy X-ray absorptiometry body composition measurements in elite male rugby league players. *Journal of Clinical Densitometry.* 18, (4), 546-550.

Barr, M.J., Newton, R.U. and Sheppard, J.M. (2014a). Were height and mass related to performance at the 2007 and 2011 World Cups? *International Journal of Sports Science and Coaching.* 9, (4), 671-680.

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

Bell, W., Evans, W.D., Cobner, D.M. and Eston, R.G. (2005). The regional placement of bone mineral mass, fat mass and lean soft tissue mass in young adult Rugby Union players. *Ergonomics.* 48, (11-14), 1462-1472.

Berg, K. and Latin, R. (2008). *Essentials of research methods in health, physical education, exercise science and recreation* (3rd edn). Baltimore: Lipincott, Williams and Wilkins.

Bilsborough, J.C., Greenway, K., Opar, D., Livingstone, S., Cordy, J. and Coutts, A.J. (2014). The accuracy and precision of DXA for assessing body composition in team sport athletes. *Journal of Sports Sciences.* 32, (9), 1821-1828.

Bilsborough, J.C., Kempton, T., Greenway, K., Cordy, J. and Coutts, A.J. (2017). Longitudinal changes and seasonal variation in body composition in professional Australian football players. *International Journal of Sports Physiology and Performance.* 12, (1), 10-17.

Bjelica, D., Gardasevic, J., Vasiljevic, I., Jeleskovic, E. and Covic, N. (2019). Body composition and morphological characteristics of soccer players in Bosnia and Herzegovina. *Kinesiologia Slovenica.* 25, (1), 5-13.

Bradley, W.J., Cavanagh, B.P., Douglas, W., Donovan, T.F., Morton, J.P. and Close, G.L. (2015a). Quantification of training load, energy intake, and physiological adaptations during a rugby preseason: a case study from an elite European rugby union squad. *The Journal of Strength and Conditioning Research.* 29, (2), 534-544.

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

British Universities and Colleges Sport (BUCS), (2023). 'BUCS' [online]. Available from: https://www.bucs.org.uk [Accessed 17 February 2023].

Brozek, J. (1963). Quantitative description of body composition: Physical anthropometry's "fourth" dimension. *Current Anthropology.* 41, (1), 3-39.

Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., Carty, C., Chaput, J.P., Chastin, S., Chou, R. and Dempsey, P.C. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine*. 54, (24), 1451-1462.

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), 229-237.

Campa, F., Toselli, S., Mazzilli, M., Gobbo, L.A. and Coratella, G. (2021). Assessment of body composition in athletes: a narrative review of available methods with special reference to quantitative and qualitative bioimpedance analysis. *Nutrients.* 13, (5), 1620.

Casserly, N., Neville, R., Ditroilo, M. and Grainger, A. (2019). Longitudinal changes in the physical development of Elite Adolescent rugby union players: Effect of playing position and body mass change. *International Journal of Sports Physiology and Performance.* 15, (4), 520-527.

Chiwaridzo, M., Munambah, N., Oorschot, S., Magume, D., Dambi, J.M., Ferguson, G. and Smits-Engelsman, B.C.M. (2019). Coaches' perceptions on qualities defining good adolescent rugby players and are important for player recruitment in talent identification programs: the SCRuM project. *BMC research notes. 12,* (1), 1-8.

Cormie, P., McGuigan, M.R. and Newton, R.U. (2011). Developing maximal neuromuscular power: part 2 – training considerations for improving maximal power production. *Sports Medicine.* 41, (2), 125-146.

Costello, N., Deighton, K., Preston, T., Matu, J., Rowe, J., Sawczuk, T., Halkier, M., Read, D.B., Weaving, D. and Jones, B. (2018). Collision activity during training increases total energy expenditure measured via doubly labelled water. *European Journal of Applied Physiology.* 118, 1169-1177.

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 and Sports Physical Therapy.* 41, (8), 600-605.

Cronin, J.B. and Hansen, K.T. (2005). Strength and power predictors of sports speed. *The Journal of Strength and Conditioning Research.* 19, (2), 349-357.

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 and Conditioning Research.* 23, (4), 1195-1203.

Curtis, C., ArjoMndkhah, N., Cooke, C., Ranchordas, M.K. and Russell, M. (2021). Seasong-long changes in the body composition profiles of competitive female rugby union players assessed via dual energy X-ray absorptiometry. *Research Quarterly for Exercise and Sport.* 93, (3), 601-607.

Darrall-Jones, J., Jones, B. and Till, K. (2015). Anthropometric and physical profiles of English academy rugby union players. *The Journal of Strength and Conditioning Research.* 29, (8), 2086-2096.

Darrall-Jones, J., Roe, g., Carney, S., Clayton, R., Phibbs, P., Read, D., Weakley, J., Till, K. and Jones, B. (2016a). The effect of body mass on the 30-15 intermittent fitness test in rugby union players. *International Journal of Sports Physiology and Performance.* 11, (3), 400-403.

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

De la Cruz Marcos, S., Redondo del Río, M.P. and de Mateo Silleras, B. (2021). Applications of Bioelectrical Impedance Vector Analysis (BIVA) in the Study of Body Composition in Athletes. *Applied Sciences.* 11, (21), 9781.

Delahunt, E., Byrne, R.B., Doolin, R.K., McInerney, R.G., Ruddock, C.T. and Green, B.S. (2013). Anthropometric profile and body composition of Irish adolescent rugby union players aged 16-18. *The Journal of Strength and Conditioning Research.* 27, (12), 3252-3258.

Delaney, J.A., Thornton, H.R., Scott, T.J., Ballard, D.A., Duthie, G.M., Wood, L.G. and Dascombe, B.J. (2016). Validity of skinfold-based measures for tracking changes in body composition in professional rugby league players. *Journal of Sports Physiology and Performance.* 11, (2), 261-266.

Department of Health and Social Care. ‘Ionising Radiation’ [online]. Available from: https://www.gov.uk/government/publications/ionising-radiation-medical-exposure-regulations-2017-guidance [Accessed 23 January 2023].

Dobbin, N., Clarke, J. and Cushman, S. (2020). The effects of an 8-week off-season period on the mechanical properties of sprinting in professional rugby league players: Implications for training recommendations. *Journal of Trainology*. 9, (1), 15-19.

