# *DXA-derived body composition and jump mechanical performance in sub-elite rugby union players*

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# Mark Douglas Christie - DXA-derived body composition and jump mechanical performance in sub-elite rugby union players


## Abstract

The purpose of this study was to investigate the associations of body composition, force and velocity on squat jump height and countermovement jump height in male sub-elite university rugby union players. Seventeen male sub-elite university rugby union players performed a countermovement jump (1kg) and squat jumps using ascending loads of 1kg, 20kg, 40kg and 60kg on one single testing session at the beginning of the season. Linear force-velocity associations and body composition using dual x-ray absorptiometry (DXA) were derived, and the following variables were acquired: total body less head (TBLH) lean mass (kg), legs lean mass (kg), TBLH body fat %, TBLH fat mass (kg), theoretical maximal force (N/kg) and theoretical maximal velocity ($m \bullet s^{-1}$). The players TBLH body fat % had a statistically significant correlation with the countermovement jump height 1kg ($r= -0.723$, $p= 0.001$), squat jump height 1kg ($r= -0.608$, $p= 0.010$), squat jump height 20kg (adjusted $r^2= 0.238$, $p= 0.027$) and squat jump height 40kg (adjusted $r^2= 0.207$, $p= 0.038$). TBLH fat mass also influenced the countermovement jump height 1kg ($r= -0.736$, $p= <0.001$), squat jump height 1kg ($r= -0.683$, $p= -0.003$), squat jump height 20kg (adjusted $r^2= 0.292$, $p= 0.015$), squat jump height 40kg (adjusted $r^2= 0.212$, $p= 0.036$) and theoretical maximal velocity ($r= -0.503$, $p= 0.039$). However, TBLH lean mass, leg lean mass, theoretical maximal force and theoretical maximal velocity had no statistically significant association on the countermovement jump or any of the squat jump loading conditions. This suggests that reducing the amount of TBLH fat mass and TBLH body fat % will improve jump performance, although having more overall mass and lean mass is not necessarily advantageous for improving jump performance. Therefore, the present study provides

foundational data for future research to further investigate the associations between body composition, force, velocity and jump height in male rugby union players.

**Keywords:** jump height; theoretical maximal force; theoretical maximal velocity; body composition; squat jump; countermovement jump; male rugby union; DXA; TBLH; lean mass; legs lean mass; body fat mass; body fat %.


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**Table of Contents**

## 1.0 Introduction

Rugby union is a collision and evasion team sport with intermittent, high intensity on field play (Till *et al*, 2017; 2020). There are a total of 15 players on the field in Rugby union with an unlimited number of stages of play. Rugby union is played over the course of 80 minutes at a senior level and includes the key fundamental movements of passing, tackling and kicking. Training and match play, demands players to carry out numerous bouts of high intensity exercise (e.g., side stepping, sprinting, jumping and collisions) combined with intervals of lower intensity effort (walking, standing and jogging) (McLellan and Lovell, 2013; Whitehead *et al*, 2018; Read *et al*, 2019). There are also other variations of rugby that must be mentioned to distinguish the differences between each one. The two main variations are 7 a-side (3 forwards and 4 backs), which is played over the course of 14 minutes (7-minute halves), and 10 a-side (5 forwards and 5 backs), which is played over the course of 20 minutes (10-minute halves) (Furukawa *et al*, 2020).

### *1.1 Body composition*

Rugby union players at an elite level are characterised by specific traits including well-developed muscular strength, power and speed (Gabbett *et al*, 2011), which can be improved by developing fat-free mass (Baker and Newton, 2008; Taber *et al*, 2019). Furthermore, large amounts of fat mass may hinder performance, through impeding the power-to-weight ratio of the player as well as decreasing a player's ability to accelerate (Brazier *et al*, 2020). It may be assumed that greater amounts of lean mass will allow for a greater production of force and velocity, however excess mass, even if it is lean mass, may cause a reduction in performance as it is empirically clear that moving excess mass requires greater effort.

Prior research looking at the body composition of rugby players has also demonstrated differences in body composition between sub-elite and elite players, and between junior and senior players (Jones *et* al, 2015; Till *et al*, 2016). Although, the reliability and scale of these observations have not been analysed, especially at a university level. Thus, it is crucial for the body composition and performance of these players to be examined to give a better insight into the physical traits of rugby players at this level and this may help guide body composition goals, as players try to advance from academy to senior level squads. This data will also allow athletes and researchers to understand what body composition variables may have a greater impact on key performance metrics, such as jumping performance, in addition to overall performance. Practitioners, such as strength and conditioning coaches, can implement this evidence-based approach to ensure that when they are working with players their training methods will in fact improve performance. As a result of the current dearth of academic literature surrounding male university rugby union players, it is imperative that steps forward are being taken to assist coaches with their decision making.

Geeson-Brown *et al* (2020) conducted a meta-analysis that revealed elite senior rugby union forwards possessed greater amounts of fat free mass which should allow them to exert larger forces (Taber *et al*, 2019), especially when they are involved in scrums or rucks. A greater overall mass may have its potential benefits in impacts and collisions because of its potential contributions to greater direct momentum, as long as velocity remains the same (Baker and Newton, 2008; Higham *et al*, 2014). Current research (Jones *et* al, 2015; Till *et al*, 2016; Geeson-Brown *et al*, 2020) mainly focusses on players that are at an elite or junior level with little insight into players playing at a university level, a critical time in player development, as they have the opportunity to progress into professional rugby union. A gap in the

knowledge as to the desired body composition traits for rugby union players at a university level and the association it has with how much force and velocity they can produce exists in the current literature.

### *1.1.1 Performance testing in rugby union*

Jump-based testing stays common practise in elite and sub-elite rugby union, with the countermovement jump and squat jump being used regularly (Jones *et al*, 2016). The key difference between these exercises is the use of the stretch-shortening cycle, which consists of a fast eccentric movement, instantly followed by a quick concentric contraction of the same muscles, allowing for effective use of the accumulation of elastic energy (Komi and Gollhofer, 1997). The countermovement jump is considered to be reflective of power and explosive strength with a stretch shortening cycle included. The squat jump also demonstrates a player's power, force and velocity but in the absence of the stretch shortening cycle (Van Hooren and Zolotarjova, 2017). As power, force, velocity and jump height are crucial performance components in rugby union (Cross *et al*, 2015; Lindsay *et al*, 2015), the countermovement jump and squat jump are reliable and practical measures of these variables in the lower limbs (Markovic *et al*, 2004). A player's squat jump performance has been previously correlated with sprint speed and strength during the back squat (Comfort *et al*, 2012; Nicholson *et al*, 2021). This makes these tests a logical choice as a means of monitoring and measuring performance. As a result, it is crucial that male rugby union players are monitored at a university level to help improve performance on the pitch by physical benchmarking. This enables professional clubs to identify potential new talent by comparing performances to existing professional players.

Rugby demands players to perform high intensity activities frequently due to the nature of the sport, consequently players must possess well developed physical traits that are linked closely to a player's body composition. Crewther *et al* (2016) reported that lower body and upper body one repetition maximum strength increased whilst lowering body fat mass and body fat %, using a randomised crossover study design over four weeks in elite senior male rugby union players. This implies that players may become stronger and more powerful if they gain lean muscle mass as well as reduce body fat mass or body fat %. Argus *et al* (2010) reported similar findings in elite male rugby union players as an increase in strength for the bench press and box squat over the course of a 4-week pre-season training programme was observed. However, even though fat-free mass increased and fat mass decreased, a reduction in jump squat power and a reduction in the bench throw was seen. Although the players fat-free mass increased, which has previously been shown to affect power-to-weight ratio and acceleration positively (Geeson-Brown *et al*, 2020), their scores did not increase for every exercise performed, illustrating the need for more research to further investigate this potentially conflicting evidence.

There are various ways that force, velocity and jump height are currently measured, with some of the devices being linear position transducers, smartphone applications, force plates, jump mats and photocell systems. The Optojump has come to light in recent years as a potential replacement for the use of force plates (gold standard), especially during field-based testing, as it has shown good reliability and validity against the force plate (Roe *et al*, 2016; Comyns *et al*, 2023). The Optojump photoelectric cells consist of two bars that are parallel to each other at floor level, which enables for athlete-surface interaction to be easily achievable because they can be placed on most surfaces (except sand) (Attia *et al*, 2017). Using this

device not only allows for jump height to be calculated, but force-velocity relationships can be developed using various other simple input variables to analyse players' mechanical capabilities (Jiménez-Reyes *et al*, 2019). These relationships are best described as the changes in power output and external force with movement velocity increasing. This can be summarised through three key variables; theoretical maximal velocity; theoretical maximal force; and maximal power output (Samozino *et al*, 2012; Jiménez-Reyes *et al*, 2017).

### *1.1.2 Factors affecting jump mechanics, force and velocity*

Although the primary focus of the present study is to assess the associations between jump mechanical performance and body composition, it must be noted that there are various other neural and morphological factors that can alter a player's ability to perform at their optimal level. It has previously been reported that knee torque during the countermovement jump contributes to jump height and power, which is rational, given the significance of knee strength for jumping performance (McErlain-Naylor *et al*, 2014). Other studies have also indicated that joint contributions and an individual's self-selected depth can aid countermovement jump and squat jump performance (Gheller *et al*, 2014). Greater ankle dorsi-flexion range of motion has been linked to greater countermovement jump performance in males and improving the knee joint range of motion from approximately 70° to approximately 90° increased countermovement jump height by 17% as well as an improving squat jump performance because of the increased time to generate joint torque (Georgios *et al*, 2006; Moran and Wallace, 2007; Bobbert *et al*, 2008).

Another way jump height can be affected is reactive strength index-modified. This is where jump height is divided by flight time and is a strong marker for a player's ability to jump within a short period of time (Vieira and Tufano, 2021). Improving technique and the

concentric phase impulse, increases the height of the jump as well as centre of gravity ascent velocity, thus reducing the amount of time spent concentrically (Nishiumi *et al*, 2023). Moreover, other factors such as myosin heavy chain isoforms, slow or fast twitch muscle fibres and post activation potential have the ability to alter jumping performance and overall performance in rugby (Gouvea *et al*, 2013; Lane, 2014; Waqqash *et al* 2017). All of these factors highlight that body composition is one of a multitude of factors that contributes to a player performing optimally within rugby and these other factors should also be acknowledged within literature to help gain a better understanding of what factors should be monitored regularly to ensure players are performing to the best of their ability.

### *1.1.3 The importance of jump mechanics, force and velocity in performance*

Strength and conditioning coaches have previously incorporated jump training and plyometric training into players' exercise programmes as it helps to develop the lower limbs through the stretch-shortening cycle (Taube *et al*, 2012). Previous research has indicated that the level of power a player possesses has been shown to differentiate amongst levels of athletic ability (e.g., elite vs sub-elite), thus improving a player's ability to generate power may allow for the improvement of sporting performance and increase their chances of performing at an elite level (Baker, 2002). Baker (2001) and Argus (2009) have also reported during competition phases, male rugby players can decrease by 1% to 3% in lower body mean power and lower body peak power due to the high frequency of training and competitive matches. Consequently, training methods that help to improve a well-trained male rugby union player's jump performance, force and velocity during the competitive season need to be identified so optimal performance can hopefully be achieved and maintained throughout a season.

The male university rugby union athletic population can be defined by the framework outlined by McKay *et al* (2021). These male rugby union players that compete on behalf of universities are categorised as playing at a national level (Tier 3 - Highly Trained/sub-elite), complete structured and periodised training and are working towards within 20% of the maximal norms within rugby union. There appears to currently be a focus on players that are at an elite or junior level with little insight into players playing at a university level. This leaves a gap of knowledge into the exploration of what are the desired body composition traits for male rugby union players at a university level and the correlation it has with their performance. Furthermore, it poses the question of what could be causing these differences in jump height, which validates the reasoning for force and velocity testing on players as their body composition may have negative implications on how much force or velocity they can produce, thus potentially impeding their progression from university level to professional rugby union.

Deficits in either force or velocity show the mechanical limits of the entire lower limb mechanical capabilities and neuromuscular system (Yamauchi and Ishii, 2007; Samozino *et al*, 2012). The collected data from the present study can help tailor training programmes to improve body composition and assist players in improving jump height as well as force and velocity deficits. These deficits may cause imbalances in maximal force production and maximal power output (Simpson *et* al, 2021), which can have negative consequences on performances as well as hinder progression into professional rugby union. Therefore, analysing players thoroughly gives them the potential to improve their performance as players imbalances (force-velocity) will be reduced, so they can generate more power and they are less likely to develop injuries (Marshall et al, 2015; Dos'Santos et al, 2017).

Traditional speed and strength measures (maximal power, isoinertial strength and 10m to 40m sprint times) allow for a few diagnostic pieces of information to be obtained but they do not allow for the full extent of a player's force and velocity to be analysed alongside body composition. The theoretical maximal force and theoretical maximal velocity capabilities of the neuromuscular system are best explained by the parabolic power-velocity and inverted force-velocity relationships when multi joint exercises are performed (Samozino *et al*, 2014). Success in multi-joint movements, such as the squat jump and countermovement jump have been closely related to power output, which is the product of external force developed by velocity. The maximum power, force and velocity of players have been demonstrated to have individual effects on performance during a squat jump and countermovement jump (Samozino *et al*, 2012; Jiménez-Reyes *et al*, 2017). No previous studies have investigated the associations between body composition, jump height, theoretical maximal force and theoretical maximal velocity production during the countermovement jump and squat jump in male university rugby union players.

Alongside force and velocity, assessing jump height is a key performance measure within rugby union. Ballistic movements, particularly jumping, have been defined as an individual's capability to accelerate their body mass, within the shortest amount of time possible and to the best of their ability (Samozino *et al*, 2012). When looking at the countermovement jump and squat jump from a mechanical point of view, assessing jump height and push-off performance is crucial as it is directly associated with the mechanical impulse generated onto the ground and power produced (Winter, 2005; McBride *et al*, 2010). Studies have also revealed that there have been strong correlations between male and female rugby players'

jump height, strength, sprinting ability and power, suggesting that they may be inter-related (Barr and Nolte, 2011; Cunningham *et al*, 2016). This signifies the importance of analysing jump height as a performance measure, alongside theoretical maximal force, theoretical maximal velocity and body composition, to determine what variables can affect jumping performance as it may be detrimental to other aspects of rugby performance.

### *1.1.4 Study aims and research questions*

In summary, the study aims to address the associations between body composition, jump height, force and velocity in male sub-elite rugby union players. There has been a lack of research looking at the body composition, force and velocity of this specific population and how it can alter a player's jump performance. Carrying out new research allows for the current gaps in knowledge to be addressed and helps contribute to a far greater understanding of some of the physical variables' rugby players might need, especially at a university level. This data can add various practical implications as well as contribute to the overall progression of sports science and player development. Furthermore, it can also contribute towards improving junior players' performances as they have comparable body composition data and jump data to see what variables have the greatest impact on their performance.

While there are many factors that influence jump performance and athletic performance, body composition, especially at a regional level, remains a fundamental consideration. It directly affects a player's biomechanics, sports-specific demands and injury risk, thus understanding and managing body composition is a crucial component to aid in the maximisation of athletic performance. This is one of the first studies to have investigated the association between body composition and jump performance in male sub-elite rugby union

players. If body composition and jump mechanical performance are left unmonitored, then it may be detrimental to a player progressing and it could have negative implications on a player's performance. Therefore, this study aims to address these gaps by answering the following research questions:

1. Are there associations between body composition components (body mass, lean mass, lower limb lean mass, body fat % and body fat mass) and countermovement jump height in sub-elite rugby union players?

2. Are there associations between body composition components (body mass, lean mass, lower limb lean mass, body fat % and body fat mass) and squat jump height in sub-elite rugby union players?

3. Are there associations between body composition components (body mass, lean mass, lower limb lean mass, body fat % and body fat mass) and theoretical maximal force production in sub-elite rugby union players?

4. Are there associations between body composition components (body mass, lean mass, lower limb lean mass, body fat % and body fat mass) and theoretical maximal velocity production in sub-elite rugby union players?

5. Are there associations between theoretical maximal force and/or theoretical maximal velocity and jump height during different squat jump loading conditions in sub-elite rugby union players?

## 2.0 Literature Review

### *2.1 Rugby Union*

Rugby Union is a game that is played over the duration of two 40-minute halves with both teams aiming to score the most points. At an elite level, the ball is generally in play for an average of 30 minutes with the rest of that time mainly consisting of the ball being out of play, injury time, conversions or penalty shots (McLean, 1992; International Rugby Board, 2010). It is a contact sport, that consists of interspersed periods including jogging, walking, running, static and sprinting exertions. Every player has a specific position and role that has been outlined by the International Rugby Board (World Rugby, 2022): (1) loose head prop; (2) hooker; (3) tight head prop; (4) left lock; (5) right lock; (6) left flanker; (7) right flanker; (8) number eight; (9) scrum half; (10) fly half; (11) left wing; (12) inside centre; (13) outside centre; (14) right wing; and (15) full back. All these positions are generally categorised corresponding to the demands which are placed on the players' positions, with numbers 1-8 being forward players and numbers 9-15 being back players.

The front row positions require large amounts of power and strength (Zabaloy *et al*¸2021), as players need to try to obtain possession of the ball during a match and they are constantly in close contact with the opposing team during scrums (Lindsay *et al*, 2015). Hookers are normally positioned between the two props and the physical characteristics of hookers are that they generally have longer arms and short backs to help them in connecting to the props during a scrum (Biscombe and Drewett, 2009). Furthermore, a prop's role in the scrum is to prop up the hooker. The loosehead prop is normally positioned to the left side of the hooker and the tight head prop is normally positioned on the right side of the hooker (Brown *et al*, 2011). Their main role is to give stability during the scrum (Biscombe and Drewett, 2009).

Locks tend to be tall, with more power and a larger body mass, which can be used as an added advantage for their positional needs. They are known for making short bursts carrying the ball into contact with the opposition ("crash balls") (Biscombe and Drewett, 2009). It is key for the loose forwards to be mobile and powerful during open play, have exceptional speed, stamina and acceleration (Nicholas, 1997). The number eight connects at the rear of the scrum and they work together with the scrum-half to help offer a clean ball to give to the backs (Bompa and Claro, 2015). The role of the flanker is to challenge the opposition and try to steal the ball so possession can be regained. Openside flankers connect onto the side of the scrum that covers the biggest vicinity on the pitch (Brown *et al,* 2011). They lightly connect to the side of the scrum so they can keep the props tightly packed into the scrum. Flankers need to be one of the first players going forward when a breakdown happens and are supposed to win possession of the ball (Bompa and Claro, 2015).

The inside backs (scrum-half, fly-half and inside centre) need a good level of endurance because they are in control of possession once the forwards have obtained possession of the ball from the opposition (Lindsay *et al*, 2015). Furthermore, having excellent speed is another skill that half backs should possess, as they need to break away from defenders that are advancing (Duthie *et al,* 2003). Fly-halves play a vital role within a team, as they keep the back line in the correct positions, so areas on the pitch are not overly exposed. They are one of the first players to get the ball from the scrum-half once there has been a scrum (Biscombe and Drewett, 2009). The scrum-half is the position that connects the forwards and backs together as well as receive the ball from the line-out and take the ball from behind the scrum. During defensive phases they play in deeper areas of the pitch to cover for long kicks.

### *2.1.1 Participation and performance structure*

Rugby union became a professional sport in 1995 and has since developed into a more physically challenging and faster sport (Eaves and Hughes, 2003). Rugby union is a sport that is played globally across all five continents and is played by both females and males (International Rugby Board, 2010). One of the main federations is World Rugby, which is an international governing body that consists of over 10 million players and 500 million fans, within 128 national member federations, that are affiliated through six differing regional associations (World Rugby, 2022). The highest level of rugby union in England is played in the Gallagher Premiership which consists of the best 11 professional clubs. There are currently two national leagues (RFU Championship and National League 1) that are below the premiership, where teams try to aim for promotion to the premiership, and the teams that are consistently poor are relegated to the league beneath them.

The British Universities & Colleges Sport (BUCS) is a national governing body that caters to all different levels of university competition with males and females competing regularly in different leagues across the United Kingdom. BUCS Super Rugby league is home to the top 10 best sub-elite university male rugby teams that compete to win the league and the Championship Knockout at the end of the season (BUCS, 2022). Figure 1 (adapted from Morgan, 2002) illustrates the direct approach, where the formation of competitions can be seen as a pathway for players to be identified, established and chosen to participate at the highest level of competition (international). This is usually in an exchange for money, which is created by commercialising the highest level of sport and is then filtered back into the expansion of Rugby Union. Televising and broadcasting elite level rugby union allows for a wider expansion of the market, which can then be exploited to aid in the growth of spectatorship and participation.