Dunican, I.C., Walsh, J., Higgins, C.C., Jones, M.J., Maddison, K., Caldwell, J.A., David, H. and Eastwood, P.R. (2019). Prevalence of sleep disorders and sleep problems in an elite super rugby union team. *Journal of Sports Sciences.* 37, (8), 950-957.

Durandt, J., Du Toit, S., Borresen, J., Hew-Butler, T., Masimla, H., Jakoet, I. and Lambert, M. (2006). Fitness and body composition profiling of elite junior South African rugby players. *South African Journal of Sports Medicine.* 18, (2), 38-45.

Duren, D.L., Sherwood, R.J., Czerwinski, S.A., Lee, M., Choh, A.C., Siervogel, R.M. and Chumlea, W.C. (2008). Body composition methods: comparisons and interpretation. *Journal of Diabetes Science and Technology.* 2, (6), 1139-1146.

Durnin, J.V. and Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16-72 years. *British Journal of Nutrition.* 32, (1), 77-97.

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

Duthie, G.M., Pyne, D.B., Marsh, D.J. and Hooper, S.L. (2006). Sprint patterns in rugby union players during competition. *Journal of Strength and Conditioning Research.* 20, (1), 208-214.

Ellis, K.J. (2000). Human body composition: in vivo methods. *Physiological Reviews.* 80, (2), 649-680.

Elloumi, M., Courteix, D., Sellami, S., Tabka, Z. and Lac, G. (2006). Bone mineral content and density of Tunisian male rugby players: differences between forwards and backs. *International Journal of Sports Medicine.* 27, (5), 351-358.

Elloumi, M., Ounis, O.B., Courteix, D., Makni, E., Sellami, S., Tabka, Z. and Lac, G. (2009). Long-term rugby practice enhances bone mass and metabolism in relation with physical fitness and playing position. *Journal of Bone and Mineral Metabolism.* 27, 713-720.

Escrivá, D., Caplliure-Llopis, J., Benet, I., Mariscal, G., Mampel, J.V. and Barrios, C. (2021). Differences in adiposity profile and body fat distribution between forwards and backs in sub-elite Spanish female rugby union players. *Journal of Clinical Medicine.* 10, (23), 5713.

Farley, A., Slater, G.J. and Hind, K. (2020). Short-term precision error of body composition assessment methods in resistance-trained male athletes. *International Journal of Sport Nutrition and Exercise Metabolism.* 31, (1), 55-65.

Fontana, F.Y., Colosio, A., De Roia, G.F., Da Lozzo, G. and Pogliaghi, S. (2015). Anthropometrics of Italian senior male rugby union players: from elite to second division. *International Journal of Sports Physiology and Performance.* 10, (6), 674-680.

Franchini, E., Brito, C.J. and Artiolo, G.G. (2012). Weight loss in combat sports: physiological, psychological and performance effects. *Journal of the International Society of Sports Nutrition.* 9, (1), 52.

Frost, G., Sleeth, M.L., Sahuri-Arisoylu, M., Lizarbe, B., Cerdan, S., Brody, L., Anastasovska, J., Ghourab, S., Hankir, M., Zhang, S. and Carling, D. (2014). The short-chain fatty acid acetate reduces appetite via a central homeostatic mechanism. *Nature Communications.* 5, (1), 3611.

Fuller, C.W., Taylor, A., Kemp, S.P. and Raftery, M. (2017). Rugby World Cup 2015: world rugby injury surveillance study. *British Journal of Sports Medicine.* 5, (1), 51-57.

Fuller, C.W., Taylor, A.E., Brooks, J.H. and Kemp, S.P. (2013). Changes in the stature, body mass, and age of English professional rugby players: a 10-year review. *Journal of Sports Sciences.* 31, (7), 795-802.

Gabbett, T. (2009). Physiological and anthropometric characteristics of starters and non-starters in junior rugby league players, aged 13-17 years. *Journal of Sports Medicine and Physical Fitness.* 49, (3), 233-239.

Gabbett, T., Jenkins, D. and Abernethy, B. (2010). Physical collisions and injury during professional rugby league skills training. *Journal of Science and Medicine in Sport.* 13, (6), 578-583.

Gabbett, T.J. (2005a). Science of rugby league football: a review. *Journal of Sports Sciences.* 23, (9), 961-976.

Gabbett, T.J. (2012). Sprinting patterns of national rugby league competition. *The Journal of Strength and Conditioning Research.* 26, (1), 121-130.

Gabbett, T.J. (2013). Sprinting patterns of national rugby league competition. *The Journal of Strength and Conditioning Research.* 26, (1), 121-130.

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

Gabbett, T.J., Jenkins, D.G. and Abernethy, B. (2011a). Correlates of tackling ability in high-performance rugby league players. *The Journal of Strength and Conditioning Research.* 25, (1), 72-79.

Gabbett, T.J., Jenkins, D.G. and Abernethy, B. (2011b). Relationships between physiological, anthropometric, and skill qualities and playing performance in professional rugby league players. *Journal of Sports Sciences.* 29, (15), 1655-1664.

Gabbett, T.J., Jenkins, D.G. and Abernethy, B. (2012). Physical demands of professional rugby league training and competition using microtechnology. *Journal of Science and Medicine in Sport.* 15, (1), 80-86.

Gabbett, T., King, T. and Jenkins, D. (2008). Applied physiology of rugby league. *Sports Medicine.* 38, (2), 119-138.

Gabbett, T.J., Kelly, J. and Pezet, T. (2008). A comparison of fitness and skill among playing positions in sub-elite rugby league players. *Journal of Science and Medicine in Sport.* 11, (6), 585-592.

Garthe, I., Raastad, T. and Sundgot-Borgen, J. (2011). Long-terms effect of nutritional counselling on desired gain in body mass and lean body mass in elite athletes. *Applied Physiology.* 36, (4), 547-554.

Geeson-Brown, T., Jones, B., Till, K., Chantler, S. and Deighton, K. (2020). Body composition differences by age and playing standard in male rugby union and rugby league: A systematic review and meta-analysis. *Journal of Sports Sciences.* 38, (19), 2161-2176.

Georgeson, E.C., Weeks, B.K., McLellan, C. and Beck, B.R. (2012). Seasonal change in bone, muscle and fat in professional rugby league players and its relationship to injury: a cohort study. *BMJ Open.* 2, (6), p.e001400.

Gibby, J.T., Njeru, D.K., Cvetko, S.T., Heiny, E.L., Creer, A.R. and Gibby, W.A. (2017). Whole-body computed tomography-based body mass and body fat quantification: a comparison to hydrostatic weighing and air displacement plethysmography. *Journal of Computer Assisted Tomography.* 41, (2), 302-308.

Ginty, F., Rennie, K.L., Mills, L., Stear, S., Jones, S. and Prentice, A. (2005). Positive, site-specific associations between bone mineral status, fitness and time spent at high-impact activities in 16-to 18-year-old boys. *Bone.* 36, (1), 101-110.

Gissane, C., Jennings, D., Kerr, K. and White, J.A. (2002). A pooled data analysis of injury in rugby league football. *Sports Medicine.* 32, (3), 211-216.

Gorla, J.I., Silva, A.D.A.C., Borges, M., Tanhoffer, R.A., Godoy, P.S., Calegari, D.R., Santos, A.D.O., Ramos, C.D., Junior, W.N. and Junior A.C. (2016). Impact of wheelchair rugby on body composition of subjects with tetraplegia: A pilot study. *Archives of Physical Medicine and Rehabilitation.* 97, (1), 92-96.

Granacher, U., Lesinski, M., Büsch, D., Muehlbauer, T., Prieske, O., Puta, C., Gollhofer, A. and Behm, D.G. (2016). Eggects of resistance training in youth athletes on muscular fitness and athletic performance: a conceptual model for long-term athlete development. *Frontiers in Physiology.* 1, 164.

Gratton, C. and Jones, I. (2014). *Research methods for sports studies.* 3rd edn. London: Routledge.

Guo, J., Zhang, X., Wang, L., Guo, Y. and Xie, M. (2013). Prevalence of metabolic syndrome and its components among Chinese professional athletes of strength sports with different body weight categories. *PLoS One.* 8, (11), p.e79758.

Hamlin, M.J., Deuchrass, R.W., Elliot, C.E. and Manimmanakorn, N. (2021). Short and long-term differences in anthropometric characteristics and physical performance between male rugby players that became professional or remained amateur. *Journal of Exercise Science and Fitness.* 19, (3), 143-149.

Hangartner, t.n., Werner, S., Braillon, P., Jankowski, L. and Shepherd, J. (2013). The official positions of the International Society for Clinical Densitometry: acquisition of dual-energy X-ray absorptiometry body composition and considerations regarding analysis and repeatability of measures. *Journal of Clinical Densitometry.* 16, (4), 520-536.

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 and Conditioning Research.* 25, (9), 2382-2391.

Harley, J.A., Hind, K. and O'hara, J.P. (2011). Three-compartment body composition changes in elite rugby league players during a super league season, measured by dual-energy X-ray absorptiometry. *The Journal of Strength and Conditioning Research.* 25, (4), 1024-1029.

Harley, J.A., Kind, K., O'Hara, J. and Gross, A. (2009). Validation of the skin-fold thickness method and air displacement plethysmography with dual energy X-ray absorptiometry, for the estimation of % body fat in professional male rugby football league players. *International Journal of Body Composition Research.* 7, (1), 7-14.

Hartmann Nunes, R.F., de Souza Bezerra, E., Orssatto, L.B., Moreno, Y.M., Loturco, I., Duffield, R., Silva, D.A. and Guglielmo, L.G. (2020). Assessing body composition in rugby players: agreement between different methods and association with physical performance. *The Journal of Sports Medicine and Physical Fitness.* 60, (5), 733-742.

Hepple, R.T. (2000). Skeletal muscle: microcirculatory adaptation to metabolic demand. *Medicine and Science in Sports and Exercise.* 32, (1), 117-123.

Higgins, P.B., Fields, D.A., Hunter, G.R. and Gower, B.A. (2001). Effect of scalp and facial hair on air displacement plethysmography estimates of percentage of body fat. *Obesity Research.* 9, (5), 326-330.

Higham, D.G., Pyne, D.B., Anson, J.M. and Eddy, A. (2012). Movement patterns in rugby sevens: effects of tournament level, fatigue and substitute players. *Journal of Science and Medicine in Sport.* 15, (3), 277-282.

Higham, D.G., Pyne, D.B., Anson, J.M. and Eddy, A. (2013). Physiological, anthropometric, and performance characteristics of rugby sevens players. *International Journal of Sports Physiology and Peroformance.* 8, (1), 19-27.

Higham, D.G., Pyne, D.B., Anson, J.M., Dziedzic, C.E. and Slater, G.J. (2014). Distribution of fat, non-osseous lean and bone mineral mass in international rugby union and rugby sevens players. *International Journal of Sports Medicine.* 35, (7), 575-582.

Hill, N.E., Rilstone, S., Stacey, M.J., Amiras, D., Chew, S., Flatman, D. and Oliver, N.S. (2018). Changes in northen hemisphere male international rugby union players' body mass and height between 1955 and 2015. *BMJ Open Sport and Exercise Medicine.* 4, (1), p.e000459.

Hind, K. (2022). Application of dual energy X-ray absorptiometry. *In:* Sport and Exercise Physiology Testing Guidelines. *2nd edn.* Routledge.

Hind, K., Oldroyd, B. and Truscott, J.G. (2011). In vivo precision of the GE Lunar iDXA densitometer for the measurement of total body composition and fat distribution in adults. *European Journal of Clinical Nutrition.* 65, (1), 140-142.

Hind, K., Slater, G., Oldroyd, B., Lees, M., Thurlow, S., Barlow, M. and Shepherd, J. (2018). Interpretation of dual-energy X-ray absorptiometry-derived body composition change in athletes: a review and recommendations for best practice. *Journal of Clinical Densitometry.* 21, (3), 429-443.

Horicka, P., Hianik, J. and Simonek, J. (2014). The relationship between speed factors and agility in sport games. *Journal of Human Sport and Exercise.* 9, (1), 49-58.

Hyatt, H.W. and Kavazis, A.N. (2019). Body composition and perceived stress through a calendar year in NCAA I female volleyball players. *International Journal of Exercise Science.* 12, (5), 433-443.

Jackson, A.S. and Pollock, M.L. (1978). Generalised equations for predicting body density of men. *British Journal of Nutrition.* 40, (3), 497-504.

Johnston, R.D., Gabbett, T.J. and Jenkins, D.G. (2014). Applied sport science of rugby league. *Sports Medicine.* 44, (8), 1087-1100.

Jones, B., Till, K., Barlow, M., Lees, M., O’Hara, J.P. and Hind, K. (2015). Anthropometric and three-compartment body composition differences between Super League and

Championship rugby league players: Considerations for the 2015 season and beyond. *PloS one.* 10, (7), p.e0133188.