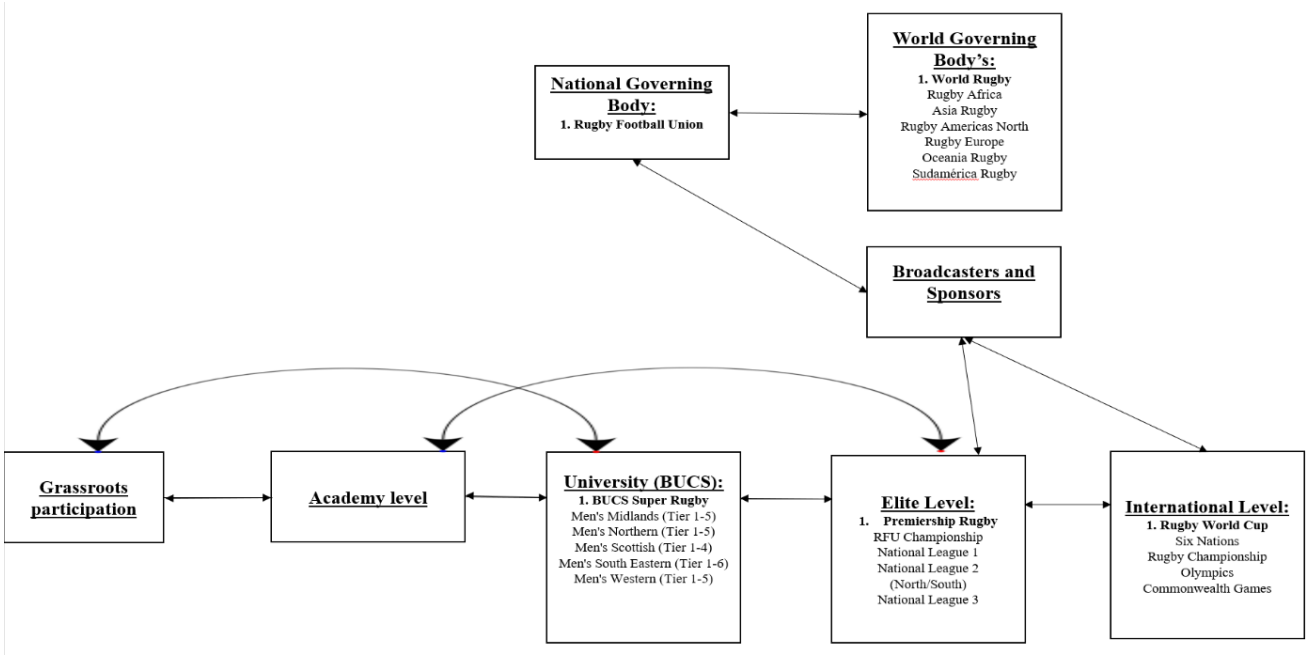



**Figure 1. Structure of Rugby Union pathway within the UK, adapted from Morgan (2002).**

Developing and analysing a rugby player's performance so they can reach their maximum potential, will aid them immensely as they begin to progress into professional rugby. Recent data from BUCS (2022) highlights that 11 recent graduates have signed professional contracts to clubs in the Premiership and a further 21 have signed professional contracts to clubs in the Championship. This emphasizes the importance of rugby at a university level and sub-elite level. The greater playing performance of elite level rugby union players can often be attributed to the superior physiological capabilities exhibited by these players (Gabbett, 2008). Geeson-Brown *et al* (2020) reported that male senior elite forwards and backs had significantly lower body fat percentages and significantly greater amounts of fat free mass when compared to senior sub-elite players. However, successful performances in rugby

union can not only be attributed to well-developed capabilities such as body composition, but players also need to display elevated levels of skill under fatigue and pressure (Till *et al*, 2020). Therefore, players that are on the brink of crossing over into professional rugby from a sub-elite level can potentially be highly valuable if they have similar body compositions and exhibit other key performance traits that are similar to elite level players. By having a similar body composition, this will hopefully contribute to them playing optimally alongside other factors such as, muscle morphology and fibre type, so they can get more recognition in the BUCS Super Rugby League and potentially draw the attention of elite level clubs.

## 2.2 Applied Physiology and Game Analysis of Rugby Union

### *2.2.1 Quantifying Movement – Aerobic*

Roberts *et al* (2008) investigated the movement patterns of 29 male English Premiership rugby players. It was reported inside (6055m ± 455m) and outside backs (6190m ± 929m) covered a greater mean distance compared to tight forwards (5408m ± 702m) and loose forwards (5812m ± 666m) but the majority of this difference was a result of the inside (2161m ± 155m) and outside backs (2517m ± 277m) walking a considerably further mean distance. The outside backs (207m ± 185m) covered approximately twice the mean sprinting distance as the tight forwards (144m ± 189m) and over double the amount of sprinting distance as the inside backs (124m ± 78m). For total distance covered, the inside and outside backs (6127m ± 724m) covered more mean total distance than the tight and loose forwards (5581m ± 692m), which is in conjunction with the previous findings of Deutsch *et al* (1998). As a result of the distances covered during rugby matches, the heart muscle may be stronger with an improved aerobic capacity, which allows for more blood to be pumped around the body and this is known as increased stroke volume. Introducing long term aerobic exercises to a rugby player's routine, alongside covering larger distances in rugby matches, has the potential to grow the internal dimension of the left ventricle as well as make the posterior

wall of the ventricle thicker and cause an alteration in the eccentric left ventricle hypertrophy (Lee and Oh, 2016). This may allow for a greater cardiac output, which will enable players to perform optimally for longer durations, resulting in a better overall performance due to a greater maximal aerobic capacity and less fatigue being experienced.

Research focussing on aerobic performance in elite male rugby players utilising multi-stage shuttle runs has been used to determine maximal aerobic capacity. Quarrie *et al* (1996) used the multi-stage shuttle test to assess 94 senior male rugby players to predict maximal aerobic capacity. It was reported that maximal aerobic capacity was generally greater in the backs than forwards, with the highest score for the forwards being the hookers (58.7 ± 15.2 mL/kg/min) and the highest score for the backs being the inside backs (62.5 ± 16.9 mL/kg/min). These findings may be as a result of the positional differences that are required between the two groups and highlights the backs greater levels of fitness when compared to forwards. However, it must be considered that the methodology of this form of testing only allows for a prediction for maximal aerobic capacity, rather than a direct measurement that can be provided by an incremental treadmill test. This can result in the findings not being as strong due to the validity and reliability of the study being weaker (Duthie *et al,* 2003). The deceleration and acceleration of the shuttle run test may make the applicability of the test greater for rugby, as it replicates the typical movements that are required during a match, which is something that lacks in the incremental treadmill test due to the constant speed running. The high levels of maximal aerobic power production displayed in the research is a characteristic that can aid players during mauls, rucks, scrums and explosive runs, as it should allow players to play at greater intensities for longer. Future research should employ different tests that involve repeated high-intensity bouts, reflecting the demands of the game,

as a lot of the current literature is outdated (Maud, 1983; Jardine *et al*, 1988; Holmyard and Hazeldine, 1993; Nicholas and Baker, 1995).

Another study by Austin *et al* (2011) assessed the physical demands of 20 male players that played for Queensland Rugby Union team using time motion analysis over the course of 7 Super 14 games. The analysis revealed that the back row forwards covered 5362m ± 131m, front row forwards covered 4662m ± 659m, outside backs covered 4774m ± 1017m and inside backs covered 6095m ± 213m during each of the 7 games. This signifies that the outside backs ($p < 0.05$) and front row forwards ($p < 0.05$) managed to cover significantly less distance in comparison to the inside backs. Sprinting and striding made up 32% of the back row forwards, 31% of the front row forwards, 38% of the inside backs and 33% of the outside backs' total mean distance covered, with the only noticeable difference between the inside backs and front row forwards. The back row and front row forwards had significantly higher average total time spent in mauls and rucks (606s ± 194s and 554s ±153s), when measured up against the outside and inside backs (120s ± 52s and 165s ± 10s).

The evidence reviewed suggests that it is advantageous for male players to obtain a high aerobic capacity. There are intense passages of play during a game where continual high-intensity bouts occur, and the players' inability or ability to complete these activities is crucial in the result of their teams' game (Swaby *et al*, 2016). Maximal oxygen uptake has been suggested to be an important marker for aerobic fitness in rugby players (Duthie *et al*, 2003; Mellalieu *et al*, 2008). The significance of obtaining a greater maximal oxygen uptake for male rugby players is still uncertain due to the nature of the sport, warranting repeated high-intensity sprints and a high frequency of challenges, but the players also need to be able to cover large distances during a match, which would suggest that there is definitely a need

for a greater aerobic capacity (Gabbett *et al*, 2007). The latter contention is strengthened through the findings of Swaby *et al* (2016) who analysed 14 male professional ruby union players and reported significant correlations ($r = 0.746$, $p < 0.001$) between maximum aerobic speed and distance covered. If a player has a greater aerobic capacity this may also suggest that their cardiorespiratory network is working efficiently (heart, lung and skeletal muscle), which will in turn allow them to have an improved utilisation and extraction of oxygen (Benson and Connolly, 2011). This may also aid them with increased isocapnic buffering, which will help with the bodies buffering capacity towards lactate accumulation through exercise-induced metabolic acidosis, resulting in them being able to play for longer periods without experiencing significant fatigue as quickly (Wasserman *et* al, 2005; Whipp, 2007).

Posthumus *et al* (2020) reported that 39 elite male rugby union players had the largest corelations for body fat percentage and the 10 and 20m sprint ($r = 0.40$) using DXA. Moreover, when it came to aerobic fitness, Yo-Yo distance correlated strongly with body fat mass ($r= -0.66$) and body fat % ($r = -0.70$). Body mass and body composition can be viewed as an important feature for rugby union players because sprint momentum (mass x speed) is a key factor of playing standard, defensive situations and ball carrying (Baker and Newton, 2008). Furthermore, the aerobic demands of exercise can increase from 1% to 14% when body mass increases by 1kg (Saunders *et al*, 2004). Given that rugby union is played over the duration of 80 minutes, restricting excess mass would appear to be necessary. Research shows that elite male players have lower skin folds and greater amounts of lean mass, leading to increased on-field playing time and improved performance compared to sub-elite players (Till *et al*, 2010; Gabbett *et al*, 2011). Monitoring other factors such as nutrition, cardiovascular fitness and recovery, along with body composition can significantly aid a player's journey towards achieving peak performance.

Currently, a lot of research assessing body composition and the performance profiles of rugby union players have used skinfold assessments (sum of 8 derivative equations) to establish body composition (Argus *et al*, 2010; Smart *et al*, 2013; Martínez-Moreno *et al*, 2014). To aid in the advancement of research, modern techniques that assess body composition, such as DXA, should be employed to improve the reliability and validity of the collected data. This can then be used, in conjunction with other factors affecting aerobic and anaerobic capacity, to help players achieve peak performance. Furthermore, this will also improve the reliability and validity of the correlations made between the performance measures and body composition.

### *2.2.2 Quantifying Movement – Anaerobic*

The aforementioned research would indicate that over the last decade, the demands of match-play have increased. In a study by Austin *et* al (2011), all positions averaged 40 sprints a game whilst playing elite male rugby union, compared to the average of 18 sprints a game in elite male rugby union reported by Duthie *et al* (2006). Austin *et* al (2011) reported that front row forwards spent 21% of their time sprinting, tackling, striding and scrummaging compared to the 11.5% of high-intensity exercise reported by the earlier work of Roberts *et al* (2008) on male English Premiership rugby players. All positions are also currently having less rest, whilst working more, as a previous study by Eaton and George (2006) analysed male English Premiership rugby union players and it was reported that work to rest ratios for the front row forwards (1:4), back row forwards (1:3), inside backs (1:4) and outside backs (1:5) were less than the forwards (1:8) and backs (1:15). Therefore, rugby players need to ensure they are constantly making powerful movements quickly and short bursts often. The intermittent nature of rugby requires the anaerobic system to be utilised as it generates

adenosine triphosphate at a much quicker speed when compared to the aerobic system (Bompa and Claro, 2015). When the production of phosphorylated creatine phosphate slows down, the lactic acid system predominates the alactic system as it supplies more ATP. Two moles of ATP are produced for every molecule of glucose that is converted to lactate (Gunnerson and Sharma, 2011). However, when high intensity efforts are being repeated, this causes a need to meet the demands of muscle ion pumps and cross-bridge cycling, which results in lactic acid being formed as a by-product (Cairns, 2006).

Energy contributions whilst players are moving during intermittent team games, such as rugby, are mainly anaerobic in nature. Rugby requires players to be extremely powerful as they need to perform scrums, mauls, tackles and explosive accelerations (Sedeaud *et al*, 2012). There is also a need for a large anaerobic capacity, as players are frequently performing repeated powerful efforts. Regarding literature, there is a scarcity in relevant data on the anaerobic traits of rugby players. A large body of research has concentrated on treadmill sprinting and cycle ergometers for short durations (<10 – 40 seconds) to help quantify and predict a player's anaerobic capabilities (Maud and Shultz, 1984; Cheetham *et al*, 1988; Ueno *et al*, 1988). Therefore, more research is required involving testing procedures that can determine a player's anaerobic capacity by simulating game conditions (field testing), so the qualities required for rugby union are evaluated effectively and most of the current research is outdated or focusses solely on lab conditions.

It appears that forwards have the ability to generate greater levels of mean and absolute peak power across various ranges of time (7 – 40 seconds) when compared with back players (Maud and Shultz, 1984; Cheetham *et al*, 1988; Ueno *et al*, 1988). However, when the data is in relation to the male players' mass, results appear to be comparable or somewhat favour the

back players in comparison to the forwards (Duthie *et al*, 2003). Moreover, there may be a need for power function ratios to be implemented to assure between group relationships are transparent and robust. The anaerobic energy system is extremely important during rugby competition, so it is staggering that there is a lack of research on these characteristics, thus more research is required with larger sample sizes on male rugby players to continue to add the existing body of research.

Research conducted by Cousins *et al* (2022) observed 89 male Premiership and Championship level rugby union players match demands over the period of two seasons. The match demands for every game were obtained via the Catapult OptimEye S5 (10 Hz), GPSports SPI-Pro (5 Hz) and STATSports APEX (10 Hz). Recent studies have revealed these systems to all be valid and reliable for their sampling frequencies (Catapult OptimEye S5, Thornton *et al*, 2019; STATSports APEX, Beato *et al*, 2018). High-speed running was defined as the distance covered at greater than 70% of the players' maximum velocity during the 40m sprint test in pre-season. The back players averaged 1.22 $m \cdot min^{-1}$ greater high-speed running (1.91 ± 1.16) when compared to the forward players (0.79 ± 0.83), and the backs averaged 7.6 $m \cdot min^{-1}$ greater distance (74.3 ± 10.8) in comparison to the forward players (66.3 ± 8.3). Activities, such as sprinting and tackling an opposing player, would be anticipated to cause an increase in the metabolic strain put on the neuromuscular system. This is due to the utilisation of the anaerobic glycolysis reserves, as well as the slowing down into the contact and the contact itself (Mullen *et al*, 2015). Supporting this notion, research from Karnincic *et al* (2009) and Dellal *et al* (2010) reported that activities involving wrestling (blood lactate before fight, 2.61 $mmol \cdot L^{-1}$; blood lactate after fight, 12.55 $mmol \cdot L^{-1}$) and short runs with an increased number of decelerations and accelerations, increase blood lactate concentrations.

### *2.2.3 Collisions, Injury and Recovery*

Van Rooyen *et al* (2008) and the later work of Quarrie *et al* (2013) reported that elite male forward players engaged in direct contact more frequently when compared to the back players. Forward players were involved in 68% of all total impact contacts, with the lowest value of impact contacts by the forward players being 199 in a game. The back players highest total of impact contacts during a game was only 148, which is considerably less than the lowest value of impact contacts (199) recorded for the forward players. Furthermore, the average number of contacts made by the forwards in a match was 257, with 174 of those impacts occurring during open play. This shows that the forwards performed 1.4 times the overall number of impact contacts during games when compared to the back row. Quantification of contacts (scrums, ground contact, tackles, mauls and rucks) from the study can be seen in Table 1.

**Table 1. Average impact contacts by the male forwards and backs across the seven games during the 2006 Vodacom Cup Tournament (Van Rooyen *et al,* 2008).**

| | **Scrum Contacts** | **Ground Contacts** | **Aggressor Tackles** | **Recipient Tackles** | **Maul Contacts** | **Ruck contacts** |
|---|---|---|---|---|---|---|
| **Forwards** | 81 | 58 | 35 | 29 | 14 | 48 |
| **Backs** | - | 50 | 29 | 31 | 4.5 | 8 |

In agreement with Van Rooyen *et al* (2008) and Quarrie *et al* (2013), Paul *et al* (2022) postulates that elite rugby union and rugby sevens forward players are much more heavily involved in contact events (scrums, rucks, tackles and lineouts) in comparison to the backs during a match. Prior research on elite and sub-elite male rugby union players indicates that

the forces and physical demands put on rugby players by scrums differs with each position (Trewartha *et al*, 2015; Martin and Beckham, 2020). It was reported that during a match there are on average a total of 116.2 (62.7–169.7) rucks, 22 scrums (19.0–25.0) and 156.1 (121.2–191.0) tackles. Backs also encounter 7.6 (4.3–10.9) tackles per game and forwards encounter 12.8 (7.5–18.1) tackles. Back players experience a mean number of 6.7 (5.1-8.4) severe impacts (7-10g) each match and a mean number of 41.7 (26.4–57.0) very heavy impacts (5-7g). However, forwards experienced a greater mean number of 10.8 (4.4–17.1) severe impacts per match and a greater mean number of 52.5 (29.8–75.2) very heavy impacts. The research suggests that forwards may experience greater impacts per match due to the positional demands that are required of them. Having greater amounts of lean mass, accompanied by a moderate amount of body fat mass, may help them deal with the impact, as body fat can provide a protective buffer to help deal with the force at both elite and sub-elite levels (Brazier *et al*, 2020).

Studies have examined the muscle damage and recovery time that elite players experience from matches and it has been reported that the amount of muscle damage a player has, is dependent on how much contact they are involved in, with full recovery still required 84 hours post-match (Gill *et* al, 2006; Smart *et al*, 2008). Doeven *et al* (2018) conducted a systematic review that monitored post-match recovery of physical performance and biomechanical markers. Creatine kinase aids with the synthesis of ATP in muscles and raises after a match has been completed due to the muscle damage that has occurred (Powers *et al*, 2007). A total of 11 studies found that there were greater peak values of creatine kinase concentration, with the higher peak values of creatine kinase being found in rugby studies. This would suggest that the muscle damage may be attributed to greater force loads, distance travelled, and accelerations performed during elite ruby union matches (Smart *et al*, 2008;

Jones *et al*, 2014). Furthermore, cortisol is a crucial catabolic stress response hormone and is believed to be heightened once a match has been played (Powers *et al*, 2007). The findings of the systematic review show that players need at least 48 hours to recover properly, which suggests that cortisol responds to higher forces and loads when partaking in elite rugby union matches (West et al, 2014). This is supported by other studies that have reported high cortisol levels and prolonged durations of the hormone during intermittent and endurance exercise (Lac and Berthon, 2000; Bonato *et al*, 2017). Nevertheless, this interesting area still requires further exploration into match induced hormonal disruption, muscle damage and potential reductions in neuromuscular function (West *et al*, 2014). Post-match recovery is fundamental for managing players and their performance. If insufficient recovery is administered, this could potentially result in injury and poor performances. With BUCS rugby union games being played mid-week, generally on a Wednesday, it would be of interest to monitor university male rugby union players to see the potential effect of hormonal milieu and neuromuscular function on strength and conditioning sessions, performance in training and the potential increase of injury risk later in the week. By doing so, it would allow for effective tailored recovery protocols to be implemented and custom training programmes to complement the players' needs.

The physiology of an individual determines the forces that they can be subjected to, along with how much load the different parts of the body can withstand. Numerous injury risk considerations contribute to or are strongly associated with a player's physiology (Kalkhoven *et al*, 2020). Modifiable intrinsic physiological factors have been identified with players getting injured. Some examples of these injury risk factors are bone mineral content, optimal muscle length for force production, body composition and the structure of tendons (Myburgh *et al*, 1990; Brockett *et al*, 2004; Nielsen *et al*, 2014; Bohm *et al*, 2015; Timmins *et al*, 2016;

Kalkhoven *et al,* 2020). Some of the non-modifiable intrinsic physiological factors that are linked with injury are gender, stature, age, previous injuries and blood type among others (Taimela *et al,* 1990). When analysing injuries, it is important to consider the external factors that are known to impact a player's physiology whether acutely or chronically. Examples of external factors may include nutrition, medication, methods of training, sleep and flexibility (Fullagar *et* al, 2015; Opar *et al*, 2015; Behm *et al*, 2016; Tenforde *et al*, 2016).

The direct contact of the front row to high-level impact forces of the scrum demands greater levels of strength than other forwards (Duthie *et al,* 2003). Incidences of injuries that occur at an elite level of male rugby union have been shown to occur during rucks (6-17%), tackles (24-58%), collisions (8-9%), mauls (12-16%) and scrums (2-8%) (Fuller *et al*, 2007). Throughout the engagement phase of the scrum, forces that are produced are significant (4430N-7982N) and these forces occur in multiple directions, with around 40% of the total number of elite male rugby-related spinal cord injuries occurring from this passage of play (Milburn, 1990; Trewartha *et al*, 2015). However, the majority of athletic injuries happen as a result of an acute strain or stress related injury, over an extended period of time, subsequently causing overuse injury (Kalkhoven *et al,* 2020). Even though the relationship amongst strain and stress is proportional for any material that has consistent mechanical properties throughout (Hooke's Law), biological tissue, including muscle, has the ability to change the relationship between strain and stress (Young's modulus) by altering mechanical elements, such as stiffness (Shinohara *et* al, 2010; Serpell *et al*, 2012). The scale at which strain and stress is felt by a specific tissue, is determined by the contact between the mechanical properties of the tissue and the force applied to it. Furthermore, for tissue to encounter strain and stress, force must be used so material failure can be achieved. Physical attributes that impact injury risk through structural loading inside the body are neuromuscular control,

muscular strength, balance, movement mechanics, technique and agonist-antagonist muscle relationships (Hrysomallis, 2007; Hendricks and Lambert, 2010; Freckleton and Pizzari, 2013; Sclafani and Davis, 2016; Barden *et al*, 2021). Additional external factors that can cause injury by effecting the forces experienced are the surface, ground reaction force and physical contact (McIntosh, 2005; Ranson *et al*, 2018). Thus, specific positions (e.g., loose forwards and props) may need extra fat mass to have an enhanced potential to withstand force through collisions and scrummaging, although additional research is needed in this area (Morehen *et al*, 2015).

## 2.3 Assessment of Body composition – Review of techniques

Body composition can be defined by the total distribution of body mass between three differing compartments: extracellular water, lean body mass and adipose tissue (Withrow and MacEwen, 2007). However, it must be mentioned that there is not a single body composition assessment method currently in existence that is error free and allows for all tissues and organs to be measured (Caballero, 2023). Moreover, if body composition assessment methods take assumptions from characteristics and body composition proportions of specific populations, then this can also create a bias (Caballero, 2023).

There are various techniques that exist for explaining the integral components of the human body, in practice, the modern techniques that are currently employed fall into reference. Field and laboratory-based methods include both the anatomical or chemical approaches. It is also crucial to understand that these techniques can be distinguished as indirect (e.g., bioelectrical impedance analysis), where the assessment is based on specific assumptions that have been drew from the finite cadaver-based data (Toomey *et al*, 2015); doubly indirect, where one indirect measure is utilised to calculate another estimate of body composition from another

form of indirect measure (Kasper *et al*, 2021); or direct, for example, through cadaver dissection.

Both the anatomical and chemical methodologies may also utilise the multi-component models. Therefore, it is seen throughout literature that many authors refer to the 2-component models, 3-component models and 4-component models (Figure 2) (Ackland *et al*, 2012). The two-compartment model (2-C) partitions the body into fat-free mass and fat mass (Kuriyan, 2018). This method is the most widely used approach to help approximate an adult's body composition. Behnke *et al's* (1942) 2-C model states the quantities of fat-free mass as protein, mineral and water are constant and known. Therefore, when the anhydrous fat (0.9007 g/cm3), fat-free mass (1.1000 g/cm3) and water content (73.72%) are assumed but not met, body composition estimations will become inaccurate as a result of the validity of the assumptions being made, rather than the technical precision of the measurements (Kuriyan, 2018).

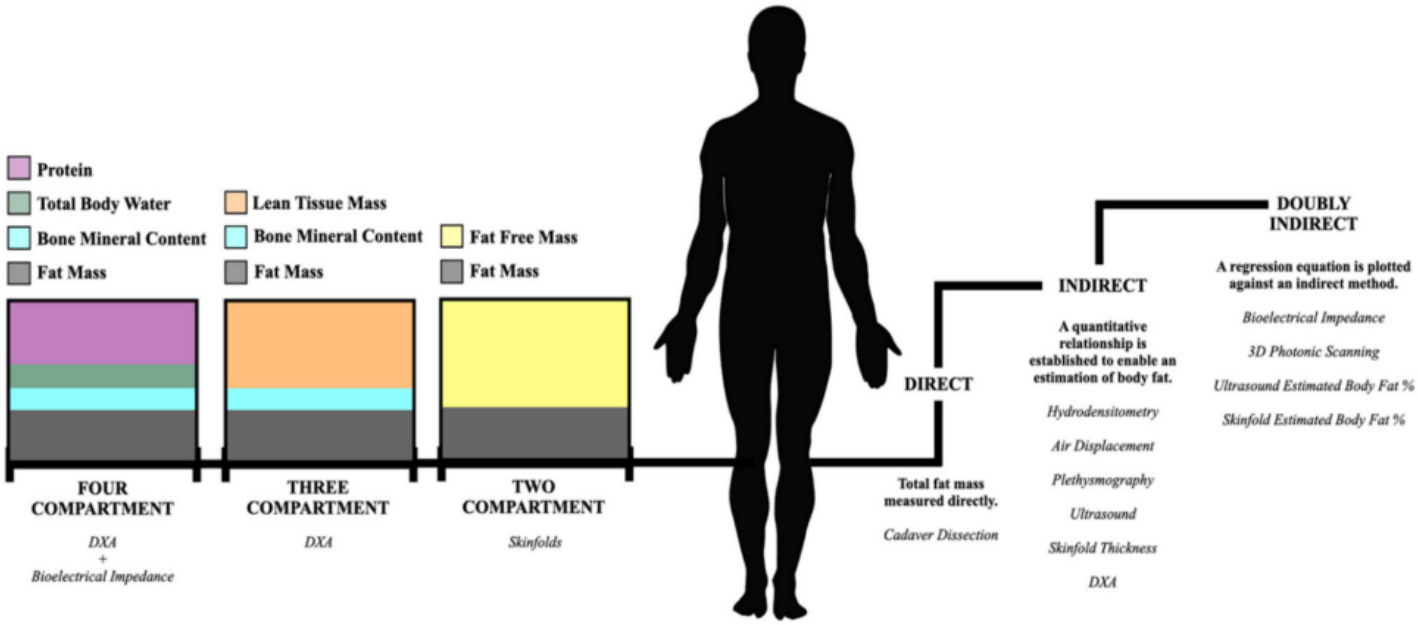



**Figure 2. The differing compartmental models of body composition (left side), accompanied with the validation hierarchy (right side) (Kasper *et al*, 2021).**

The three-compartment (3-C) model of body composition allows for the differentiation of a third component, additionally separating fat-free mass into bone mineral content and lean mass (Kuriyan, 2018). However, even though this method is generally more reliable and valid compared to the 2-C model, it is still under scrutiny from confounding inter-assessment differences in glycogen, muscle creatine levels and hydration being assumed (Aragon *et al*, 2017). This undoubtedly can have a significant effect in populations that are comprised of athletes with specific recovery periods and detailed exercise plans (Bone *et al*, 2016; Toomey *et al*, 2017).

The four-compartment model (4-C) of body composition is based around merging numerous methods together. It involves partitioning the individual's body mass into mineral, fat, protein and total body water, thus avoiding the need to assume the ratio between protein and mineral in fat-free mass is constant (Wells *et al*, 1999; Kuriyan, 2018). This makes the 4-C model theoretically more accurate than the 3-C model as it can control biological variability rather than assuming a continuous hydration of 73.72% and density of 1.1000 g/cm$^3$, making it more valid and accurate (Fields and Goran, 2000). Schubert *et al* (2019) concluded that all body composition assessment methods predicted greater values of body fat mass in 32 young male and female adults, when compared with the multifrequency-bioelectrical impedance analysis-derived total body water scan (4-C), as air displacement plethysmography (1.1%) and DXA (5.4%) produced the greatest values. Conversely, Ng *et al* (2018) reported that body fat % measurements from the 2-C and 3-C compartment models, compared well against the Lohman 4-C criterion model when assessing 31 healthy adults. This suggests that these body composition assessment methods may be reliable and precise when measuring the body fat mass of participants at a normal hydration status. While the 4-C model is desired, it is

unfeasible for most laboratories due to the cost, time and equipment needed to conduct several measurements of bone mineralisation and total body water.

### *2.3.1 Field methods*

One method for assessing body composition that is questionably one of the most measured anthropometric variables is skinfolds (Hume and Marfell-Jones, 2008). To reduce the amount of technical error that occurs between repeat skinfold measures, measurement techniques and measurement sites have been specified. An example of such definitions can be seen in the International Standards for Anthropometric Assessment (Marfell-Jones *et al*, 2012). The International Society for the Advancement of Kinanthropometry defines 8 different skinfold sites, and for each of them, it is stated that the measurement site at which the skinfold is picked up from is clearly specified as being on a recognisable anatomical landmark. Even though this method is convenient, non-invasive and relatively inexpensive, its reliability and validity has been questioned due to the amount of training anthropometrists need (Norgan, 2005; Ackland *et* al, 2012).

Aandstad *et al* (2014) analysed the body composition of active soldiers at 7 skinfold sites and it was reported that the male skinfold measurements were greater at 6 out of 7 retest sites signifying that it may not be the most desirable method for analysing body composition due to reliability. A recent study by Delaney *et al* (2016) tested the fat free mass of 22 male rugby league players using a prediction equation and skinfold thickness at 7 sites (doubly indirect). The results of the skinfold-based measures displayed significant validity ($r= 0.97$, $P < .001$) against DXA for the prediction of fat-free mass at any given time. However, bioelectrical impedance analysis (BIA) showed a slightly lesser relationship ($r= 0.93$, $P < .001$). These

contrasting findings in the present research show that more research is required to determine how effective skinfold thickness measurements are, as the previous findings have shown mixed reliability and validity when compared to other assessment methods such as DXA and BIA.

Ultimately, even with International Society for the Advancement of Kinanthropometry practitioners, it is not surprising to see greater inconsistencies in data outcomes, especially in larger athletes such as rugby players, which can inevitably cause problems if numerous testers are used to complete the same set of measurements across one population. Another potential issue with employing skinfold thickness in a clinical setting is that measurements of body fat mass are normally conveyed as a body fat %, which can add more complexity to the data by turning an indirect method into a doubly indirect method (Kasper *et al,* 2021). Using a doubly indirect method means a regression equation will be incorporated by calculating results alongside a criterion method to produce an estimation of body composition. However, the challenge with regression equations is that there are hundreds of variations of the formulae for the approximation of body fat % from skinfold measurements alone (Timothy, 1988; Chambers *et al,* 2014). These equations are also not validated when tracking changes in body composition over a period of time, they are established in differing populations and various protocols are used (Silva *et al,* 2009). Thus, the transformation of skinfold thickness into body fat % should be opposed, as the sum of 8 skinfold sites, instead of 7, has been seen to give reliable and accurate results for the assessment of body composition (Rodriguez *et al,* 2005; Reilly *et al,* 2009).

BIA is another frequently used technique to examine body composition based around the 2-C body composition model. BIA assesses the resistance to a small electrical current as it makes its way through the bodies water pool (Kyle *et al*, 2004). Total body water is estimated, and total body fat-free mass is then determined based on the assumption that 73.72% of the body's fat-free mass is water (Lee and Gallagher, 2008). There are numerous advantages to BIA some of which include its safety, low cost, ease of use and non-invasive nature, thus making it appealing for studies with larger sample sizes. The validity of BIA can also be influenced by different factors including race, ethnicity, sex, disease and body fat mass (Rush *et al*, 2006). Total body water and relative extracellular water are generally higher in obese individuals in comparison with individuals of a normal weight. It was reported that single frequency BIA had a stronger correlation with DXA at assessing body fat mass ($r^2$= 0.65) and fat-free mass ($r^2$= 0.76) estimates in obese and overweight males when compared to multifrequency BIA (Pateyjohns *et al*, 2006). The superior precision and reliability of BIA compared to skinfolds (sum of 8 derivative equations), a common measure of body composition, has also been established through interlaboratory comparisons (Sun *et* al, 2005; Macias *et al*, 2007).

Adopting BIA as a body composition assessment method does however present itself with numerous limitations involving sensitivity to electrode placement and sensitivity to the conductive surface on the electrodes (Mialich *et al*, 2014). Regardless of population, assumptions are also made on the composition of the body (hydration status of the individual) within the calculations and formulas (Ackland *et al*, 2012). Additionally, upper and lower limbs contribute greatly to whole-body impedance, even though they add little mass to overall body mass (Coppini *et al*, 2005; Davydov *et al*, 2021). Inside athletic populations,

especially rugby, there has been an insufficient amount of research that has analysed the validity of BIA when measuring fat-free mass and body fat mass, with contradictory findings in comparison to DXA. Some studies have reported an overestimation of fat-free mass and an underestimation of body fat mass (Svantesson *et al*, 2008; Nunes *et al*, 2020; Syed-Abdul *et al*, 2021), giving BIA devices greater variability between body composition assessment methods (Carrion *et al*, 2019). Nevertheless, employing BIA to assess changes in rugby players' body compositions may be beneficial for regular monitoring, as the equipment is relatively easy to access and has proven to be reliable, but where possible DXA should be used to allow for more accurate results.

### *2.3.2 Laboratory methods – 2-C model*

Ultrasound is a fast, relatively inexpensive, non-invasive and available tool that helps estimate adiposity within clinical practice and numerous research settings (Bazzocchi *et al*, 2016). Ultrasound tends to operate at a frequency around >20KHz, and for ultrasonic imaging frequencies exceed 2MHz. Within the transducer of the scan head, Piezo-electric crystals produce pulses of ultrasound, which help produce an image (Sprawls, 1987). The ultrasound beam is then transmitted through the skin and when the beam hits tissue (e.g., muscle or subcutaneous fat under skin) it is partly echoed back to the transducer (Wagner, 2013). Furthermore, the validity and reliability of ultrasound has shown strong correlations against DXA. Leahy *et al* (2012) conducted a study on 83 males and 52 females, aged 18-29 and a single ultrasound measurement of subcutaneous adipose tissue was seen to have a strong correlation with body fat % in both females (r=0.905) and males (r=0.907). However, it must be noted that ultrasound imaging does have limitations. It requires an experienced technician, costs more than field-based methods and still needs continued standardisation for anatomical placement (Wagner, 2013).

An advantage of ultrasound is that the device produces a greater inter-rater reliability than skinfolds in beginner practitioners (Wagner and Teramoto, 2020). This may be beneficial in a rugby context, as it highlights that it can be a useful tool in the repeatability of data when there is not a qualified International Society for the Advancement of Kinanthropometry practitioner available. Players can also be monitored over the course of a season with much greater ease and their body composition data can be compared to their performance measures, which will provide strength and conditioning coaches with a wealth of normative data. Although the use of portable ultrasound devices may show an exciting new pathway for body composition assessment, it still necessitates further research to analyse the reliability and accuracy of the device when assessing male rugby players.

Hydro-densitometry is an indirect method of underwater weighing that applies formulae and uses predetermined densities to formulate the two-compartmental method of body fat mass and fat-free mass (Brožek *et al*, 1963; Kasper *et al*, 2021). In the past, hydrostatic weighing was the 'criterion method' for measuring body density as it was used as a method to be validated against (McCrory *et al*, 1995; Lockner *et al*, 2000). The 'Archimedes principle' for assessing body volume is employed, this technique is cemented on the knowledge that when an individual or object is entirely underwater, the measurement of the water that is displaced is equal to the 'buoyant force' (Ryan and Elahi, 2007). When this method is undertaken by a qualified technician, it can be valid and reliable. Although, some of the limitations consist of residual lung volume, it is now uncommon in laboratories, it is expensive, the distribution of fat-free mass and body fat mass cannot be measured, it is extremely time consuming and it is potentially uncomfortable for the individual (Pizzorno and Murray, 2020; Kasper *et al*, 2021).

Even though this method has long been deemed the 'criterion method' for the analysis of body composition, there are currently more accurate and reliable alternative methods that can be used in sports science research and in an applied sport context (Milsom *et al,* 2015; Schubert *et al,* 2019).

Another indirect method for assessing body composition is air displacement plethysmography. This method allows for a replacement to hydrostatic weighing and is more practical in the field of applied sport as an alternative to hydrostatic weighing, as air is used to measure body density. It has been reported that air displacement plethysmography has helped overcome some of the problems hydro-densitometry faced, such as residual lung volume and the assumption of certain tissue densities, which can differentiate between athletic populations (Gibby *et al*, 2017). Devices such as the BOD POD, employ Poison's Law to help determine volumetric calculation and air displacement (Fields *et al*, 2004). Moreover, isothermal air is then calculated through intrinsic software and formulae, which are then combined to analyse an adjusted body composition and body volume through various equations (Fields *et al*, 2015; Lowry and Tomiyama, 2015). The reliability (CV = 3.09 ± 1.07%) and validity have also been seen to be high when assessing body density alongside hydro-densitometry and DXA (Wagner *et al*, 2000; Noreen and Lemon, 2006; von Hurst *et al*, 2016).

Although there are numerous benefits, air displacement plethysmography can be sensitive to external artefacts, air pressure and temperature changes (Fields *et al*, 2004; Peeters and Claessens, 2011), inadequately sensitive to athletic body composition changes during competition (Eston and Reilly, 2003), and costly to purchase for individuals in an applied

sport context. Furthermore, when assessing adipose tissue in comparison to DXA, air displacement plethysmography varies at the extremities of the BMI spectrum (Lowry and Tomiyama, 2015). This may be a deterrent for studies examining rugby players as they generally tend to have high BMIs, thus it may overestimate or underestimate the data, which would inevitably affect the reliability and validity of the study. Air displacement plethysmography is also absent of the ability to distinguish fat mass distribution (2-C model), making the 3-C model and DXA scans more attractive to practitioners.

### *2.3.3 Laboratory methods – 3-C model and 4-C model*

DXA is the current 'gold standard' for the assessment of body composition, both in athletic and infirm populations (Nana *et al*, 2015; Shepherd *et al*, 2017). Unlike the skinfold (sum of 8 derivative equations) and BIA techniques that operate on a 2-C model (Fosbøl and Zerahn, 2015), DXA follows a 3-C model by evaluating a participant's regional lean mass, lean mass and whole-body mass as well as bone mineral density, bone area and bone mineral content (Hind *et al*, 2018; 2022). Benefits to DXA are that it is rapid, non-invasive and the radiation administered to the participant is low. However, this method is not as easily accessible due to its lack of portability, and it is more expensive than field-based methods. When assessing the body composition of 591 healthy adults, the 3-C model has shown to be superior at providing more reliable and valid results, as multi frequency BIA overestimated body fat % in lean males (3.03%) and lean females (4.40%) as well as underestimated body fat % in obese males (4.32%) and obese females (2.71%) (Sun *et al*, 2005).

Nevertheless, DXA must be used with caution in participants with diminished bone mineral mass or body protein, as they will have skewed final estimates of body fat mass due to the

already estimated values of density (mineral-to-protein ratio of 0.35) (Withers *et al*, 1998; Ellis, 2000). When examining an athletic population and specifically team sports, Bilsborough *et al* (2014) concluded that DXA provided accurate and precise measurements of bone mineral content (%CV, 0.6; ICC, 1) and fat-free soft tissue mass (%CV, 0.3; ICC, 1). In contrast, other studies have shown that there is an underestimation of body fat mass with leaner populations against the 4-C model (Santos *et al*, 2010; Toombs *et al*, 2012). Despite being used in clinical settings for the diagnosis of osteoporosis and other bone-related diseases, DXA should be employed to assess athletic populations. Its ability to analyse body composition at a regional level, and its ease of application, can help better understand the relationship between body composition and athletic performance. This will allow for the greater understanding of evidence-based training, nutritional recommendations, and additional data that can be gathered for research purposes.