Jones, B., Weaving, D., Tee, J., Darral-Jones, J., Weakley, J., Phibbs, P., Read, D., Roe, G., Hendricks, S. and Till, K. (2018). Bigger, stronger, faster, fitter: the differences in physical qualities of school and academy rugby union players. *Journal of Sports Sciences.* 36, (21), 2399-2404.

Joo, C.H. (2018). The effects of short-term detraining and retraining on physical fitness in elite soccer players. *PloS one.* 13, (5), p.e0196212.

Kasper, A.M., Langan-Evans, C., Hudson, J.F., Brownlee, T.E., Harper, L.D., Naughton, R.J., Morton, J.P. and Close, G.L. (2021). Come back skinfolds, all is forgiven: a narrative review. Of the efficacy of common body composition methods in applied sports practice. *Nutrients.* 13, (4), 1075.

Keil, M., Totosy de Zepetnek, J.O., Brooke-Wavell, K. and Goosey-Tolfrey, V.L. (2016). Measurement precision of body composition variables in elite wheelchair athletes, using dual-energy X-ray absorptiometry. *European Journal of Sport Science.* 16, (1), 65-71.

Kerr, A., Slater, G.J. and Byrne, N. (2017). Impact of food and fluid intake on technical and biological measurement error in body composition assessment methods in athletes. *British Journal of Nutrition.* 117, (4), 591-601.

Koundourakis, N.E., Androulakis, N.E., Malliaraki, N., Tsatsanis, C., Venihaki, M. and Margioris, A.N. (2014). Discrepancy between exercise performance, body composition, and sex steroid response after a six-week detraining period in professional soccer players. *PloS one.* 9, (2), p.e87803.

Kravitz, L. and Heyward, V.H. (1992). Getting a grip on body composition. *IDEA Today.* 10, (4), 34-39.

Kuriyan, R. (2018). Body composition techniques. *Indian Journal of Medical Research.* 148, (5), 648-658.

Kutáč, P., Bunc, V. and Sigmund, M. (2019). Whole-body dual-energy X-ray absorptiometry demonstrates better reliability than segmental body composition analysis in college-aged students. *Plos One.* 14, (4), p.e0215599.

Kyle, U.G., Bosaeus, I., De Lorenzo, A.D., Deurenberg, P., Elia, M., Gómez, J.M., Heitmann, B.L., Kent-Smith, L., Melchior, J.C., Pirlich, M. and Scharfetter, H. (2004). Bioelectrical impedance analysis – part II: utilisation in clinical practice. *Clinical Nutrition.* 23, (6), 1430-1453.

La Monica, M.B., Fukuda, D.H., Miramonti, A.A., Beyer, K.S., Hoffman, M.W., Boone, C.H., Tanigawa, S., Wang, R., Church, D.D., Stout, J.R. and Hoffman, J.R. (2016). Physical differences between forwards and backs in American collegiate rugby players. *Journal of Strength and Conditioning Research.* 30, (9), 2382-2391.

Laskey, M. (1996). Dual-energy X-ray absorptiometry and body composition. *Nutrition.* 12, (1), 45-51.

Last Word on Sports, (2020). ‘Top 20 rugby union countries with most registered players’ [online]. Available from: https://lastwordonsports.com/rugby/2020/07/14/top-20-rugby-union-countries-registered-players/ [Accessed 7 November 2022].

Lees, M.J., Oldroyd, B., Jones, B., Brightmore, A., O’Hara, J.P., Barlow, M.J., Till, K. and Hind, K. (2017). Three-compartment body composition changes in professional rugby union players over one competitive season: a team and individualized approach. *Journal of Clinical Densitometry*. 20, (1), 50-57.

Lewiecki, E.M., Binkley, N., Morgan, S.L., Shuhart, C.R., Camargos, B.M., Carey, J.J., Gordon, C.M., Jankowski, L.G., Lee, J.K. and Leslie, W.D. (2016). Best practices for dual-energy X-ray absorptiometry measurement and reporting: International Society for Clinical Densitometry Guidance. Journal of clinical densitometry. *19*, (2),127-140.

Licata, A.A. and Williams, S.E. (2014). What happens after I order a DXA? *In:* A DXA Primer for the Practicing Clinician. *Springer*. New York.

Lindsay, A., Draper, N., Lewis, J., Gieseg, S.P. and Gill, N. (2015). Positional demands of professional rugby. *European Journal of Sport Science.* 15, (6), 480-487.

Liu, J., Fox, C.S., Hickson, D.A., May, W.D., Hairston, K.G., Carr, J.J. and Taylor, H.A. (2010). Impact of abdominal visceral and subcutaneous adipose tissue on cardiometabolic risk factors: the Jackson Heart Study. *The Journal of Clinical Endocrinology and Metabolism.* 95, (12), 5419-5426.

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 and Conditioning Research.* 29, (4), 980-988.

Lowry, D.W. and Tomiyama, A.J. (2015). Air displacement plethysmography versus dual-energy x-ray absorptiometry in underweight, normal-weight and overweight/obese individuals. *PloS One.* 10, (1), p.e0115086.

Lukaski, H.C. (2013). Evolution of bioimpedance: a circuitous journey from estimation of physiological function to assessment of body composition and a return to clinical research. *European Journal of Clinical Nutrition.* 67, (1), S2-S9.

Malina, R.M., Bouchard, C. and Bar-Or, O. (2004). Growth, maturation and physical activity. *Human Kinetics.*

Marriott, B.M. and Grumstrup, J. (1992). *Body composition and physical performance: applications for military services.* Washington: Natl.

Martin, A.D., Spenst, L.F., Drinkwater, D.T. and Clarys, J.P. (1990). Anthropometric estimation of muscle mass in men. *Medicine and Science in Sports and Exercise.* 22, (5), 729-733.

McHugh, C., Hind, K., Wyse, J., Davey, D. and Wilson, F. (2021). Increases in DXA-derived visceral fat across one season in professional rugby union players: importance of visceral fat monitoring in athlete body composition assessment. *Journal of Clinical Densitometry.* 24, (2), 206-213.

McKay, A.K., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., Sheppard, J. and Burke, L.M. (2021). Defining training and performance calibre: a participant classification framework. *International Journal of Sports Physiology and Performance.* 17, (2), 317-331.