Magnetic resonance imaging and computed tomography have gained a large amount of attention in recent years. These methods are excellent for analysing a healthy adult population and computed tomography, specifically, can assess large statures. However, due to the high radiation dosage, it is not suitable to conduct whole-body assessments (Duren *et al,* 2008). Computed tomography can differentiate body tissue based on signal attenuation. This method can be particularly helpful for analysing the fatty infiltration of skeletal muscle and the non-adipose fat (Goodpaster *et al,* 2000). Having the ability to analyse the fatty infiltration of skeletal muscle is extremely advantageous for future research, as it allows for the muscle morphology of a player to be assessed to see if there is a relationship between the fatty infiltration and chosen performance measures.

Magnetic resonance imaging uses differing magnetic properties of the nuclei, of specific chemical elements (usually fat and hydrogen in water) within the cells, to create images of the soft tissue in the body (Borga *et al*, 2018). In comparison to computed tomography and DXA, magnetic resonance imaging does not implement the use of ionising radiation, which allows for actual volumetric 3D imaging in healthy participants and adolescents (Andreoli *et al*, 2016). The limitations to these body composition assessments are that it is not suitable for routine monitoring due to radiation (computed tomography), time (magnetic resonance imaging) and cost, which means that they are limited to medical diagnosis and research studies.

### *2.3.4 The practicality of DXA versus the 4-C model for the assessment of body composition in athletic populations*

In a clinical setting, computed tomography and magnetic resonance imaging have been suggested to be the 'gold standard' procedures when it comes to analysing body composition, especially muscle mass (Beaudart *et al*, 2016; Albano *et al*, 2020). Furthermore, from a practical standpoint, DXA evaluates body fat mass in relation to the total chemical compartment of triglycerides, whereas magnetic resonance imaging and computed tomography analyse fat tissue corresponding to the particular anatomical compartments, which comprises fibroblasts, fibres, capillaries and adipocytes (Guglielmi *et al*, 2016). This results in DXA underestimating body fat mass when compared to cross-sectional imaging such as, magnetic resonance imaging and computed tomography. However, when DXA measures lean mass, it has previously been shown to report higher measurements in contrast to magnetic resonance imaging and computed tomography, as it incorporates body proteins alongside carbohydrates, soft tissue minerals, body water and non-fat lipids (Chen *et al*,

2007; Heymsfield *et al*, 2015). Nevertheless, there are still many constraints that reference methods pose and currently there is still no accurate way of accurately assessing body composition without any errors (Caballero, 2023).

Both magnetic resonance imagining and computed tomography are extremely costly and require specialised post-processing techniques to analyse the scans, which are carried out by trained professionals (Codari *et al*, 2020). Some of the other limitations of these assessment methods include the potential for player motion, with reduced image quality, claustrophobia and the higher dosage of radiation administered by computed tomography when compared to DXA, which makes it hard to use for the regular monitoring of players' body compositions (Beaudart *et al*, 2016). More notably, there is currently a lack of data surrounding what low muscle mass should be defined as because specific cut-off values have not been fully implemented for magnetic resonance imaging and computed tomography (Cruz-Jentoft *et al*, 2019). However, DXA combats a lot of these limitations by utilising lower radiation dosages, is more accessible for athletic populations, more comfortable for those using it and can offer rapid assessments of body composition indices within minutes (Messina *et al*, 2020). Additionally, despite the previously discussed disparities between cross-sectional techniques and DXA, studies have reported strong correlations between body fat mass measured with magnetic resonance imaging, computed tomography and DXA (Guglielmi *et al*, 2016). Specifically, Chen *et al* (2007) compared DXA measurements of lean mass with magnetic resonance imagining measurements of skeletal muscle mass in postmenopausal females, resulting in large correlations seen for leg regional analysis ($r= 0.91$) and whole-body lean mass ($r= 0.94$). Another study by Midorikawa *et al* (2017) supported these strong relationships in adolescent males and females. Bredella *et al* (2010) also compared the

accuracy of DXA and computed tomography, which revealed comparable findings for correlations in body composition measurements (r= 0.77 – 0.95).

Due to all of these reasons, throughout research there is a widespread consensus suggesting that DXA should be considered the 'gold standard' in clinical practice and especially athletic populations for assessing body composition regularly (Chen *et al*, 2014; Cruz-Jentoft *et al*, 2016; Messina *et al*, 2016; Scafoglieri *et al*, 2018). Although, a lot of research is still needed comparing DXA to magnetic resonance imaging and computed tomography, as most of the research focuses on sarcopenic patients and females, thus the reliability and validity of assessing male rugby union players' body compositions is still largely underdetermined.

### *2.3.5 Body composition of elite and sub-elite rugby union players*

Successful performances within male rugby union demand players to possess a high level of strength, speed, and muscular power, as well as having a high anaerobic and aerobic capacity (Duthie *et al,* 2003; Roberts *et al,* 2008). It is important for players to have an optimal power-to-weight ratio through obtaining a greater amount of lean mass and avoiding unnecessary body fat mass (Duthie *et al,* 2003; O'Connor, 2014). This aids players in reaching their full potential for anaerobic and aerobic capacity (Darrall-Jones *et al,* 2015).

Research has indicated that forward players are heavier than back players on the pitch. This is evidenced in table 2 as male forwards ranged between a mean mass of 83.63kg - 112.40 kg and male backs ranged between a mean mass of 73.65kg - 93.30 kg (Delahunt, 2013; Jones *et al,* 2015; Zemski *et* al, 2015; Till *et al,* 2016; Lees *et al,* 2017; Malovic and Bacovic, 2020). Having a greater body mass has a strong correlation with being successful as a forward

competitively and their ability to generate a higher scrummaging force (r= 0.54; 95% CI= 0.27-0.73) (Quarrie and Wilson, 2000; Olds, 2001). Forward players are seen to possess greater mobility, which may be attributed to them having more lean body mass and low body fat mass (Olds, 2001; Duthie *et al*, 2003). Other than physical qualities, high level players must have exceptional technical abilities on and off the ball. For example, by having a wide base for support and lowering the centre of gravity will help improve stability (McKenzie *et al*, 1989). Howard *et al* (2016) states that mass influences stability, thus having a greater lean body mass may aid with this technique.

Tong *et al* (2001) indicated that international and elite male forwards and backs have similar statures. This contradicts earlier studies that indicated forwards are significantly taller than backs when they are playing at the same standard of rugby (Quarrie et al, 1995; Nicholas, 1997). However, the change may be a result of the physiological player development that professionalism has brought to the sport. In table 2 the evidence suggests that forwards ranged between a mean stature of 1.82m -1.91m and back players ranged between a mean stature of 1.78m - 1.83m. Although the lowest mean statures for male forwards and male backs were from the same study (Delahunt, 2013), where the mean age was 16.93, players may not have reached their full stature as a result of not being matured completely. At sub-elite and elite level rugby, there is an evident difference in stature when comparing the forwards and backs. Thus, the demands that are required of players based on their position necessitate specific characteristics to help them progress and stay at an elite level.

Anthropometric assessments of male rugby players have involved quantifying the body fat mass of players. Therefore, calculating the body fat % of players can become challenging because of the limitations that come with creating body fat percentages from estimations of

skinfold measurements (sum of 8 derivative equations) and body density (Martin *et al*, 1985; Harley *et al*, 2009). In table 2, the mean body fat % for male forwards ranged between 14.20% - 18.46% whereas the male backs ranged between 10.70% - 15.20%. Forwards appear to possess a higher body fat %, which may be due to the different demands between positions. While added body fat mass or a greater body fat % may be beneficial for contact situations, it becomes a drawback when running and sprinting are being performed as it increases total energy expenditure over longer durations (Duthie *et* al, 2003; Breivik, 2007). Backs may also possess lower body fat mass in comparison to the forwards due to the nature of their role requiring higher speeds (Carlson *et al*, 1994; Zemski *et al*, 2015). As players increase to higher levels of rugby, body fat mass is generally seen to decrease as they gain more experience. These differences observed could be due to professionalism, nutritional practices and greater training levels that are carried out by elite players (Ohtani *et* al, 2001; Kelly *et al*, 2020).

Greater amounts of lean mass can be seen as advantageous for players to improve their strength, speed and power (Hawes and Sovak, 1994; Pasin *et al*, 2017). During the 1999 Rugby World Cup the teams that had the greatest success were forwards that carried the greatest total mass (Olds, 2001). However, greater amounts of body fat mass have been shown to decrease acceleration and reduce power-to-weight ratio (Duthie *et al*, 2003). This suggests that if a player is to obtain a higher body mass it would be better carried as lean mass instead of body fat mass, so performance is not negatively affected. Table 2 shows that male forwards mean lean mass ranged between 65.09 kg - 96.50 kg and male backs mean lean mass was 60.51 kg - 82.80 kg.

**Table 2. Physical characteristics and body composition of elite level rugby union players grouped by playing position.**

| Study | Level of performance and age | Methods | Participants | Anthropometry and body composition; mean ± sd (95% CI) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | *Body mass (kg)* | *Stature (m)* | *Body fat%* | *Fat mass (kg)* | *Lean mass (kg)* |
| **Delahunt (2013)** | High level Irish school rugby union<br><br>Age (Years) – 16.93 ± 0.87) | DXA | Forwards (n=72) | 83.60 ± 10.50 | 1.82 ± 0.07 | 18.46 ± 5.91 | 15.21 ± 6.47 | 65.09 ± 6.77 |
| | | | Backs (n=64) | 73.70 ± 6.61 | 1.78 ± 0.06 | 14.34 ± 3.08 | 10.18 ± 2.55 | 60.51 ± 5.36 |
| **Jones *et al* (2015)** | European Super League<br><br>Forwards Age (Years) – 25.2 ± 2.9<br><br>Backs Age (Years) – 24.80 ± 4.30 | DXA | Forwards (n=38) | 99.80 ± 8.10 | 1.84 ± 0.03 | - | 16.80 ± 4.20 | 78.50 ± 6.40 |
| | | | Backs (n=29) | 90.20 ± 9.10 | 1.81 ± 0.06 | - | 12.70 ± 3.40 | 73.20 ± 7.90 |
| **Zemski *et al* (2015)** | Australian Wallabies National Squad<br><br>Age (Years) – 25.4 (24.40 - 26.40) | DXA | Forwards (n=20) | 111.70 (108.10 to 115.2) | 1.91 (1.88 to 1.94) | 14.2 (13.40 to 15.00) | 16.10 (14.90 to 17.30) | 92.20 (89.50 to 94.90) |
| | | | Backs (n=17) | 91.7 (89.10 to 94.30) | 1.83 (1.80 to 1.85) | 10.70 (10.00 to 11.40) | 9.90 (9.2 to 10.7) | 81.8 (81.0 to 82.60) |
| **Till *et al* (2016)** | European Super League<br><br>Forwards Age (Years) – 26.3 ± 4.9<br><br>Backs Age (Years) – 26.00 ± 4.30 | DXA | Forwards (n=36) | 100.40 ± 7.80 | 1.84 ± 0.06 | 17.20 ± 3.70 | - | - |
| | | | Backs (n=27) | 91.30 ± 8.60 | 1.82 ± 0.06 | 15.20 ± 3.40 | - | - |
| **Lees *et al* (2017)** | English Premiership Rugby Union<br><br>Forwards Age (Years) – 25.80 ± 4.70<br><br>Backs Age (Years) – 26.10 ± 4.50) | DXA | Forwards (n=20) | 111.70 ± 7.80 | 1.86 ± 0.07 | - | 21.52 ± 5.10 | 81.92 ± 6.15 |
| | | | Backs (n=15) | 93.30 ± 7.40 | 1.83 ± 0.04 | - | 14.05 ± 3.92 | 71.24 ± 6.24 |
| **Malovic and Bacovic (2020)** | Australian Wallabies National Squad<br><br>Age (Years) – 25.70 ± 3.10 | DXA | Forwards (n=23) | 112.40 ± 7.30 | 1.91 ± 0.07 | - | 17.40 ± 4.00 | 96.50 ± 6.30 |
| | | | Backs (n=16) | 92.20 ± 6.60 | 1.82 ± 0.05 | - | 10.80 ± 2.20 | 82.80 ± S5.90 |

## 2.4 Factors affecting force, velocity and performance

### *2.4.1 Neuromuscular*

The nervous system has the ability to manipulate the initiation of specific muscles and muscle groups through changes in firing frequency, muscular and motor coordination, motor unit recruitment and synchronisation. If one of these neural factors is not working effectively then it may lead to weaknesses being exposed in a player's performance.

Motor units are employed in an organised order during graded, controlled contractions of the muscle with force increasing in nature according to the size principle (Bickel *et al*, 2011). At first, small motoneurons stimulate the type one fibres before increasingly greater motoneurons activate type two fibres (a and x). This is because the fast-twitch motor units are generally activated at higher thresholds of force where as slow-twitch motor units require lower thresholds (De Luca and Contessa, 2012). However, it must be noted that ballistic movements demand lower motor unit thresholds compared to slower gradual contractions, as quick escalations of force are needed to get to high levels (Duchateau and Baudry, 2014). It has been estimated that the maximum force a motor unit is able to produce can fluctuate up to 50 times (Enoka, 1995; Heckman and Enoka, 2012). Consequently, during a movement, the motor units that are recruited will determine the amount of force that can be produced. During movements that demand maximal power, the necessity for type two fibres (high threshold motor units) is advantageous for producing high amounts of force, as they stimulate large amounts of high-rate force development muscle fibres (Maffiuletti *et al*, 2016). Thus, the capacity to quickly recruit high-threshold motor units can affect the amount of maximum muscular power produced. Studies have shown that male back players in rugby cover the greatest amount of sprinting distance compared to forward players (Roberts *et al*, 2008). This would suggest that recruiting and obtaining more type two muscle fibres (fast twitch) as a

back player would be highly advantageous, due to these fibres being correlated to producing high amounts of velocity and acceleration, inevitably contributing to optimal performance (Mero *et al*, 1992; Plotkin *et al*, 2021).

The firing frequency of the motor units is represented by the rate at which the neural impulses are sent from the motoneuron to the muscle fibres (Cormie *et al*, 2011). The rate at which the motor units fire can dramatically affect the capacity of the muscle fibre to produce force in two ways. Firstly, increasing the firing frequency will drastically improve the amount of force produced during the contraction part of the movement (Purves *et al*, 2001). Secondly, the firing frequency of the motor units affects the rate of force development of muscle contractions. When ballistic contractions (e.g., vertical jumping or running) occur, motor units start triggering at high rates, which is normally accompanied with a quick decline (Burke and Howells, 2017). Once the firing rate is at its highest, individual muscle fibres have achieved the state of tetanus - which is, the overall tension generated in the individual motor units that do not require troughs and peaks to parallel the individuals' twitches that are induced by the motor neurons action potentials (Purves *et al*, 2001; Celichowski and Krutki, 2019). Previous research has shown that tetanic force increases after 'conditioning' contractile exercises are undertaken and it has been implied that this post activation potentiation can be affected by the intensity of the activity and how much 'conditioning' activity is done prior (Sale, 2002; Wilson *et al*, 2013). Subsequently, this poses the question that post activation potentiation may increase the rate of force development, by increasing the firing frequency and rate of force development, causing a rapid rise in the amount of velocity attained. This would theoretically mean that a shift in the force-velocity relationship would occur by shifting it upward and to the right (less concave). If this occurred in relation to rugby union, movements such as jumping to receive the ball, punt kicks to shift the

momentum of the game and passing the ball may become enhanced because of post activation potentiation and the muscle firing frequency increasing (Sale, 2002; Tillin and Bishop, 2009; Blazevich and Babault, 2019).

Motor unit synchronisation happens when multiple motor units are initiated simultaneously and more regularly than anticipated for random independent processes (Farina and Negro, 2015). However, it is still uncertain whether synchronisation has a positive effect on the rate of force development and the augmentation of force production (Semmler and Enoka, 2000; Škarabot *et al*, 2022). Moreover, synchronisation has theoretically been suggested to be an adaptation of the nervous system that aids with the coactivation of various muscles and muscle groups to improve the rate of force development (Mellor and Hodges, 2005; Mohr *et al*, 2015). The way in which synchronisation impacts the rate of force development and force itself has still not been extensively explored. Voluntary contractions have also been shown to generate larger rates of force development compared to when all motor units are firing at tetanus (Cormie *et al*, 2011).

Synchronisation might be a possible strategy for inter-muscular coordination, which may influence the rate of force development and/or the force during intricate ballistic movements as opposed to simple single-jointed movements where synchronisation might not be as effective (Young, 2006). Inter-muscular coordination illustrates the applicable amount of activation needed for antagonist, agonist and synergist muscles during movements (Young, 2006). For movements to be highly precise and effective, it is imperative that there needs to be a decrease in the co-contraction of antagonists and an increase in synergist activity and agonist activity (Sale, 2003; Hedayatpour and Falla, 2015). The inter-muscular coordination

of the muscles is a requirement for the highest possible amount of force to be generated within a given direction (Sale, 2003). Extension in the plantar flexion of the ankles, hips, and knees, typical of movements such as jumping and running within rugby, involves intricate interactions between uni-articulate and multi-articulate musculotendinous units executing numerous activities (Cormie *et al*, 2011). Furthermore, it is only when the level of activation, accurate timing, and moderation of the antagonists, synergists, and agonists that power flow throughout the kinetic chain will be heightened, stimulus on the surface maximised, and consequently, velocity during take-off will be increased (Cormie *et al*, 2011). Thus, the inter-muscular coordination of the muscle can be a significant factor in a player's performance as it has the potential to inhibit maximum power output if it is not functioning efficiently.

### *2.4.2 Morphological*

A player's capability to produce maximal power whilst performing a movement is controlled by the contractile ability of the muscle or muscle groups involved. This is generally influenced by a number of morphological factors such as muscle architecture and the fibre type of the muscle.

As a result of the distinctive features of each specific fibre type, how much of each fibre-type within the muscle determines the amount of force and velocity that muscle can produce (Yamauchi and Ishii, 2007; Arnold *et al*, 2013). In previous research, type 2 muscle fibres have been shown to have the ability to produce more power per unit of cross-sectional area (10-fold greater) (Widrick *et al*, 2002; Malisoux *et al*, 2006). However, studies that have examined muscle fibres closer to *in vivo* muscle temperature show that the peak power, per unit of cross-sectional area, are not as different compared to the observations made at lower

temperatures (Cormie *et al*, 2011). A rare piece of research examined the contractile properties of muscle fibres at 37°C and it was discovered that the type 2 muscle fibres had 4-fold superior maximum power output and 3-fold maximum velocity production in comparison to type 1 muscle fibres (Faulkner *et al*, 1986). These differences that are observed in peak power per unit of cross-sectional area are a result of changes in the curve of the force-velocity relationship between fibre types, maximal force and maximal velocity (Bottinelli *et al*, 1996; Lieber, 2010; Wilson *et al*, 2012). Type 2 fibres generally display greater levels of myofibrillar ATP and sarcoplasmic reticulum as well as short contraction times between cross-bridge cycles, thus allowing for high velocities to be achieved (Scott *et al*, 2001; Schiaffino, 2010; Casas *et al*, 2014). Unlike type 2 fibres, type 1 fibres tend to have lower maximum velocities and ATP activity with slower contraction times (Cormie *et al*, 2011). This can be seen in previous research, as maximal velocity differs from around 5.6 to 3.5 fibre lengths in type 2x and type 2a fibres, whereas in type 1 fibres, it is around 0.8 fibre lengths (Widrick *et al*, 1996; Trappe *et al*, 2003; Malisoux *et al*, 2006). However, this research must be taken with caution as the temperatures taken during the research were not *in vivo* and were sub-physiological, thus research going forward should think about increasing temperature to ensure the data is more valid. Some research has indicated that sub-elite rugby union players who possess a larger amount of type 2 muscle fibres can generate greater maximal muscle power during sprinting and jumping (Bellinger *et al*, 2021). Although, this research cannot be applied to all levels of rugby union and more research is still required to determine the association between fibre type and rugby performance at differing levels.

The maximal force produced by muscle fibres is correlated to the cross-sectional area of the muscle, regardless of the fibre type (Jones *et al*, 2008). Power is also strongly associated with maximal force, which means muscle fibres with greater cross-sectional area can produce

greater maximal power (Widrick *et al*, 2002; Shoepe *et al*, 2003; Malisoux *et al*, 2006). Previous studies assessing single fibres are reinforced with evidence showing that whole-muscle cross sectional area was associated with maximal isometric force (Rospars and Meyer-Vernet, 2016). Maughan *et al* (1984) utilised computed tomography scans to analyse the cross-sectional area of muscles and it was reported that muscles with a larger cross-sectional area could generate greater maximal force. However, the cross-sectional area was not seen to be considerably different between the participants who had insignificant lifting experience and participants who were strength-trained, indicating that the difference observed in maximal force was due to the variation in cross-sectional area. When there is growth in the size and number of myofibrils within the muscle, this causes an expansion in fibre cross-sectional area (Burd *et al*, 2010; Damas *et al*, 2016). In response to strength training, hypertrophic changes primarily occur in type 2 muscle fibres but also have an effect on type 1 fibres (Staron *et al,* 1994; Martel *et al*, 2006; Dankel *et al*, 2019). It is well established that increasing maximal force or cross-sectional area of the muscle will allow for greater maximal muscle power production (MacIntosh and Holash, 2000; Malisoux *et al*, 2006; Cormie *et al*, 2011). Consequently, obtaining a large anatomical cross-sectional area within the muscles may permit players to withstand displacements and accelerations to the neck from different angles, greater hip extension torque, faster sprint times and greater vertical jumps (Waldron *et al*, 2014; Chavarro-Nieto *et al*, 2021; Kawama *et al*, 2022).

The maximal velocity of a muscle can also vary quite substantially between different fibre types and the length of the muscle fibre is correlated to maximal velocity (Arnold *et al*, 2013; Bohm *et al*, 2018; Sugi and Ohno, 2019). For instance, if the sarcomere shortens at five fibre lengths every second, a fibre having twenty sarcomeres firing at once would have a larger maximal velocity than a fibre only having ten sarcomeres (e.g., 100 vs 50 fibre lengths a

second). As a result of maximal velocity being highly correlated to power, obtaining longer muscle fibres may be advantageous in producing maximal power (Lieber and Ward, 2011; Arnold *et al*, 2013). Numerous studies have reported strong correlations between the fascicle lengths of the gastrocnemius lateralis, vastus lateralis and sprint times in male and female sprinters (r= -0.43 to -0.57) (Kumagai *et al*, 2000; Abe *et al*, 2001). Although, it is not certain if the findings of these studies are due to the sprinters having adapted fascicle lengths from strength training or if they are genetically predisposed to have shorter/longer fascicle lengths. Nevertheless, despite the architectural differences, the data highlights the significance of possessing a longer fascicle length to aid in the production of maximal power and force whilst performing ballistic movements that are common within male rugby union.

The pennation of a muscle is the angle between the line of action and the muscles fascicles, which highlights its physiological significance as it can affect maximal power production and the force-velocity relationship (Secomb *et al*, 2015; Trevino *et al*, 2023). More sarcomeres can be placed in parallel when pennation angle rises, which allows for more contractile tissue to attach to a particular area of a tendon or aponeurosis, thus allowing the muscle to generate force (Rekabizaheh *et al*, 2016). Furthermore, because pennate muscle fibres rotate during contraction, a larger pennation angle permits muscle fibres to shorten less for a specific tendon displacement (Cormie *et al*, 2011). Based on the length-tension relationship, this suggests that the fibre will be able to produce more force as it is working closer to its optimum length (Stokes, 2004). These components all contribute to increasing maximal force, signifying how pennation angle impacts the amount of maximal power produced by a given muscle. Although, research has shown that the maximal velocity of a muscle may be negatively impacted by increasing the pennation angle because a larger pennation angle has been associated to slower contraction velocities (Spector *et al*, 1980; Degens *et al*, 2009).

Nevertheless, it has been theorised that the increase in maximal force has a considerably larger impact on maximal power production compared to the increases in maximal velocity as a result of the pennation angle increasing (MacIntosh and Holash, 2000). This means that an increase in pennation angle will allow for a greater force generating capacity, which in turn should improve jumping, running, tackling and overall rugby performance (Scott *et al*, 2022).

### *2.4.3 Body Compensation*

A player's physical performance is a result of the complex combination of numerous factors, some of which include anthropometrics, genetic elements, nutritional intake and physiological hormonal status (Tucker and Collins, 2012). However, the literature is outdated, limited and reports differ in analysis of body composition and anthropometrics in relation to testing physical performance (Reid and Williams, 1974; Bell, 1979; Maud, 1983). The intermittent nature of rugby union means it can be challenging to identify an optimal body composition that encompasses everyone because of the variations that exist within teams, players and playing positions (Gabbett, 2005).

Analysing the body composition of elite male rugby players is usually performed within their regular monitoring procedures, so they can improve competitive performance and examine the success of training regimes (Zemski *et al*, 2019). Pasin *et al* (2017) assessed elite male rugby players and how anthropometric measures may impact their physical performance. The results concluded that a positive association was seen between the players' body weight squat jump ($r= 0.81$, $p= <0.001$), 70kg squat jump ($r= 0.83$, $p= <0.001$) and lean mass. Persistent exposure to resistance training is known to stimulate an increase in muscular strength because of specific morphological and neurological changes (Folland and Williams, 2007). This suggests that increasing lower body lean mass is required to achieve a well-developed

physique and this may enable better repeated high-intensity work rates in rugby players (Gabbett, 2002; De Lacey *et al*, 2014).

Posthumus *et al* (2020) analysed 39 elite male rugby players where their body composition was measured using DXA to investigate potential correlations with their fitness testing scores. It was reported that forwards demonstrated a strong correlation with their lean mass, bodyweight countermovement jump relative power (r= -0.74) and countermovement jump 40kg relative power (r= -0.68). The lean mass of the backs showed a strong correlation in the countermovement jump 40 kg relative power (r= -0.82), a moderate correlation was also seen for both the one repetition maximum squat (r= 0.60) and the bodyweight countermovement jump relative power (r= -0.65). This data suggests that lean mass is associated with a variety of performance measures, and players having lean tissue rather than fat mass is considered more functional (Brazier *et al*, 2020). Players with greater amounts of lean mass may have the potential to increase power, aerobic capacity and acceleration in the vertical and horizontal plane, thus monitoring these factors and how they correlate with overall performance throughout a season is vital for players and coaches to obtain important data (Olds *et al*, 2001; Duthie *et al*, 2003).

Additional body fat mass may also reduce the amount of force produced and increase energy expenditure, resulting in a decline in speed, strength and power, whilst potentially increasing fatigue (Zemski *et al*, 2019). Smart *et al* (2014) reported that a player's ability to have a high work rate and their ability to frequently carry out tasks may be enhanced by lowering body fat %. Posthumus *et al* (2020) also reported that higher body fat percentages and body fat mass had a strong association with decreasing the male forward players' speed, aerobic fitness and power. Taken together, these findings indicate that forwards who are leaner may

possess more desirable fitness attributes. Although, excess body mass, no matter what body composition, can lead to reduced power and slower sprint times (Duthie, 2006). Thus, specific positions (e.g., locks and props) may need to obtain a desirable body composition that is comprised mainly of lean mass with low to moderate body fat mass. This may help players produce greater amounts of strength and power whilst being able to endure large amounts of impact force, however more research is required to fully elucidate the link (Quarrie and Wilson, 2000; Morehen *et al*, 2015).

Even though elite male rugby players generally have a high BMI (~30 $kg.m^{-2}$), they also tend to possess larger amounts of lean mass which may help in the resistance against fractures and the conservation of bone strength (Hind *et al*, 2015). It is still uncertain if this association between body composition, bone strength and force absorption is greater in players with a higher BMI. This suggests that further research using body composition assessment methods and performance measures needs to be carried out to discover if greater amounts of lean mass aid in absorbing impact, reducing injuries, the effect it has on bones and overall performance. While prior studies have suggested that an increase in strength is associated with an increase in power production, most of the current research uses participants with little training experience and low-to-moderate strength levels (Cormie *et al*, 2010). This suggests that developments in muscular function can be seen with ease and generally non-specific. Consequently, for well-trained rugby players wishing to increase maximal muscular power and enhance performance, it requires a multifaceted approach that includes various training approaches (e.g., ballistic exercises, resistance training and plyometrics) that focus on specific areas of the force-velocity relationship (Cormie *et al*, 2011; Suchomel *et al*, 2018). Further research is still required to fully understand what variables impact an individuals' force-velocity profile and performance.

## 2.5 Assessment of lower body force, velocity and jump height – Review of techniques

### *2.5.1 Optojump*

A player's ability to generate high velocities during a change of direction (inside spin) or release (jumping) is a contributing factor in predicting performance in various sports (Giroux *et al*, 2015). Ballistic movements can be defined as the maximal amount of movement that is intended to accelerate a moving mass as fast as possible, to achieve the greatest potential velocity in the shortest amount of time while pushing off (Samozino *et al*, 2012). Newton's second law of motion asserts that the velocity of an object's centre of mass during take-off is directly determined by the mechanical impulse imparted to it during the motion, thus a player's mechanical impulse at the start of the movement will directly affect the jump. (Knudson, 2009; McBride *et al*, 2010). The force-velocity relationship can be identified as the dependence of muscle force upon its velocity of shortening, for both muscle groups and *in vitro* muscles (Hill, 1938).

The first way force-velocity and jump height can be measured is using the Optojump photoelectric cells (1000 Hz). This consists of two bars (one transmitter and one receiver) that are positioned parallel to each other on the floor. They measure flight time and jump height once the centre of mass leaves the contact surface at take-off and returns at landing (Attia *et al*, 2017). A force-velocity profile can then be devised from a combination of the Optojump data, simple anthropometric data (body mass, stature and lower limb length) and a validated equation from Samozini *et al* (2008). An advantage to this piece of equipment is that, due to its portability and lack of wires, it allows for athlete-surface interaction to be recognised, as it can be placed on all differing types of sports surfaces except for sand (Glatthorn *et al*, 2011). It is also simple to use and relatively cost effective (£4000) when compared to force plates.

The validity and reliability are reported to be strong in numerous studies (Glatthorn *et al*, 2011; CV mean 2.7%, ICC mean 0.985; Healy *et al*, 2016; ICC < 0.975; Rago *et al*, 2018; CV 4.2%, ICC 0.87%). Glathorn *et al* (2011) also reported that the Optojump had a strong concurrent validity, but clear differences were observed in the level of systematic difference between the Optojump and force plate in 28 males and 12 females. More recently, Montalvo *et al* (2021) analysed the reliability and validity of the Optojump using trained recreational males and females performing the squat jump and countermovement jump. Results of the study showed the Optojump to have great reliability for the countermovement jump (CV 8.14%, ICC 0.98%), but the reliability of the squat jump was not seen to be as strong, as it breached the mean acceptable threshold (> 10% of CV; CV 10.4%, ICC 0.95%). The validity of the Optojump was also seen to be very high for both the countermovement jump (CV 7.95%, ICC 0.94%) and squat jump (CV 9.42%, ICC 0.89%). However, these studies did not analyse the effectiveness of the Optojump photoelectric cells in determining meaningful difference, and the population of participants used were not male rugby union players. Thus there is a need for further studies to assess alternate populations (male rugby union players) and assist practitioners in determining which field-based method is the best for determining vertical jump height, maximal force and maximal velocity.

### *2.5.2 Force plate*

Force and velocity can also be assessed and recorded using a force plate. The majority of previously published literature have used force plates to record vertical jumps and biomechanics, which is why it may be regarded as the ‘gold standard’ when it comes to measuring force (Cronin *et al*, 2004). Even though force plates can give researchers valuable

data in athletic populations, generally, laboratory-based force plates can range between £30,000 - £70,000 and portable force plates can range between £10,000 - £15,000, which is considerably more than field-based methods such as the Optojump (Lake *et al*, 2018). Once force is applied to the plate, the sensors detect a change causing significant voltage changes that are relative to how much force is applied (Lamkin-Kennard and Popovic, 2019). Force is then measured by relying on the use of load cells that may be comprised of strain gauges, beam load cells and piezoelectric elements (Beckham *et al*, 2014). This kind of assessment for measuring force normally necessitates a laboratory, which makes it limited in field use due to force platforms being sensitive to extraneous vibrations from the environment. Therefore, force plates must be fitted in alignment with the instructions of the manufacturer to keep the reliability of the signal (Cronin *et al*, 2004). The reliability and validity of the force plate has been continuously reported and is used as a reference procedure (Hatze, 1998; Rahmani *et* al, 2001; Rogan *et al*, 2015; Jiménez-Reyes *et al*, 2017).

Jiménez-Reyes *et al* (2017) reported that the force plate had a 0.999 ICC (95% CI) and 0.3% CV for mean vertical force as well as a 0.985 ICC (95% CI) and 0.7% CV for mean vertical velocity during the countermovement jump performed by 16 high-level male sprinters and jumpers. It was also reported that there was a strong correlation between the force plate method and computation method for analysing the slope of the linear force-velocity relationship ($r= 0.985$, $p= < 0.001$). Comyns *et al* (2023) reported excellent reliability between the force plate (CV 4%, ICC 0.98%) and Optojump (CV 4.4%, ICC 0.98%) for measuring the jump height of 28 participants (21 male, 7 female) who played team sports, with near perfect correlation coefficients and coefficients of determination between the Optojump and force plate ($r= 0.997$, $r^2= 0.994$). Furthermore, one of the few pieces of earlier

research that focussed on elite male youth rugby players, analysed the between-day reliability of the force plate whilst players performed one maximal effort countermovement jump, the highest score from two maximal efforts was taken and the highest score from three maximal efforts was taken (Roe *et al*, 2016). It was reported that there was strong coefficient of variations for taking the highest score from two maximal efforts of countermovement jumps (CV 4.9%) and taking the highest score from three maximal efforts of countermovement jumps (CV 4.6%), with standardised differences being negligeable between methods (<0.2). In order to determine if the Optojump is a suitable replacement for laboratory-based force plates, more research is needed focussing on male rugby union players as the current literature mainly focusses on portable force plates and general athletic populations.

### *2.5.3 Linear position transducers*

Linear position transducers are compact and portable tools that help measure the velocity and displacement of an object utilising optical encoding technology (Harris *et al*, 2010). Once a jump has begun, vertical displacement of the bar is distinguished to help calculate instantaneous velocity, and instantaneous force is established by calculating total acceleration and the product of system mass (Giroux *et al*, 2015; García-Ramos *et al*, 2016). Linear position transducers have become more common inside of strength and conditioning facilities because of coaches adopting more velocity and force-based training into their players' programmes (De Lacey *et al*, 2014; Mann *et al*, 2015). They analyse the distance the barbell travels and this purpose can allow for vertical jumps to be assessed before a training session to evaluate if a player is ready to perform. Dependent on the players test score prior to training and in relation to their norm, the strength and conditioning coaches can then utilise this feedback to decrease or increase training load (Claudino, *et* al, 2016). The displacement and time of an object allows the equipment to calculate velocity (velocity = displacement /

time) and acceleration can then be determined from velocity and time (acceleration = velocity / time), which means a force-velocity profile can be generated (Harris *et al*, 2010). Lastly, the reliability and validity of the linear position transducer has seen to be mixed, therefore more research needs to be done to determine how reliable and valid it is (Harris *et al*, 2010).

Cronin *et al* (2004) reported good reliability for force-related variables during the countermovement jump in 25 athletically trained males, as CV values ranged between 2.1% and 7.4%. However, Hori *et al* (2007) reported peak force varied greatly (CVs of 9.0% and 2.9%, respectively), as it was seen to be substantially greater than research conducted by Cronin *et al* (2004). Wadhi *et al* (2018) also reported statistically significant differences between the linear position transducer and force plate, when measuring the countermovement jump height (95% CI: 8.18 cm to 9.18 cm; $p < 0.001$) and squat jump height (95% CI: 7.52 cm - 8.50 cm; $p < 0.001$) of 28 participants with differing exercise experiences. However, interclass correlation coefficients between both days of testing were seen to be high for the squat jump (ICC = 0.84) and countermovement jump (ICC = 0.95) when using the linear position transducer. Another study by Hansen *et al* (2011) analysed 25 elite male rugby union players who performed loaded squat jumps over two days and the linear position transducer displayed a slightly lower ICC value (0.88) and slightly greater CV value (4.8%) when compared to the force plate (CV 2.3%, ICC 0.96%) for peak mean force. These conflicting findings between the linear position transducer and the force plate suggest that more research is required to verify how reliable and valid this piece of equipment is at measuring force, velocity and jump height when compared to other methods such as the Optojump.

In conclusion, the Optojump appears to be a beneficial and cost-effective device for assessing the force, velocity and jump height of players, particularly when conducting research in a field-based setting where a fixed force plate may not necessarily be available. However, it is clear more research is required to assess the long-term reliability of all these devices, as very few longitudinal studies have been carried out, which would provide a more comprehensive understanding. Furthermore, more comparative analysis is needed between the devices, and greater sport-specific application is required in male rugby union players to determine its effectiveness.

## 2.6 The force-velocity profile

Most resistance training programmes that are used by players place a strong emphasis on hypertrophy, power and strength. This is because a strong-powerful lower body and a durable shoulder girdle are essential to maximal force production and the absorption of impacts (McMaster *et al*, 2016). Power and velocity production during the subsequent actions are also key to excelling in rugby union: pulling, tackling, throwing and fending.

The force-velocity relationship signifies a characteristic property of muscle that denotes the maximal amount of power that any given muscle can produce. The characteristic hyperbola can help explain the inverted relationship that occurs between velocity and force whilst a muscle is contracting concentrically (Hill, 1938). When the velocity of the concentric muscle movement is increased, a reduced amount of force can be produced during that contraction (Cormie *et al*, 2011). This is accurate for a group of muscles or muscle that is triggered at a steady rate and is due to the actin-myosin cross-bridge cycling (Fenwick *et al*, 2017). It requires a specific amount of time for the cross-bridges to detach and attach, with the overall number of cross-bridges connected decreasing with the increasing velocity of muscles

shortening (Lieber, 2009). Since the total force created by a muscle is reliant on the number of connected cross-bridges, production of force reduces as the velocity of contraction increases, and power is maximised as a result of the combination between velocity and sub-maximal force.

The force-velocity profiling of players can be used as a tool to aid in improving performance (Samozino *et al*, 2012; De Lacey *et* al, 2014; Samozino *et al*, 2014). An individualised training programme can be developed around a player's force-velocity profile and is based on the concept of a theoretical optimal force-velocity profile. Samozino *et al* (2010) signified that the difference between the actual calculated force-velocity profile and the theoretical optimal force-velocity profile, otherwise known as the force-velocity imbalance, is associated with jumping performance both experimentally and theoretically. This demonstrates that the theoretical framework can calculate a player's jump height based on their force-velocity maximal power and force-velocity imbalances. The greater the force-velocity imbalance a player has predicts a smaller jump height (Lindberg *et al*, 2021). Therefore, analysing a player's force-velocity profile will assist in tailoring future training programmes to lessen the force-velocity imbalance. By evaluating the player's current theoretical maximal velocity and theoretical maximal force, overall performance can be improved, allowing them to jump higher.

Prior research has shown that specified training programmes based around a player's force-velocity profile and targeting the least developed traits of the player, is a useful approach to aid in improving a sub-elite rugby union player's jump height (Jimenez-Reyes et al, 2017). Players that possess a 'force-oriented profile' should undertake exercises that are predominantly high-velocity orientated, however players that have 'velocity-oriented

profiles' should perform exercises that are focussed on producing high forces in their training (Jiménez-Reyes et al, 2017). This can theoretically reduce the force-velocity imbalance and may ultimately improve performance.

Simpson *et* al (2021) assessed the effectiveness of a strength and power programme that was adjusted to elite male rugby players' force-velocity profiles during a pre-season. It was reported that when specific force-velocity training was implemented into the players' regime, there were greater changes in their squat jump, maximal strength and vertical peak power when they were compared to the control group. This supported the work of Jiménez-Reyes *et al* (2017), as they aimed to test an individualised training programme based on the force-velocity profiles of male sub-elite footballers and male sub-elite rugby players. The results concluded that an enhanced and specific programme that addressing the players' theoretical maximal force imbalances and theoretical maximal velocity imbalances is more effective for increasing jump performance (all participants increased their jump height) when compared to a conventional resistance training programme (10 out of 18 participants improved). These findings also show that an effective programme targeting the force-velocity profile of a player is a useful strategy for increasing ballistic jumping performance when the time to reach an optimal force-velocity profile is controlled. Overall, by evaluating a player's theoretical maximal force and theoretical maximal velocity, it can lead to numerous benefits in a variety of rugby performance variables that correlate to their force-velocity relationship (De Lacey *et al*, 2014; Samozino *et al*, 2014).