Meir, R., Newton, R., Curtis, E., Fardell, M. and Butler, B. (2001). Physical fitness qualities of professional rugby league football players: determination of positional differences. *The Journal of Strength and Conditioning Research.* 15, (4), 450-458.

Meir, R.A. (1993). Seasonal changes in estimates of body composition in professional rugby league players. *Sport Health.* 11, (4), 27-31.

Milanese, C., Piscitelli, F., Lampis, C. and Zancanaro, C. (2012). Effect of a competitive season on anthropometry and three-compartment body composition in female handball players. *Biology of Sport.* 29, (3), 199-204.

Mittal, B. (2019). Subcutaneous adipose tissue and visceral adipose tissue. *Indian Journal of Medical Research.* 149, (5), 571-573.

Mølgaard, C., Thomsen, B.L., Prentice, A., Cole, T.J. and Michaelsen, K.F. (1997). Whole body bone mineral content in healthy children and adolescents. *Archives of Disease in Childhood*. *76,* (1), 9-15.

Moon, J.R. (2013). Body composition in athletes and sports nutrition: an examination of the bioimpedance analysis technique. *European Journal of Clinical Nutrition.* 67, (1), S54-S59.

Morehen, J.C., Clarke, J., Batsford, J., Highton, J., Erskine, R.M., Morton, J.P. and Close, G.L. (2020). Development of anthropometric characteristics in professional Rugby League players: Is there too much emphasis on the pre-season period? *European Journal of Sport Science.* 20, (8), 1013-1022.

Morehen, J.C., Routledge, H.E., Twist, C., Morton, J.P. and Close, G.L. (2015). Position specific differences in the anthropometric characteristics of elite European Super League rugby players. *European Journal of Sport Science.* 15, (6), 523-529.

Morgan, P.J. and Callister, R. (2011). Effects of a preseason intervention on anthropometric characteristics of semi-professional rugby league players. *The Journal of Strength and Conditioning Research.* 25, (2), 432-440.

Mulasi, U., Kuchnia, A.J., Cole, A.J. and Eartman, C.P. (2015). Bioimpedance at the bedside: current applications, limitations, and opportunities. *Nutrition in Clinical Practice.* 30, (2), 180-193.

Murata, H., Oshima, S., Torii, S., Taguchi, M. and Higuchi, M. (2016). Characteristics of body composition and cardiometabolic risk of Japanese male heavyweight Judo athletes. *Journal of Physiological Anthropology.* 35, (1), 1-6.

Nana, A., Slater, G.J., Hopkins, W.G. and Burke, L.M. (2012). Effects of daily activities on dual-energy X-ray absorptiometry measurements of body composition in active people. *Medicine and Science in Sports and Exercise.* 44, (1). 180-189.

Nana, A., Slater, G.J., Stewart, A.D. and Burke, L.M. (2015). Methodology review: using dual-energy X-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people. *International Journal of Sport Nutrition and Exercise Metabolism.* 25, (2), 198-215.

National Health and Nutrition Examination Survey (NHANES) (2011). 2011 Body Composition Procedures Manual.

Neeland, I.J., Ayers, C.R., Rohatgi, A.K., Turer, A.T., Berry, J.D., Das, S.R., Vegam G.L., Khera, A., McGuire, D.K., Grundy, S.M. and de Lemos, J.A. (2013). Associations of visceral and abdominal subcutaneous adipose tissue with markers of cardiac and metabolic risk in obese adults. *Obesity.* 21, (9), E439-E447.

Nikolaidis, P.T. and Karydis, N.V. (2011). Physique and body composition in soccer players across adolescence. *Asian Journal of Sports Medicine.* 2, (2), 75-82.

Nirmalendran, R. and Ingle, L. (2010). Detraining effect of the post-season on selected aerobic and anaerobic performance variables in national league rugby union players: a focus on positional status. *Medicina Sportiva.* 14, (4), 161-168.

O'Connor, D. (1996). Physiological characteristics of professional rugby league players. *Strength and Conditioning Coach.* 4, (1), 21-26.

Olds, T. (2001). The evolution of physique in male rugby union players in the twentieth century. *Journal of Sports Sciences.* 19, (4), 253-262.

Owen, S.M., Venter, R.E., Du Toit, S. and Kraak, W.J. (2015). Acceleratory match-play demands of a Super Rugby team over a competitive season. *Journal of Sports Sciences.* 33, (19), 2061-2069.

Özkan, A., Kayihan, G., Köklü, Y., Ergun, N., Koz, M., Ersöz, G. and Dellal, A. (2012). The relationship between body composition, anaerobic performance and sprint ability of amputee soccer players. *Journal of Human kinetics.* 35, (1), 141-146.

Pain, M.T., Tsui, F. and Cove, S. (2008). In vivo determination of the effect of shoulder pads on tackling forces in rugby. *Journal of Sports Sciences.* 26, (8), 855-862.

Paul, D.J., Gabbett, T.J. and Nassis, G.P. (2016). Agility in team sports: Testing, training and factors affecting performance. *Sports Medicine.* 46, (3), 421-442.

Peeters, M.W. and Claessens, A.L. (2011). Effect of different swim caps on the assessment of body volume and percentage body fat by air displacement plethysmography. *Journal of Sports Sciences.* 29, (2), 191-196.

Pietrobelli, A., Wang, Z., Formica, C. and Heymsfield, S.B. (1998). Dual-energy X-ray absorptiometry: fat estimation errors due to variation in soft tissue hydration. *American Journal of Physiology-Endocrinology and Metabolism*. 274, (5), E808-E816.

Pludowski, P., Jaworski, M., Matusik, H., Kobylinska, M., Klimek, P. and Lorenc, R.S. (2010). The evaluation of consistency between body composition assessments in pediatric population using pencil beam and fan beam dual-energy X-ray absorptiometry. *Journal of Clinical Densitometry.* 13, (1), 84-95.

Pontaga, I., Liepina, J., Kazoka, D. and Umbrasko, S. (2019). Fatness and thermoregulation of qualified rugby players. *SHS Web of Conferences.* 68, (1), p.e02011.

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

Prado, C.M. and Heymsfield, S.B. (2014). Lean tissue imaging: a new era for nutritional assessment and intervention. *Journal of Parenteral and Enteral Nutrition.* 38, (8), 940-953.

Quarrie, K.L. and Hopkins, W.G. (2007). Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. *Journal of Sports Sciences.* 25, (8), 895-903.