The assessment of a player's force-velocity profile could be of great interest to strength and conditioning coaches and researchers, considering the force-velocity profile differs with the individual characteristics of each player (maximal power output, limb extension and different

loaded squat jumps) (Samozino *et al*, 2012). This would permit the need to potentially implement training programmes that focus on improving maximal power output (Morin and Samozino, 2016). However, despite the large increases in jump performance that have been previously reported, there still appears to be further research required. This would allow future researchers to identify what other neuromuscular capabilities, mechanical capabilities and body composition variables affect jump performance.

It is unclear if a reduction in force-velocity imbalances in exercises such as the squat jump, with no changes in maximal power output, will be beneficial for other measures of performance such as sprinting and the countermovement jump. A change in the force-velocity profile with no increase in the maximal power output, suggests that there has been a reduction in power at low or high velocities (e.g., sprint running) (Jiménez-Reyes *et al*, 2017). This may become challenging to analyse if there are various desired performance outcomes. Strength and conditioning coaches may need to examine the effectiveness of specific training programmes based on the players' theoretical maximal velocity and theoretical maximal force, as it may impact multiple performance outcomes such as maximal strength, 40m sprint and measures of power. To the best of the authors knowledge there is currently no research surrounding the potential associations of body composition and the amount of theoretical maximal force and theoretical maximal velocity produced during the countermovement jump and squat jump in male university rugby union players.

### *2.6.1 Importance of an external load protocol and performance measures*

The force-velocity profile for jumping is naturally linear in nature, hence absolute loads can be applied, which completely simplifies the testing process. This means it is not a

requirement to determine and implement relative external loads (as a % of one-repetition maximim squat or as a % of body mass) given that the velocity and force values taken will align on the same line as those obtained from the absolute external loads (Morin and Samozino, 2017). Utilising additional external loads can allow for the exploration into what muscular mechanical characteristics are affected through the force-velocity profile (Rahmani *et al*, 2001; Samozino *et al*, 2008), which is imperative for a complete assessment of a player. The regular testing protocol to assess the force-velocity relationship relies on executing numerous vertical jumps against more than two external loads (Giroux *et al*, 2016; Jimenez-Reyes *et al*, 2017; Pérez-Castilla *et al*, 2018). As the force-velocity relationship of vertical jumps have been shown to be linear in nature (Morin and Samozino, 2017), Jaric (2016) implied that the force-velocity relationship can be precisely measured under just two different external loading conditions. This is highlighted through the findings of García-Ramos *et al* (2018), as they reported that countermovement jumps and squat jumps produced reliable force-velocity relationships for the two-point method at distant loads compared to the multiple point method. Although, the studies reliability and validity can be questioned as it was not completed under field conditions (e.g., only employing two external loads during the testing protocol) and the population was not made up of male elite or sub-elite rugby union players, making the data harder to compare. Therefore, since there is only one other study that has tested the two-point method under field conditions and found somewhat reliable results for theoretical maximal force (CV = 4.30, range: 2.87-5.78%), and power (CV = 3.74, range: 3.24-4.22%), it is still best practise to utilise at least four external loading conditions when analysing the force-velocity relationship of players.

The routine monitoring of vertical jump tests has been utilised for developing the force-velocity relationship during recent years and has consisted of measuring velocity and force

outputs under various external loading conditions (Cuk *et al*, 2014; Feeney *et al*, 2016; García-Ramos *et al*, 2017). Subsequently, a linear regression model can then be employed to the force-velocity data to establish the parameters of the force-velocity relationship (theoretical maximal force, theoretical maximal velocity, theoretical maximal power and force-velocity slope) (Iglesias-Soler *et al*, 2019). It must be mentioned that following this testing procedure allows for the discernment of theoretical maximal velocity, theoretical maximal force and theoretical maximal power capacities of the individual (Jaric, 2015). Normally when specific loads are applied to a given individual, mechanical outputs are interdependent, which can make the recorded data predictably lower than the theoretical maximum of the individuals' velocity, force and power (Garcia-Ramos *et al*, 2018). Thus, using different external loads to establish a force-velocity relationship allows for a more comprehensive evaluation relating to lower-body performance during vertical jump tests (Jaric, 2015).

Previous research by Samozino *et al* (2013) indicated that male rugby players demonstrated force-velocity imbalances towards force attributes when performing jump tests. This may be attributed to rugby players generally performing movements against resistant forces as well as undertaking higher training loads. Therefore, in instances like this, it may be beneficial to introduce loads that are lower than body mass. A change in force-velocity and force-time may occur as a result of training over an extended period of time, inevitably improving the rugby player's ability to generate velocity (Djuric *et al*, 2016). It is important to note that vertical jump tests, such as the squat jump and countermovement jump test, can simulate concurrent extension and flexion of lower limb joints, which are typically utilised during running and sprinting movements (Feeney *et al*, 2016). Consequently, standardising loaded vertical jumps could make this procedure more ecologically valid for testing lower leg muscle capacity

compared to cycling ergometers. In comparison to cycle ergometers, previous research has also reported vertical jump performance tests to be strongly correlated with running and sprint performance (Baker and Nance, 1999; Driss *et al*, 2002; Cunningham *et al*, 2016; Furlong *et al*, 2021). Furthermore, whilst a player is performing a vertical jump test, the force and velocity that is exhibited has been associated with various other key parts of a player's performance such as rucks, mauls, scrums and changes of direction (Robinson and Mills, 2000; Duthie *et al*, 2003; Freitas *et al*, 2018).

It has been indicated that for a given maximal power output, there can be an unbalanced favouring relating to force and velocity that can cause a 30% decrease in performance (Samozino *et al*, 2012). Utilising external loads with vertical jump testing can identify weaknesses in a player's performance, for example, if a player lacks the ability to produce force at higher velocities, it could potentially reveal weaknesses in their neuromuscular coordination or potentially type two muscle fibres. This may be a cause for concern for strength and conditioning coaches, as previous findings have shown male rugby players to display a greater proportion of type two muscle fibres (Hopwood *et al*, 2023). Subsequently, targeted training programmes can then be implemented to try to increase the amount of type two muscle fibres as well as muscle architecture. Future studies, unlike the aforementioned, should incorporate performance tests such as the squat jump or countermovement jump alongside magnetic resonance imaging scans. This approach will allow for comprehensive data to be collected surrounding the association between muscle fibre typology and performance measures in male rugby union players. Furthermore, instead of the players being divided into subgroups (forwards and backs), players can be categorised by position to investigate the differences in positional muscle typology and performance.

# 3.0 Methodology

## *3.1 Ontological approach*

Positivism follows the idea that simply 'factual' understanding is gained through observation (all the human senses), including measurement, when it is considered reliable (Howell, 2012). The researcher distances themselves from the study as they need to conduct it as an objective analyst without holding on to any personal values (Research Methodology, 2014; Quick and Hall, 2015). Therefore, the ontological approach adopted in the present study was positivist and it is established around the concept that there is an independently existing reality with a realist focus (Slevitch, 2011). Emphasis on the study is also narrow as there is particular attention on the research questions instead of adopting a broader approach that a qualitative study might embrace. Furthermore, a repeatable, fair, logical method, utilising data collection and statistical analysis of quantitative data at a single time point, was employed so generalisable conclusions can be drawn (Jones, 2022). It is acknowledged that employing this ontological approach may be restrictive as participants' emotions, opinions, and previous experiences are omitted. However, adopting a positivist approach permits statistical confidence and objectivity whilst recognising the previous theories and viewpoints of the researcher as well as the potential bias of the researcher influencing the results (Gratton and Jones, 2014).

### *3.1.1 Study design*

This study adopted an observational cross-sectional design. A sample of sub-elite male university rugby union players were observed and they were all linked together through performing the same exercises during one testing session as well as receiving one DXA scan each. The study is regarded as quantitative research as it highlights data collection about certain patterns, in a specific, well-defined group that can be quantified with ease (Smith,

2010). Given that the focus of the research was to explore 'associations', a cross-sectional design has been implemented. The choice of players within a cross-sectional study design also relies on the exclusion and inclusion criteria, which means the randomisation of the study becomes reduced (Setia, 2016). Furthermore, in comparison to longitudinal studies where confounding variables can be managed to a greater degree, small intervention points are deemed more practical with sub-elite and elite athletes, due to the acknowledged intricate scheduling and planning needed for high-quality reliable and valid data collection (Halperin *et al*, 2018). One of the biggest advantages to using a cross-sectional study design is that they can be extremely helpful for gathering preliminary data to assist more extensive studies in the future (Thompson and Panacek, 2007).

All players in the study were informed of how the DXA scan was performed and how the one-day testing programme was going to run prior to the testing being carried out as well as sets, repetitions and rest periods for each exercise being explained thoroughly. This was because of two practice sessions being completed as part of their preseason training (once at the end of their previous season and once in the middle of their current preseason) before the testing day to familiarise themselves with the testing protocols. Following the two practice sessions that allowed the players to be familiarised with the testing procedures, players were assessed for body composition variables (TBLH lean mass (kg), legs lean mass (kg), TBLH body fat %, TBLH fat mass (kg) and TBLH mass (kg)) and jump height using the countermovement jump 1kg and squat jump height under various loading conditions (1kg, 20kg, 40kg, 60kg). Furthermore, theoretical maximal force and theoretical maximal velocity were assessed against the same body composition variables to determine the association between body composition variables and how much theoretical maximal force and theoretical maximal velocity is produced. Finally, squat jump 1kg, squat jump 20kg, squat jump 40kg

and squat jump 60kg were used to predict the association between the same body composition variables, theoretical maximal force and theoretical maximal velocity.

The squat jump and countermovement jump were selected as ballistic performance tests because they have been associated as key determinants for success in numerous sports including rugby and this success in such performances has been closely linked to how much maximal power output a player can generate (Cronin and Sleivert, 2005; Yamauchi and Ishii, 2007). The tests provide an objective assessment of explosive lower-body muscular power (associated with theoretical maximal force and theoretical maximal velocity production), neuromuscular status and supercompensation (Taylor *et al*, 2012; Balsalobre-Fernández *et al*, 2014). Therefore, theoretical maximal force, theoretical maximal velocity and jump height were examined as performance measures because a strong-powerful lower body and a durable shoulder girdle are essential to maximum force production and the absorption of impacts (McMaster *et al*, 2016). Velocity production during the subsequent actions is also key to excelling in rugby union: pulling, tackling throwing and fending (McMaster *et al*, 2016).

### *3.1.2 Study sample*

Participants in the study were selected through non-probability purposive sampling, which was undertaken in collaboration with the team's strength and conditioning coach (gatekeeper). Non-probability sampling is a procedure that consists of a non-random way of selecting participants within a sample to participate in a research study (Etikan and Bala, 2017). Even though this method has been criticised because it is established that sample bias occurs, non-probability purposive sampling allows for applicable cases to be precisely

identified and these cases are relevant to the study design, which enables a greater quality of data to be collected (Rai and Thapa, 2015).

Participants included in the study were 17 male sub-elite rugby union players (Tier 3 - Highly Trained/National Level) who form a British Colleges and University (BUCS) side (McKay *et al*, 2021). Players that were included in the study, competed in the Super BUCS Premiership, the top tier of university rugby in the UK. Recruitment of players came from a pool of the top two performance squads at the university; however, it was not possible to test all the players across both squads due to DXA scan availability and scheduling times. These players were included in the study due to the lack of current research surrounding body composition and performance at their level and age. Players were excluded from the study if they were not consistently playing in the top two performance squads from the BUCS side as these players were most likely not going to progress further into professional rugby. If any players were suffering from any injuries, then this would put them at more risk of further injury and would affect the results of the sample significantly, so they were also excluded. All players that were involved within the study had a strength-training background ranging from one to more than three years training experience, were familiar with the testing procedures as the exercises were prescribed in their routinely strength and conditioning programme and they were all highly trained (averaged ten hours a week of training and one rugby union match).

### *3.1.3 Ethical considerations*

Following the research ethics policy set out by the Department of Sport and Exercise Sciences at Durham University, the study was granted ethical approval from the NHS IRAS committee and the Departmental Ethics Sub-committee (Appendix H - IRAS Project ID: 308072 and Durham University departmental approval reference number: SPORT-2022-05-

28T09_56_39-hwhs25; Appendix I – Durham University departmental approval reference number: SPORT-2022-06-24T16_05_50-cvmc73). Throughout the study, there were numerous ethical considerations that needed to be accounted for. All players were made aware that they had the right to remove themselves from the study at any time without any reason warranted and they were all notified of the procedures, risks and possible benefits. The information that was presented to the players was delivered in a way that allowed them to understand and comprehend it fully, which enabled the players to evaluate the consequences of what they were about to agree to (Cardinal, 2000). Before any testing or DXA scans were performed on the players, they were all given an informed consent form, university privacy policy sheet and study information sheet at the beginning of their DXA scans the week before testing began (Appendix C, Appendix E, Appendix B). These documents explained the withdrawal procedure, risks, how data was handled, benefits and study requirements. Once data collection began, all recorded data was stored on a university secured computer account, anonymised and only distributed between members of the research team. Furthermore, prior to the testing session, the test protocols were explained rigorously and players were asked if they had any questions before the session commenced.

During the entirety of the study, it was of great importance that the players health and safety was paramount. As the study required a field-based setting, risk assessments were conducted on the training facilities, equipment and performance tests to ensure that any dangers or hazards during data collection were minimised. To ensure the research was conducted to the highest possible standard, the guidelines and code of conduct set out by the British Association of Sport and Exercise Sciences were followed (Jones *et al*, 2016; Davison *et al*,

2022). Every player collected a participation completion debriefing sheet (Appendix D) and a copy of their personal result after the study was completed.

### *3.1.4 Dual energy X-ray absorptiometry*

DXA is a medical imaging tool that uses two X-ray beams of differing energies to attenuate bone mass and tissue (Hind *et al,* 2018). DXA is currently the gold standard for assessing the body composition of athletes due to the excellent precision it is capable of when standardised (Lewiecki, 2005; Hemmingsson *et al*, 2009; Bazzocchi *et al*, 2016; Scafoglieri and Clarys, 2018). To support this further, Hind *et al* (2010) reported that DXA was highly precise at evaluating lean tissue mass and bone mineral content (root mean square 0.015 and coefficients of variation (CV) 0.6%, respectively) in 18 males and 34 females. Barlow *et al* (2015) also analysed DXA precision error on 45 elite male rugby players and it was discovered that DXA had a lean mass precision of 1.6% CV and a body fat mass precision of 2.3% CV.

To measure and analyse the body composition of the 17 male sub-elite rugby union players within the present study, one total body less head (TBLH) DXA scan was administered between 9am – 4pm (depending on the players appointment slot) during the week prior to the season commencing (Lunar iDXATM; GE Healthcare, WI; Encore software version 15.0) with the exercise testing session taking place the following week. The players were familiar with how the scans were conducted as they had previously been shown the DXA scanning room after their second practice session was completed. The head was also removed from the scan as around 10% of DXA-measured whole-body lean mass is found in the head because of the quantity of water situated within it (Krueger *et al,* 2017). This part of the body represents a region that offers little contribution to a player's physical performance and skeletal

function, thus it is not likely to be administered into any exercise programmes to be improved (Jones *et al*, 2022). Rugby players are also often tall and sit outside the scanning region, so by eliminating the head, it allows for the collected data to be accurate and reliable.

Scans were conducted by a densitometrist and regional and total lean mass, bone mineral content, body fat mass and body % were derived. Each scan and scan evaluation were carried out by the same densitometrist using the latest GE Lunar 77 recording software package (Version 15.0, GE Healthcare, Madison, WI). Continuous planning with further information was given to the players at least 24 hours before scans were conducted. The information that was given included an overnight rested state and fast with no consumption of water upon awake, no heavy exercise or training 24 hours before the scan and no alcohol consumption. Following the protocol of Hind *et al* (2018), players were asked to wear lightweight clothing with no metal so the body composition scans would not be impacted by excess external artefacts that could potentially alter the results. Players then positioned their bodies in the supine position with their heads in the Frankfurt plain, while maintaining their bodies in the centre of the scanning region (Figure 3)**.** Furthermore, the players legs and arms were laid in positioning aids to standardise their positioning.

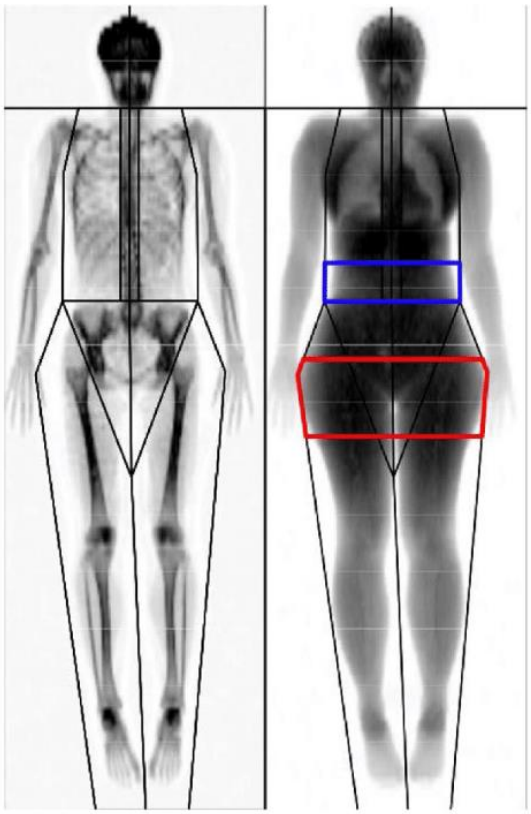


**Figure 3. Example of DXA scanning region (De Blasio *et al*, 2016).**

Recent software updates from GE-Lunar suggest that participants should now have their hands placed in a mid-prone position with at least a 1cm gap between their hips and hands (Figure 4). This allows for the scan width of the participants to be reduced, which enables the participant to fit inside of the scan boundaries and this is further validated through the comprehensive methodological work of Nana *et al* (2012). Once a participant's hand was placed in the mid-prone position, there was approximately a 5cm gap between the thigh and palm, the thumb was positioned in alignment with the first finger and the arms were placed with ease inside of the scanning region (Thurlow *et al*, 2018). This gap was purposeful, to enable separation for regional body composition analysis.

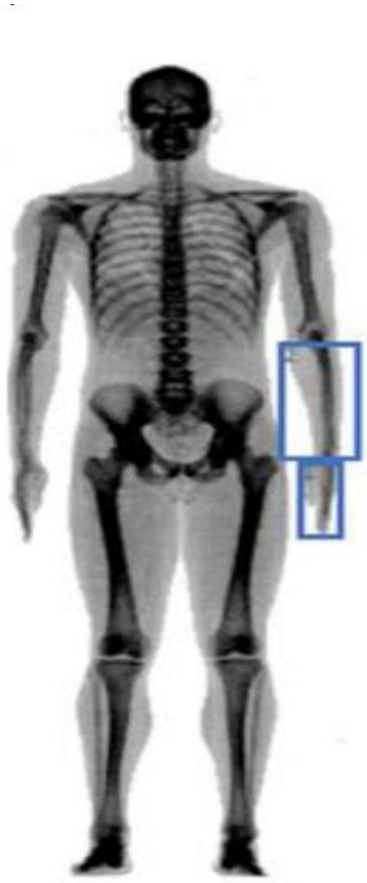


**Figure 4. Example of the standard anatomical position with the head placed in the Frankfort plane and hands in mid-prone position (Thurlow *et al*, 2018).**

## 3.2 Performance assessment protocols

### *3.2.1 Warm-up*

To standardise the jumps throughout the practice sessions and on the testing day, players were required to always wear weightlifting shoes and all assessed jumps were carried out between 7am – 11am. All countermovement jumps and squat jumps preceded with a 20-minute warm-up. Following the protocol of Perrier *et al* (2011), the warm-up consisted of an easy skip with arm swings; skip for distance using arms to drive forward; skip for height using arms to drive upward; backwards run (heels facing backwards at all times); backwards low shuffle (open hips); hop into single leg Romanian deadlift; lunges with twist; knee pulls

(knee to chest, opposite foot on toes); carioca fast feet (no rest or walking); scissor kicks; submaximal barbell squats (40kg x 3, 60kg x 2, 80kg x 1, 100kg x 1). This warm-up was performed over 15 metres and each exercise was performed twice. After the warm-up was completed, participants had their stature measured using a Seca 217 stadiometer (Seca Weighing and Measuring Systems, Birmingham, UK) and body mass taken with a Tanita WB-100MA scale (Tanita Europe B.V. Amsterdam, The Netherlands). Furthermore, lower limb length was measured prior to testing to allow for data to be collected on the distance covered by the centre of mass during take-off, which would later be recorded into a Microsoft Excel spreadsheet (Microsoft Excel, Microsoft Corporation, 2018) to develop a force-velocity profile (Samozino *et al*, 2008). This was carried out by calculating the difference between the players individual standardised starting jump position (iliac crest to ground for vertical distance) and the extended lower limb length (iliac crest to toes with plantar flexed ankle).