Quarrie, K.L. and Wilson, B.D. (2000). Force production in the rugby union scrum. *Journal of Sports Sciences.* 18, (4), 237-246.

Quarrie, K.L., Handcock, P., Waller, A.E., Chambers, D.J., Toomey, M.J. and Wilson, B.D. (1995). The New Zealand rugby injury and performance project. III. Anthropometric and physical performance characteristics of players. *British Journal of Sports Medicine.* 29, (4), 263-270.

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), 353-359.

Ramos-Álvarez, J.J., Montoya, J.J., Solís-Mencia, C., Miguel-Tobal, F., López-Tapia, P., Sánchez-Oliver, A.J., Domínguez, R. and Martínez-Sanz, J.M. (2021). Anthropometric profile assessed by bioimpedance and anthropometry measures of male and female rugby players competing in the Spanish National League. *Applied Sciences.* 11, (24), 11759.

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

Redman, K.J., Wade, L., Whitley, R., Connick, M.J., Kelly, V.G. and Beckman, E.M. (2021). The relationship between match tackle outcomes and muscular strength and power in professional rugby league. *Journal of Strength and Conditioning Research.*

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), 825-833.

RugbyPass. (2019). ‘Heaviest players at 2019 World Cup revealed’ [online]. Available from https://www.rugbypass.com/news/heaviest-players-at-2019-rugby-world-cup-revealed/ [Accessed 22 November 2022].

Rush, E.C., Freitas, I. and Plank, L.D. (2009). Body size, body composition and fat distribution: comparative analysis of European, Maori, Pacific Island and Asian Indian adults. *British Journal of Nutrition.* 102, (4), 632-641.

Sanchez-Muñoz, C., Muros, J.J. and Zabala, M. (2017). World and Olympic mountain bike champions' anthropometry, body composition and somatotype. *The Journal of Sports Medicine and Physical Fitness.* 58, (6), 843-851.

Sayers, M. (1999). Running techniques for running rugby. *New Zealand Coach.* 7, (1), 20-23.

Seabolt, L.A., Welch, E.B. and Silver, H.J. (2015). Imaging methods for analysing body composition in human obesity and cardiometabolic disease. *Annals of the New York Academy of Sciences.* 1353, (1), 41-59.

Sedeaud, A., Marc, A., Schipman, J., Tafflet, M., Hager, J.P. and Toussaint, J.F. (2012). How they won the Rugby World Cup through height, mass and collective experience. *British Journal of Sports Medicine.* 46, (8), 580-584.

Sedeaud, A., Vidalin, H., Taffflet, M., Marc, A. and Toussaint, J.F. (2013). Rugby morphologies: "bigger and taller", reflects an early directional selection. *The Journal of Sports Medicine and Physical Fitness.* 53, (2), 185-191.

Sedeaud, A., Vidalin, H., Tafflet, M., Marc, A. and Toussaint, J.F. (2013). Rugby morphologies: “bigger and taller”, reflects an early directional selection. *The Journal of Sports Medicine and Physical Fitness.* 53, (2), 185-191.

Selkirk, G.A. and McLellan, T.M. (2001). Influence of aerobic fitness and body fatness on tolerance to uncompensable heat stress. *Journal of Applied Physiology.* 91, (5), 2055-2063.

Sesbreno, E., Slater, G., Mountjoy, M. and Galloway, S.D. (2020). Development of an anthropometric prediction model for fat-free mass and muscle mass in elite athletes. *International Journal of Sport Nutrition and Exercise Metabolism.* 30, (2), 174-181.

Shepherd, J., Ng, B., Sommer, M. and Heymsfield, S.B. (2017). Body Composition by DXA. *Bone.* 104, 101-105.

Shepherd, J., Ng, B., Sommerm M. and Heymsfield, S.B. (2018). Body Composition by DXA. *Bone.* 104, (1), 101-105.

Shuster, A., Patlas, M., Pinthus, J.H. and Mourtzakis, M. (2012). The clinical importance of visceral adiposity: a critical review of methods for visceral adipose tissue analysis. *The British Journal of Radiology.* 85, (1009), 1-10.

Siervogel, R.M., Demerath, E.W., Schubert, C., Remsberg, K.E., Chumlea, W.C., Sun, S., Czerwinski, S.A. and Towne, B. (2003). Puberty and body composition. *Hormone Research in Paediatrics.* 60, (Suppl_1), 36-45.

Silva, A.M., Fields, D.A., Quitério, A.L. and Sardinha, L.B. (2009). Are skinfold-based models accurate and suitable for assessing changes in body composition in highly trained athletes? *The Journal of Strength and Conditioning Research.* 23, (6), 1688-1696.

Silva, A.M., Heymsfield, S.B. and Sardinha, L.B. (2013). Assessing body composition in taller or broader individuals using dual-energy X-ray absorptiometry: a systematic review. *European Journal of Clinical Nutrition.* 67, (10), 1012-1021.

Silva, J.R., Brito, J., Akenhead, R. and Nassis, G.P. (2016). The transition period in soccer: a window of opportunity. *Sports Medicine.* 46, (3), 305-313.

Silvestre, R., Kraemer, W.J., West, C., Judelson, D.A., Spiering, B.A., Vingren, J.L., Hatfield, D.L., Anderson, J.M. and Maresh, C.M. (2006b). Body composition and physical performance during a National Collegiate Athletic Association Division I men’s soccer season. *Journal of Strength and Conditioning Research.* 20, (4), 962-970.

Silvestre, R., West, C., Maresh, C.M. and Kraemer, W.J. (2006a). Body composition and physical performance in men’s soccer: A study of a National Collegiate Athletic Association Division I team. *The Journal of Strength and Conditioning Research.* 20, (1), 177-183.

Siri, W.E. (1961). Body composition from fluid spaces and density: analysis of methods. *In:* Brokzek J. and Henschel A. (eds). *Techniques for measuring body composition. National Academy of Sciences National Research Council.* Washington, D.C.

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 Sports Science.* 14, (Suppl_1), 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 and Conditioning Research.* 27, (11), 3033-3044.

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

Stefanaki, C., Pervanidou, P., Boschiero, D. and Chrousos, G.P. (2018). Chronic stress and body composition disorders: implications for health and disease. *Hormones.* 17, 33-43.

Stewart, A.D. (2010). Kinanthropometry and body composition: A natural home for the three-dimensional photonic scanning. *Journal of Sports Sciences.* 28, (5), 455-457.