Before testing begun, players were asked to adhere to some simple protocols. During time spent in the air for the countermovement jump and squat jump, players-maintained extension in the hip, knee, and ankle joints to prevent attainment of additional flight time through bending their legs (Markovic *et al*, 2004; Glatthorn *et al*, 2011). Players were asked to land with their toes pointed due to the potential of getting more flight time artificially compared to landing with a flat foot, which would affect the results (Bosco, 1992). The players were also instructed to attempt to land in a similar position to take off, as forward, backward, or sideways travel may affect results. Furthermore, the dowel and Olympic barbell had to remain rested on the players trapezius for the entirety of the countermovement jumps and squat jumps to ensure no additional jump height and flight time were gained by propelling the barbell in the air whilst in the process of jumping (Cormie *et al*, 2007). Ensuring these protocols were adhered to for the countermovement jump and squat jump allowed for

minimal error to occur, which meant the collected data would be more reliable and valid. If participants for the countermovement jumps and squat jumps landed outside of the testing area, did not reach the self-selected depth, the Olympic barbell or dowel left their trapezius whilst jumping, jumped earlier than being instructed for the squat jump or did not land with toes pointed, then it was deemed a failed repetition, and the participant was asked to perform the repetition again.

### *3.2.2 Countermovement jump*

In the present study, countermovement jump height was assessed against body composition variables to see if they had a positive or negative association on jump height. This performance measure was chosen as previous literature has mainly focussed on elite rugby players (Darrall-Jones *et al*, 2015; Dobbin *et al*, 2018). There is a gap in the literature to allow for data to be collected at a sub-elite level, enabling comparisons to be made based on body composition variables and jump performance.

The countermovement jump can be conducted with or without an arm-swing. However, as arm-swing has been found to improve performance by approximately 10%, this has been omitted from the test protocol in an attempt to precisely measure the performance output of the lower limbs in isolation (Cheng *et al*, 2008). Players performed 3 maximal countermovement jumps, under 1 sub-maximal loading condition (1kg) on a deadlift platform outside of the squat rack. Before each jump, players were told to stand up straight and still within the testing area (between the parallel OptoJump sensors on the deadlift platform) with their hands placed on a dowel (1kg). This hand position remained the same during the entirety of the movement to standardise positioning, and the players were told to keep the dowel in a high bar back (trapezius) squat position. At this point, players initiated a

downwards movement into a squatting position with a knee angle of 90° (this differed between players), followed instantly by a maximal jump in a vertical direction (Figure 5). It was important to let the players choose a self-selected depth when performing the countermovement jump and squat jump, as research indicates that trained players will automatically modify their squat depth so they can perform at an optimal level when performing movements that involve jumping (Bobbert *et al*, 2008).

Out of the 3 maximal countermovement jumps (1kg), the greatest jump height out of the 3 was recorded with the Optojump photocell jump system (1000 Hz, Microgate SRL, Bolzano, Italy), it was then inputted into a Microsoft Excel spreadsheet so further analyses could be conducted and approximately 5-15 seconds rest was administered between each jump repetition (Chen *et al*, 2013; Hughes *et al*, 2021).

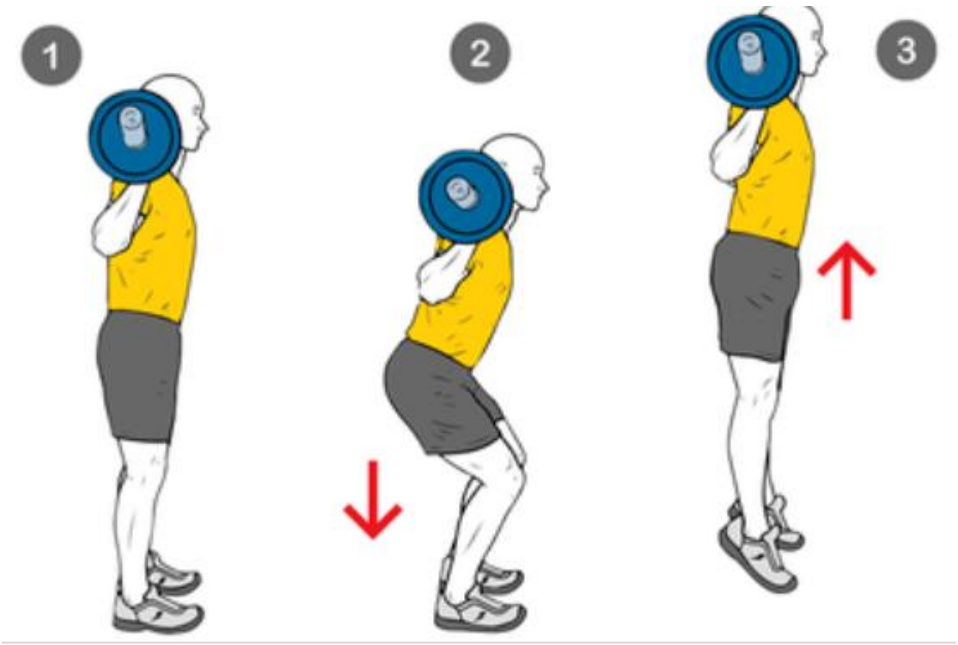



**Figure 5. Example of a countermovement jump being performed (Workoutsprograms, 2022).**

### *3.2.3 Squat Jump*

The squat jump under various loading conditions was also used as a performance test to determine the force-velocity profile of each player, and the performance measures that were examined from this test were jump height, theoretical maximal force and theoretical maximal velocity. Furthermore, theoretical maximal force and theoretical maximal velocity were examined as they have been shown to affect how much maximal power output is produced. Instead of selecting individually adjusted external loads, various preselected loading conditions (1kg, 20kg, 40kg and 60kg) were implemented because of the time constraints that were placed on the study. It would not have been feasible to conduct the study with any different or heavier loads, as there was a little amount of allocated time to assess the players on the testing day. This meant the loads that were selected still enabled sufficient data to be gathered, which would allow for the jump height, theoretical maximal force and theoretical maximal velocity to be extracted from the force-velocity profile and OptoJump (Samozini *et al*, 2008). Stated in the work of Morin and Samozino (2017), the force-velocity profile for jumping is naturally linear in nature. This means it is not a requirement to determine and implement relative or optimal external loads (as a percent of one-repetition max squat or as a percent of body mass), given that the theoretical maximal velocity and theoretical maximal force values taken will align on the same line as those obtained from the absolute external loads.

When instructed to perform the jumps, the players were told to keep constant downwards pressure on the barbell so it did not move from the trapezius while the movement was being performed (Cormie *et al*, 2007). During testing, players were told to stand up straight and still within the testing area (between the OptoJump sensors on the deadlift platform) and squat down to a knee angle of 90° (this differed between the players self-selected depth), followed

by a 2-second pause before being instructed to perform a maximal jump in a vertical direction. A 5-15 second rest was also administered between each jump repetition. Research by Willardson (2008) suggested that the greatest jump height is achieved at approximately 2 and 4 minutes, so an approximate 2-minute rest was implemented after each loading condition due to the time constraints.

The players performed 3 maximal squat jumps under 4 different sub-maximal loading conditions (1kg, 20kg, 40kg and 60kg). The greatest jump height of the 3 maximal squat jump repetitions for each loading condition (1kg, 20kg, 40kg and 60kg) was recorded with the OptoJump photocell jump system and then inputted into a Microsoft Excel spreadsheet for further analyses.

## 3.3 Outcome Measures

### *3.3.1 The Optojump and force-velocity profile*

Throughout each session, jump height for the squat jump and countermovement jump was recorded using the OptoJump photocell jump system (1000 Hz, Microgate SRL, Bolzano, Italy) and the corresponding software (Optojump Next, Microgate, Bolzano,Italy). The OptoJump photocell jump system, which contains two bars that are parallel to each other (one receiver and one transmitter, each bar measures 100 x 4 x 3 cm, 2.1kg), was positioned at the extremities of each side of the deadlift platform to ensure players had plenty of room to step into the testing area. After each individual jump, the data was sent to a computer and the greatest jump height (calculated to the nearest 0.1cm) of the 3 maximal countermovement jumps and 3 maximal squat jumps for each loading condition was recorded and held back for further analyses in Microsoft Excel and SPSS version 28 (SPSS Inc., Armonk, NY).

The OptoJump software records the height of vertical jumps by using flight time, which uses a simple equation ($9.81 \times \text{flight time}^2 / 8$) outlined by Bosco *et al* (1983). The Optojump photocell jump system has demonstrated a good criterion validity (vs force plate: r= 0.98, trivial difference = 0.33) and a high test-retest reliability for flight time (ICC= 0.96, 95% CI= 0.91; 0.99, CV(%)= 1.8 (1.4; 2.3)) and jump height (ICC= 0.87, 95% CI= 0.62;0.97, CV(%)= 4.2 (3.3;5.1)) when compared to a video-based motion capture system, force platform, Myotest, Ergojump and Myjump in 15 male university students (Rago *et al*, 2018).

The force-velocity profile of players performing squat jumps under various loading conditions was determined by the methods outlined by Samozini *et al* (2008) and Morin and Samozino (2017). This method has been validated against a force plate for measuring the force-velocity of players performing the squat jump under various loading conditions and was later modified by Jimenez-Reyes *et al* (2017) so it can also be used to measure the force-velocity of players performing the countermovement jump. The protocol allows for the automatic calculation of the jumping force-velocity profile of players by inputting their greatest jump height for each loading condition, anthropometrical data (lower limb length and body mass) and loads used (1kg, 20kg, 40kg, 60kg) into a Microsoft Excel spreadsheet (Microsoft Excel, Microsoft Corporation, 2018) developed by Morin and Samozino (2017), who incorporated the previously validated equations by Samozini *et al* (2008). From there, the force-velocity curves were extrapolated, allowing for the theoretical maximal velocity and theoretical maximal force to be obtained, These, correspond to the force and velocity axis and force-velocity curve. An example of the force-velocity profile devised by Samozino *et al* (2008) can be seen in Figure 6. The blue line indicates the force-velocity profile for 90° angle movements (e.g., countermovement jump), the red line indicates the force-velocity profile for

30° angle movements (e.g., 40m sprint), and the black line is the player's current performance score.

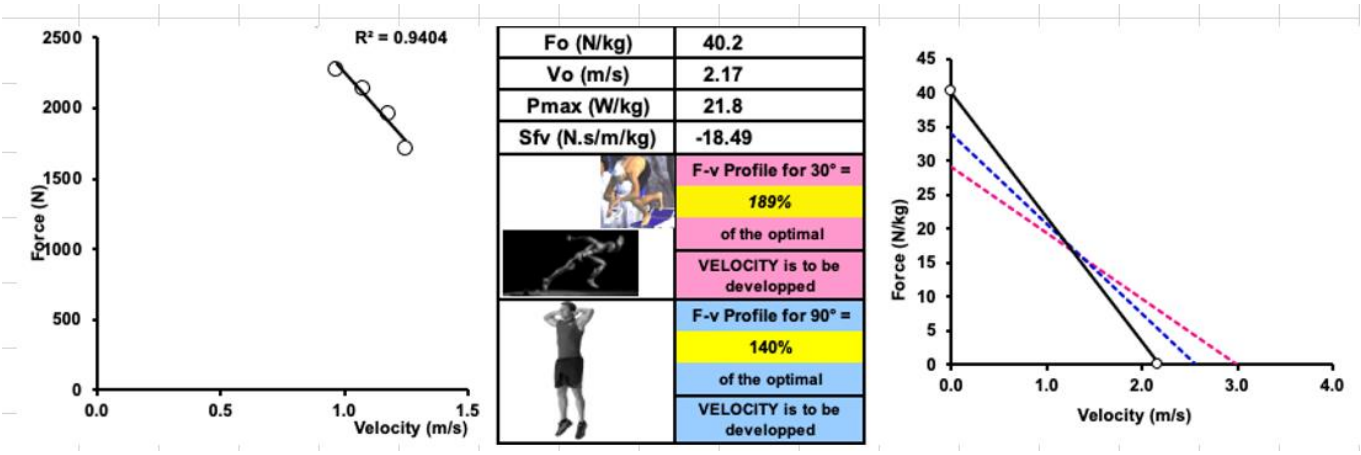



**Figure 6. Example of a force-velocity profile (Samozino *et al*, 2008).**

### *3.3.2 Statistical analysis*

All data analyses were carried out using SPSS version 28 (SPSS Inc., Armonk, NY) and Microsoft Excel for windows (Microsoft Excel, Microsoft Corporation, 2018). The means and standard deviations of the players' body compositions and anthropometrics were calculated after confirming the data was normally distributed. To test for normality, a Sharpio-Wilk's test was carried out on the data and an assessment of the box plots, Q-Q plots and histograms revealed that the data across all players were normally distributed (Shapiro and Wilk, 1965; Razali and Wah, 2011). To help protect the data from type 2 errors and to make assumptions about the true value of the associations in the study, the uncertainty within the associations were presented as 95% confidence intervals (Faul *et al*, 2007).

For all outcome measures – theoretical maximal force, theoretical maximal velocity and jump height - a Pearson's r correlation test was computed to measure the statistical linear association between the body composition variables of interest. Statistical significance was identified at $P \leq 0.05$ and trends were identified at $P < 0.10$. Effect size was implemented as it summarises the strength of the bivariate relationship and is independent to the sample of players. The value of the effect size for the Pearson's r correlation fluctuates amongst -1 (an ideal negative correlation) to +1 (an ideal positive correlation). Cohen (1992) stated that the effect size is low when the value of r is around 0.1, medium if it is around 0.3 and large if it is around 0.5 or greater. Thus, the effect size within the study was deemed trivial if it was <0.1 – 0.3, moderate if it was <0.3 – 0.5 and large if it was <0.5.

When assessing the squat jumps under different loading conditions (squat jump height 1kg, squat jump height 20kg, squat jump height 40kg and squat jump height 60kg), to determine which independent variables (TBLH lean mass (kg), legs lean mass (kg), TBLH body fat %, TBLH fat mass (kg) and TBLH mass (kg)) had an influence, singular linear regression analysis was conducted. This allows for the independent variables that affect the squat jumps under different loading conditions the most to be confidently determined, and the other independent variables can be dismissed. Results were again seen to be statistically significant at $P \leq 0.05$ and the adjusted R square was analysed (SPSS version 28, SPSS Inc., Armonk, NY). This provides a realistic insight into the analytical power of the model by measuring how well the regression model explains the observed data (Schneider *et al*, 2010). The closer the coefficient of determination for the adjusted R square value is to one, the more significant the independent variable is at affecting the dependant variable. The formula for calculating the adjusted R square in SPSS can be seen below (Akossou and Palm, 2013):

$$R_a^2 = \frac{SCE_p \ / \ p}{SCE_{tot} \ / \ (n-1)} = \frac{SCE_{res} \ / \ (n-p-1)}{SCE_{tot} \ / \ (n-1)}$$

Where:

$R_a^2$ = adjusted R square

$SCE_p$ = sum of squares (related to regression)

$SCE_{tot}$ = total sum of squares

$SCE_{res}$ = errors sum of squares

$n$ = number of observations

$p$ = number of parameters estimated in the model

## 4.0 Results

### *4.1 Descriptive statistics, anthropometrics and body composition*

Players that were included in the study had a mean age of 19.88 ± 0.86 and were tall, as they were seen have a mean stature of 183.52cm ± 8.28cm (Table 3). Furthermore, the TBLH mass of the group was 87.80kg ± 10.82kg and their BMI was 27.48kg/m² ± 1.56 kg/m² (Table 4). This BMI may be deemed relatively high compared to a normal active population, however, rugby players need to be larger to meet the demands of the sport. They also had a mean TBLH lean mass of 68.57kg ± 8.33kg, which is not reflected in the overall conclusion of BMI. The combined cohort of descriptive statistics and anthropometrics for all players can be seen in Table 3 and Table 4.

**Table 3. Players' descriptive and anthropometric characteristics obtained from day of testing.**

| Variables | (Mean ± SD) |
|---|---|
| **Age (y)** | 19.88 ± 0.86 |
| **Stature (cm)** | 183.50 ± 8.30 |
| **Mass (kg)** | 92.90 ± 11.20 |
| **BMI (kg/m²)** | 27.48 ± 1.56 |

**Table 4. Players' regional and whole-body composition obtained from DXA total body less head analysis (TBLH).**

| Variables | Mean ± SD |
|---|---|
| **TBLH mass (kg)**† | 87.80 ± 10.82 |
| **Arms total mass (kg)** | 12.06 ± 1.39 |
| **Legs total mass (kg)** | 32.74 ± 5.10 |
| **Trunk total mass (kg)** | 43.00 ± 4.71 |
| **TBLH lean mass (kg)** | 68.57 ± 8.33 |
| **Arms lean mass (kg)** | 9.67 ± 1.17 |
| **Trunk lean mass (kg)** | 33.77 ± 4.07 |
| **Legs lean mass (kg)** | 25.12 ± 3.55 |
| **TBLH BMD (g)** | 1.485 ± 0.997 |
| **TBLH fat mass (kg)** | 15.72 ± 5.64 |
| **TBLH body fat %** | 17.74 ± 5.23 |
| **Arms body fat %** | 14.85 ± 3.91 |
| **Legs body fat %** | 18.15 ± 4.35 |
| **Trunk body fat %** | 18.18 ± 6.45 |

### *4.1.1 Countermovement jump height 1kg and squat jump height 1kg*

The degrees of freedom (n-2) were 15 for all correlation results, as 17 players were included in each analysis.

The mean countermovement jump height 1kg and squat jump height 1kg of the players were 0.412m ± 0.060m and 0.405m and 0.052m. Furthermore, the body composition variables that had an association with the countermovement jump height 1kg and squat jump height 1kg can be seen for each player in Figure 7A – Figure 7D.

Countermovement jump height 1kg was significantly negatively associated (Table 5) with TBLH fat mass (r= -0.736, p= <0.001, 95% CI -0.899; -0.396) (Figure 7A) and TBLH body fat % (r= -0.723, p= <0.001, 95% CI -0.893; -0.372) (Figure 7B). However, TBLH lean mass (r= -0.025, p= 0.924, 95% CI= -0.461; -0.500) and legs lean mass (r= -0.100, p= 0.702, 95% CI= -0.554; -0.400) were not associated to the jump height of the players' countermovement jump 1kg.

Similar findings for the squat jump 1kg (Table 5) were discovered in relation to the countermovement jump 1kg. TBLH fat mass (kg) (Figure 7C) and TBLH body fat % (Figure 7D) were shown to be significantly correlated with the players' squat jump performance. Players' TBLH lean mass (r= -0.128, p= 0.624, 95% CI= -0.573; 0.376) and legs lean mass (r= -0.265, p= 0.303, 95% CI= -0.662; 0.247) demonstrated no significant correlation to their squat jump height. However, although it was not seen to be statistically significant, there was a small trend for a low to moderate correlation for TBLH mass (kg) and squat jump 1kg height (r = -0.473, p = 0.055, 95% CI= -0.777; -0.10), which highlights that there may be an association between TBLH mass (kg) and Squat jump 1kg height (figure 7E).