Stewart, D. and Hannan, W.J. (2000). Prediction of fat and fat-free mass in male athletes using dual X-ray absorptiometry as the reference method. *Journal of Sports Sciences.* 18, (4), 263-274.

Stodden, D.F. and Galitski, H.M. (2010). Longitudinal effects of a collegiate strength and conditioning program in American football. *The Journal of Strength and Conditioning Research.* 24, (9), 2300-2308.

Stöggl, T., Enqvist, J., Müller, E. and Holmberg, H.C. (2010). Relationships between body composition, body dimensions, and peak speed in cross-country sprint skiing. *Journal of Sports Sciences.* 28, (2), 161-169.

Stoop, R., Hohenauer, E., Rucker, A.M.L. and Clijsen, R. (2019). Anthropometric properties versus physical performance in rugby union forwards and backs – A systematic review. *Annals of Applied Sport Science.* 6, (2), 1.13.

Suarez-Arrones, L.J., Nunez, F.J., Portillo, J. and Mendez-Villanueva, A. (2012). Running demands and heart rate responses in men rugby sevens. *The Journal of Strength and Conditioning Research.* 26, (11), 3155-3159.

Suchomel, T.J., Nimphius, S. and Stone, M.H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine.* 46, 1419-1449.

Sutton, L., Scott, M., Wallace, J. and Reilly, T. (2009). Body composition of English Premier League soccer players: Influence of playing position, international status and ethnicity. *Journal of Sports Sciences.* 27, (10), 1019-1026.

Syed-Abdul, M.M., Soni, D.S., Barnes, J.T. and Wagganer, J.D. (2021). Comparative analysis of BIA, IBC, and DXA for determining body fat in American Football players. *The Journal of Sports Medicine and Physical Fitness.* 61, (5), 687-692.

Taber, C.B., Vigotsky, A., Nuckols, G. and Haun, C.T. (2019). Exercise-induced myofibrillar hypertrophy is a contributory cause of gains in muscle strength. *Sports Medicine.* 49, (7), 993-997.

Tchernof, A. and Despres, J.P. (2013). Pathophysiology of human visceral obesity: an update. *Physiological Reviews.* 93, (1), 359-404.

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 and Coaching.* 11, (2), 200-211.

Thurlow, S., Oldroyd, B. and Hind, K. (2018). Effect of hand positioning on DXA total and regional body composition parameters, precision error, and least significant change. *Journal of Clinical Densitometry.* 21, (3), 375-382.

Tierney, G.J., Joodaki, H., Krosshaug, T., Forman, J.L., Crandall, J.R. and Simms, C.K. (2018). Assessment of model-based image-matching for future reconstruction of unhelmeted sport head impact kinematics. *Sports Biomechanics.* 17, (1), 33-47.

Till, K., Cobley, S., O’Hara, J., Brightmore, A., Cooke, C. and Chapman, C. (2011). Using anthropometric and performance characteristics to predict selection in junior UK Rugby League players. *Journal of Science and Medicine in Sport.* 14, (3), 264-269.

Till, K., Cobley, S., O’Hara, J., Chapman, C. and Cooke, C. (2013). A longitudinal evaluation of anthropometric and fitness characteristics in junior rugby league players considering playing position and selection level. *Journal of Science and Medicine in Sport.* 16, (5), 438-443.

Till, K., Jones, B., Darrall-Jones, J., Emmonds, S. and Cooke, C. (2015). Longitudinal development of anthripometric and physical characteristics within academy league players. *The Journal of Strength and Conditioning Research.* 29, (6), 1713-1722.

Till, K., Jones, B., O’Hara, J., Barlow, M., Brightmore, A., Lees, M. and Hind, K. (2016). Three-compartment body composition in academy and senior rugby league players. *International Journal of Sports Physiology and Performance.* 11, (2), 191-196.

Till, K., Scantlebury, S. and Jones, B. (2017). Anthropometric and physical qualities of elite male youth rugby league players. *Sports Medicine.* 47, (11), 2171-2186.

Till, K., Tester, E., Jones, B., Emmonds, S., Fahey, J. and Cooke, C. (2014). Anthropometric and physical characteristics of English academy rugby league players. *The Journal of Strength and Conditioning Research.* 28, (2), 319-327.

Till, K., Weakley, J., Read, D.B., Phibbs, P., Darrall-Jones, J., Roe, G., Chantler, 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), 1-20.

Toombs, R.J., Ducher, G, Shepherd, J.A. and De Souza, M.J. (2012). The impact of recent technological advances on the trueness and precision of DXA to assess body composition. *Obesity.* 20, (1), 30-39.

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 and Exercise Medicine.* 7, (1), p.e000885.

Turner, C.H. and Robling, A.G. (2003). Designing exercise regimes to increase bone strength. *Exercise and Sport Sciences Reviews.* 31, (1), 45-50.

Van Den Berg, P.H., De Ridder, J.H., Malan, D.D. and Ellis, S.M. (2021). An anthropometric comparison of different player positions in elite rugby union sevens. *International Journal of Sports and Physical Education.* 7, (1), 11-18.

Van Der Ploeg, G.E., Withers, R.T. and Laforgia, J. (2003). Percent body fat via DEXA: comparison with a four-compartment model. *Journal of Applied Physiology.* 94, (2), 499-506.

Van Loan, M.D. (1998). Is dual-energy X-ray absorptiometry ready for prime time in the clinical evaluation of body composition? *The American Journal of Clinical Nutrition.* 68, (6), 1155-1156.

Van Rooyen, M., Yasin, N. and Viljoen, W. (2014). Characteristics of an 'effective' tackle outcome in Six Nations rugby. *European Journal of Sport Science.* 14, (2), 123-129.

Vaz, L., Morais, T., Rocha, H. and James, N. (2014). Fitness profiles of elite Portuguese rugby union players. *Journal of human kinetics*. *41*, (1), 235-244.

Vehovar, V., Toepoel, V. and Steinmetz, S. (2016). Non-probability sampling. *The Sage Handbook of Survey Methods.* 1, (1), 329-345.

Vescovi, J.D., Zimmerman, S.L., Miller, W.C. and Fernhall, B.O. (2002). Effects of clothing on accuracy and reliability of air displacement plethysmography. *Medicine and Science in Sports and Exercise.* 34, (2), 282-285.

Virr, J.L., Game, A., Bell, G.J. and Syrotuik, D. (2014). Physiological demands of women's rugby union: time-motion analysis and heart rate response. *Journal of Sport Sciences.* 32, (3), 239-247.

Viviers, P.L., Viljoen, J.T. and Derman, W. (2018). A review of a decade of rugby union injury epidemiology: 2007-2017. *Sports Health.* 10, (3), 223-227.

Vuori, I.M. (2001). Dose-response of physical activity and low back pain, osteoarthritis and osteoporosis. *Medicine and Science in Sports and Exercise.* 33, (6_Suppl), S551.

Waldron, M., Worsfold, P., Twist, C. and Lamb, K. (2014). Changes in anthropometry and performance, and their interrelationships, across three seasons in elite youth rugby league players. *The Journal of Strength and Conditioning Research.* 28, (11), 3128-3136.

Wang, X. and Cheng, Z. (2020). Cross-sectional studies: strengths, weaknesses and recommendations. *Chest.* 158, (1), S65-S71.

Wang, Z. (1997). *Human body composition models and methodology: Theory and experiment.* Wang.

Watkins, C.M., Storey, A., McGuigan, M.R., Downes, P. and Gill, N.D. (2021). Horizontal force-velocity-power profiling of rugby players: A cross-sectional analysis of competition-level and position-specific movement demands. *The Journal of Strength and Conditioning Research.* 35, (6), 1576-1585.

Weaving, D., Sawczuk, T., Williams, S., Scott, T., Till, K., Beggs, C., Johnston, R.D. and Jones, B. (2019). The peak duration-specific locomotor demands and concurrent collision frequencies of European Super League rugby. *Journal of Sports Sciences.* 37, (3), 322-330.

Wells, J.C.K. and Fewtrell, M.S. (2006). Measuring body composition. *Archives of Disease in Childhood.* 91, (7), 612-617.

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), 2549-2575.

Williams, A., Day, S., Stebbings, G. and Erskine, R. (2017). What does ‘elite’ mean in sport and why does it matter? *The Sport and Exercise Scientist.* 51, (6), 6.

World Rugby. (2022). ‘Player Numbers’ [online]. Available from: https://www.world.rugby/photo/59707# [Accessed 22 March 2022].

World Rugby. (2023). ‘Laws of the Game: Rugby Union’ [online]. Available from: https://resources.world.rugby/worldrugby/document/2023/01/20/9f77a933-29a2-4b04-80c0-892111d8a85f/WorldRugby_Laws_2023_en.pdf [Accessed 12 July 2023].

Young, W., Rayner, R. and Talpey, S. (2021). It’s time to change direction on agility research: A call to action. *Sports Medicine-Open.* 7, (1), 1-5.

Young, W.B., James, R. and Montgomery, I. (2002). Is muscle power related to running speed with changes of direction? *The Journal of Sports Medicine and Physical fitness.* 42, (3), 282-288.

Yu, J., Sun, Y., Yang, C., Wang, D., Yin, K., Herzog, W. and Liu, Y. (2016). Biomechanical insights into differences between the mid-acceleration and maximum velocity phases of sprinting. *Journal of Strength and Conditioning Research.* 30, (7), 1906-1916.

Zemski, A.J., Broad, E.M. and Slater, G.J. (2018). Skinfold prediction equations fail to provide an accurate estimate of body composition in elite rugby union athletes of Caucasian and Polynesian ethnicity. *International Journal of Sport Nutrition and Exercise Metabolism.* 28, (1), 90-99.

Zemski, A.J., Keating, S.E., Broad, E.M. and Slater, G.J. (2019a). Longitudinal changes in body composition assessed using DXA and surface anthropometry show a good agreement in elite rugby union athletes. *International Journal of Sport Nutrition and Exercise Metabolism.* 29, (1), 24-31.

Zemski, A.J., Keating, S.E., Broad, E.M., Marsh, D.J., Hind, K. and Slater, G.J. (2019b). Preseason body composition adaptations in elite white and Polynesian rugby union athletes. *International Journal of Sport Nutrition and Exercise Metabolism.* 29, (1), 9-17.

Zemski, A.J., Slater, G.J. and Broad, E.M. (2015). Body composition characteristics of elite Australian rugby union athletes according to playing position and ethnicity. *Journal of Sports Sciences.* 33, (9), 970-978.

Appendix A: Challenges encountered during the study period

Throughout the course of this study, numerous challenges presented themselves. The original intent of this project was to examine the relationship between sprint performance and body composition in sub-elite rugby union players over the course of a competitive season. However, issues with technology occurred during multiple testing sessions. Issues with timing gates and laser guns made the sprint data unusable. The weather also caused issues with testing as the first testing session had to be conducted indoors which hindered the validity of the data. Similarly, the second testing session was negatively impacted by bad weather. This caused me to have to change the focus of my study as these issues caused the sprint data to be deemed unusable. Therefore, the focus of this study altered to examining body composition between elite and sub-elite rugby union athletes during the pre-season period.

This study was conducted throughout the Covid-19 pandemic, which caused issues with testing sessions as on multiple occasions some participants and researchers were not present due to the need to self-isolate. Finally, a year into the study period, my initial primary supervisor left the university. This resulted in me having only one supervisor for a period of time, which caused delays in feedback on draft chapters as the new supervisory arrangements were sorted. This also occurred during the period when the focus of my dissertation was shifting and having the support of a primary supervisor to guide this refocusing would have been particularly useful.

Appendix B: Participant 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 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.

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 C: Privacy Notice

Privacy Notice

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 D: 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 E: Pre-DXA scan Preparation Guidance

version 1. June 2021

Pre-DXA scan Preparation Guidance

The following pre-scan preparation protocol ensures that your DXA scan results will be as accurate as possible.
Please follow this guidance before attending your DXA scan appointment and if you have any questions, please contact: Dr Karen Hind, karen.hind@durham.ac.uk.

- My appointment is before 11am = Please fast overnight (last meal no later than 10pm)
- My appointment is after 11am = Please fast for 5 hours prior to your scan appointment
- Drink 500ml of water 3 hours before your appointment
- No moderate-vigorous exercise in the 12 hours before your appointment
- No caffeine in the 5 hours before your appointment
- No alcohol in the 24 hours before your appointment
- Please wear /bring light weight, close-fitting clothing that does not contain metal, underwire, plastic or reflective strips. Ideal clothing could lightweight shorts and t-shirt.

A drinking water station (single use cups) is available for you to use following your scan.
Please bring a snack with you for after your scan.

Appendix F: Debriefing Sheet

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