**Table 5. Associations between countermovement jump height (1kg), squat jump height (1kg) and body composition variables.**

| | Variables | *R* | 95% CI | Sig. (2-tailed) |
|---|---|---|---|---|
| **Countermovement Jump height 1kg (m)** | **TBLH lean mass (kg)** | 0.025 | -0.461 to 0.500 | 0.924 |
| | **Legs lean mass (kg)** | -0.100 | -0.554 to 0.400 | 0.702 |
| | **TBLH body fat %** | -0.723 | -0.893 to -0.372 | <0.001** |
| | **TBLH fat mass (kg)** | -0.736 | -0.899 to -0.396 | <0.001** |
| | **TBLH mass (kg)** | -0.377 | -0.726 to 0.127 | 0.136 |
| **Squat Jump height 1kg (m)** | **TBLH lean mass (kg)**† | -0.128 | -0.573 to 0.376 | 0.624 |
| | **Legs lean mass (kg)** | -0.265 | -0.662 to 0.247 | 0.303 |
| | **TBLH body fat %** | -0.608 | -0.843 to -0.180 | 0.010** |
| | **TBLH fat mass (kg)** | -0.683 | -0.876 to -0.301 | -0.003** |
| | **TBLH mass (kg)** | -0.473 | -0.777 to -0.10 | 0.055 |

** Correlation is significant at the 0.01 level (2-tailed).

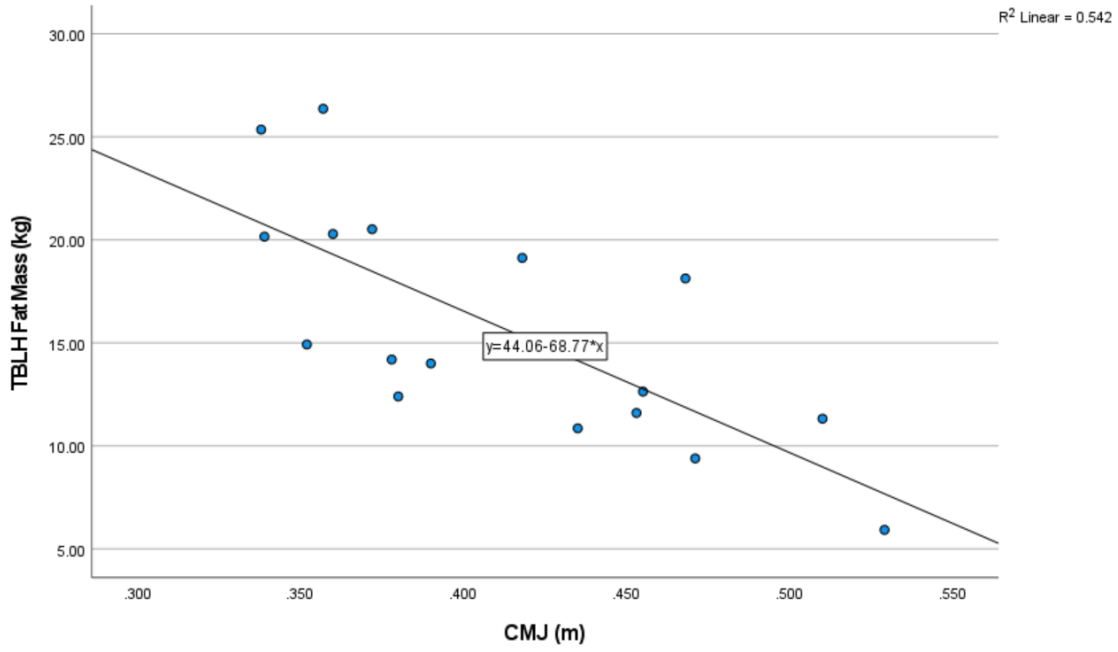



**Figure 7A. Association between countermovement jump height 1kg (CMJ) and TBLH Fat Mass (kg)**

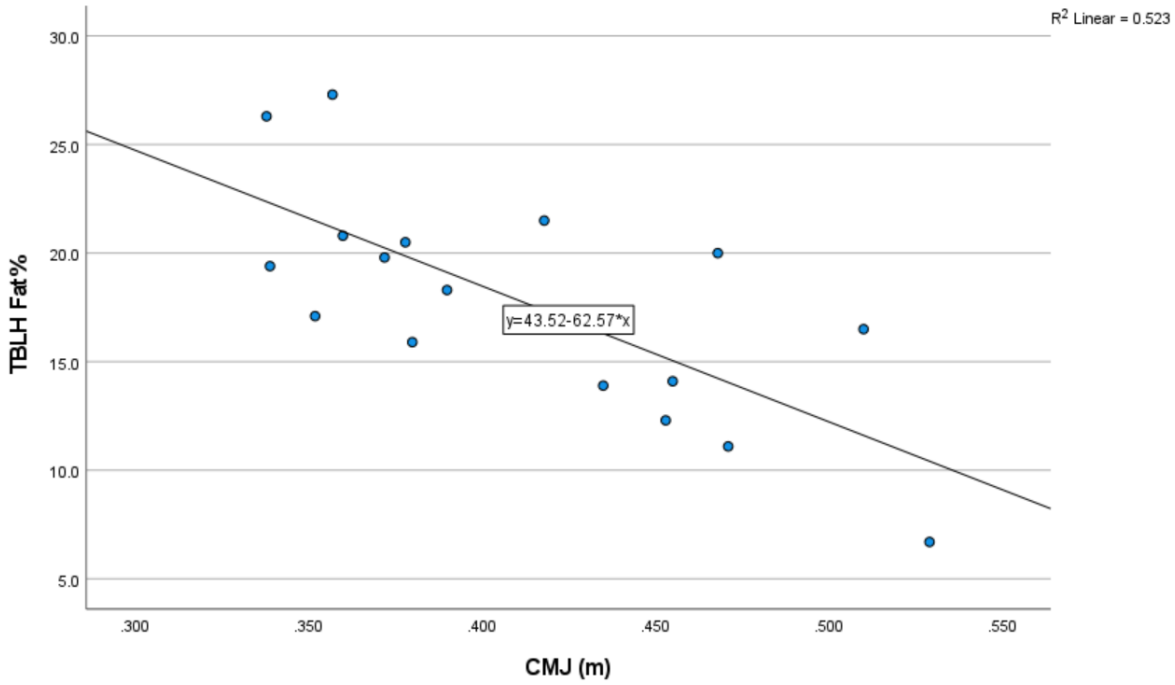



**Figure 7B. Association between countermovement jump height 1kg (CMJ) and TBLH Fat %**

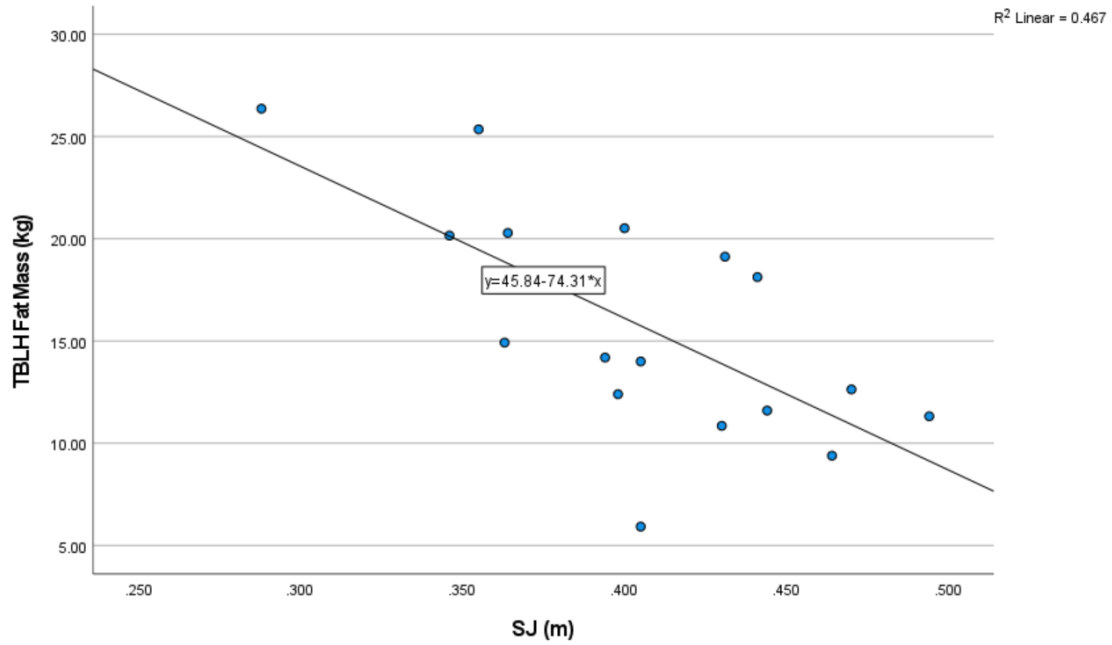



**Figure 7C. Association between squat jump height 1kg (SJ) and TBLH Fat Mass (kg)**

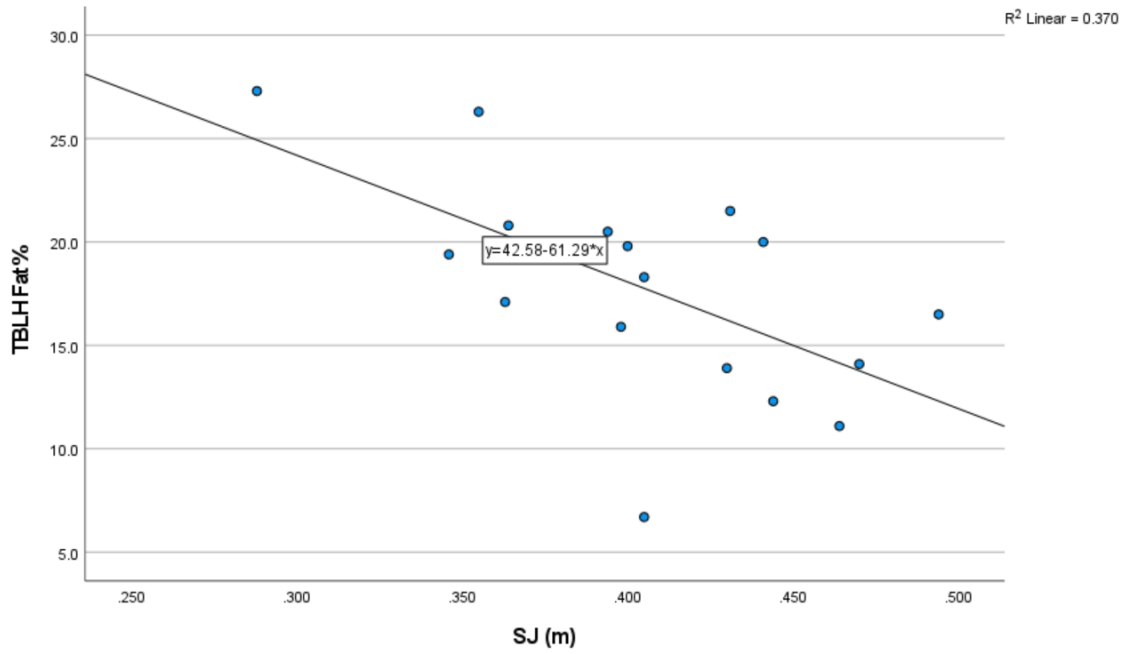



**Figure 7D. Association between squat jump height 1kg (SJ) and TBLH body fat %**

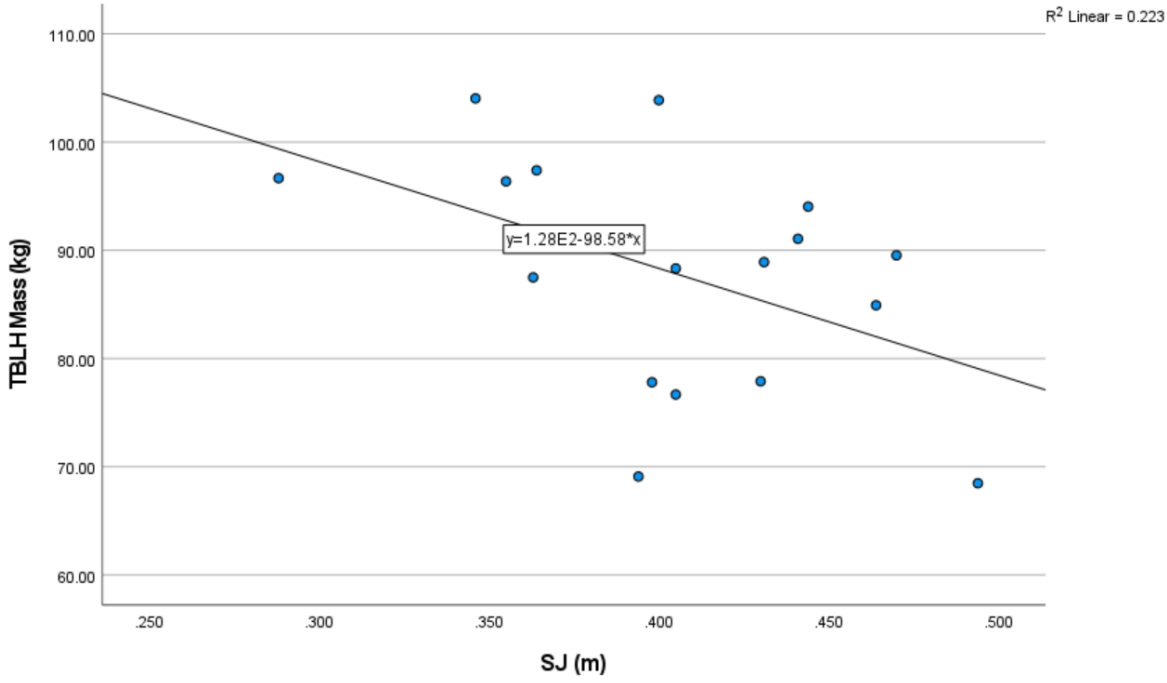



**Figure 7E. Association between squat jump height 1kg (SJ) and TBLH Mass (kg)**

### *4.1.2 Body composition, theoretical maximal force and theoretical maximal velocity*

Highlighted in table 6, theoretical maximal force (N/kg**)** was not seen to be associated with TBLH lean mass, legs lean mass (kg), TBLH body fat %, TBLH fat mass (kg) and TBLH mass (kg). Although none of the variables p values were significant, there was a trend for a low to moderate correlation for TBLH fat mass (kg) (r= -0.441, p= 0.077), which shows that that there may be an association between theoretical maximal force (N/kg**)** and TBLH fat mass (kg).

The players' theoretical maximal velocities were also compared to the same body composition variables (Table 6), and it was reported that TBLH fat mass (kg) (r= -0.503, p= 0.039, 95% CI= -0.662; 0.247) was statistically significant and moderately negatively correlated with theoretical maximal velocity ($m \bullet s^{-1}$) (Figure 8B). No statistically significant results were seen for TBLH lean mass (kg), legs lean mass (kg), TBLH body fat % and TBLH mass (kg). Even though TBLH body fat % was not statistically significant, the analysis revealed a trend towards significance with a potential moderate negative association with theoretical maximal velocity ($m \bullet s^{-1}$) (r= -0.471, p= 0.056).

**Table 6. Associations between theoretical maximal force, theoretical maximal velocity and body composition variables**

| | Variables | *R* | 95% CI | Sig. (2-tailed) |
|---|---|---|---|---|
| **Theoretical maximal force (N/kg)** | **TBLH lean mass (kg)** | -0.133 | -0.577 to 0.371 | 0.611 |
| | **Legs lean mass (kg)** | -0.251 | -0.653 to 0.261 | 0.331 |
| | **TBLH body fat %** | -0.385 | -0.730 to 0.118 | 0.127 |
| | **TBLH fat mass (kg)** | -0.441 | -0.760 to 0.051 | 0.077 |
| | **TBLH mass (kg)** | -0.344 | -0.708 to 0.164 | 0.176 |
| **Theoretical maximal velocity ($m \bullet s^{-1}$)** | **TBLH lean mass (kg)** | -0.012 | -0.490 to 0.471 | 0.962 |
| | **Legs lean mass (kg)** | -0.120 | -0.568 to 0.383 | 0.647 |
| | **TBLH body fat %** | -0.471 | -0.776 to 0.013 | 0.056 |
| | **TBLH fat mass (kg)** | -0.503 | -0.792 to -0.030 | 0.039* |
| | **TBLH mass (kg)** | -0.278 | -0.669 to 0.234 | 0.280 |

*Correlation is significant at the 0.05 level (2-tailed).

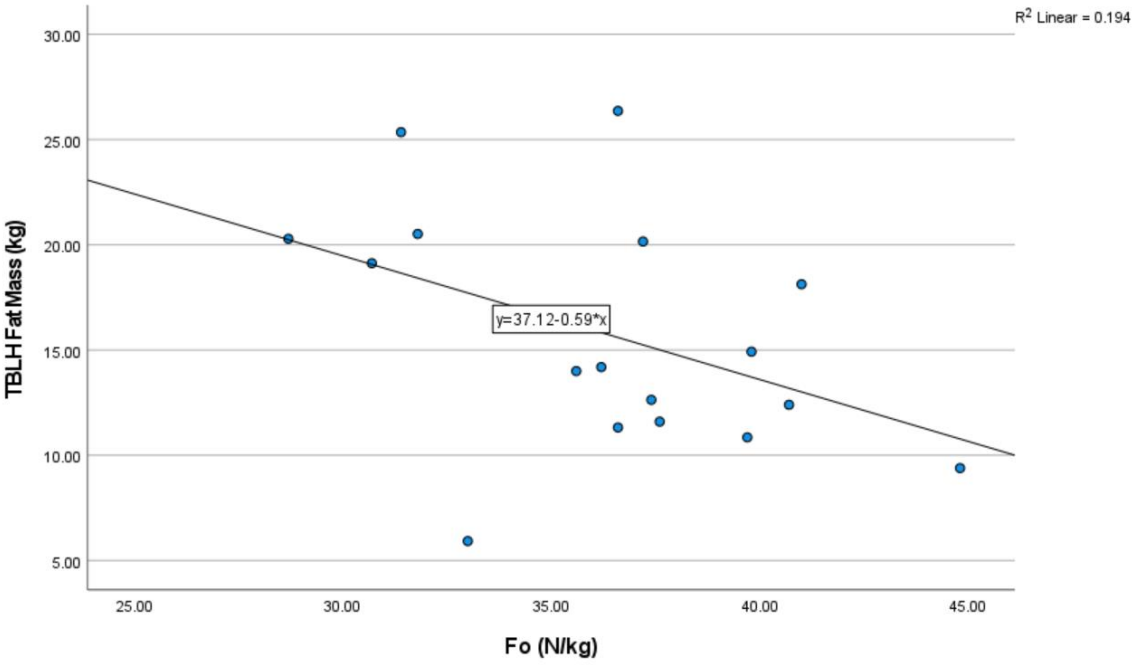



**Figure 8A. Association between theoretical maximal force produced (Fo) and TBLH fat mass (kg)**

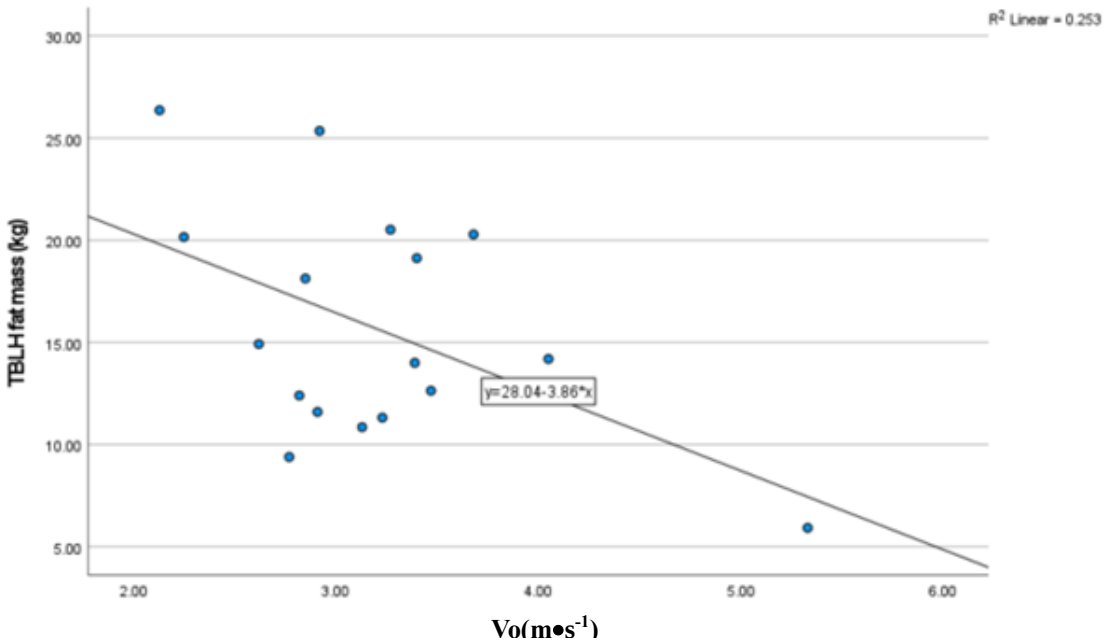



**Figure 8B. Association between theoretical maximal velocity produced (Vo) and TBLH fat mass (kg)**

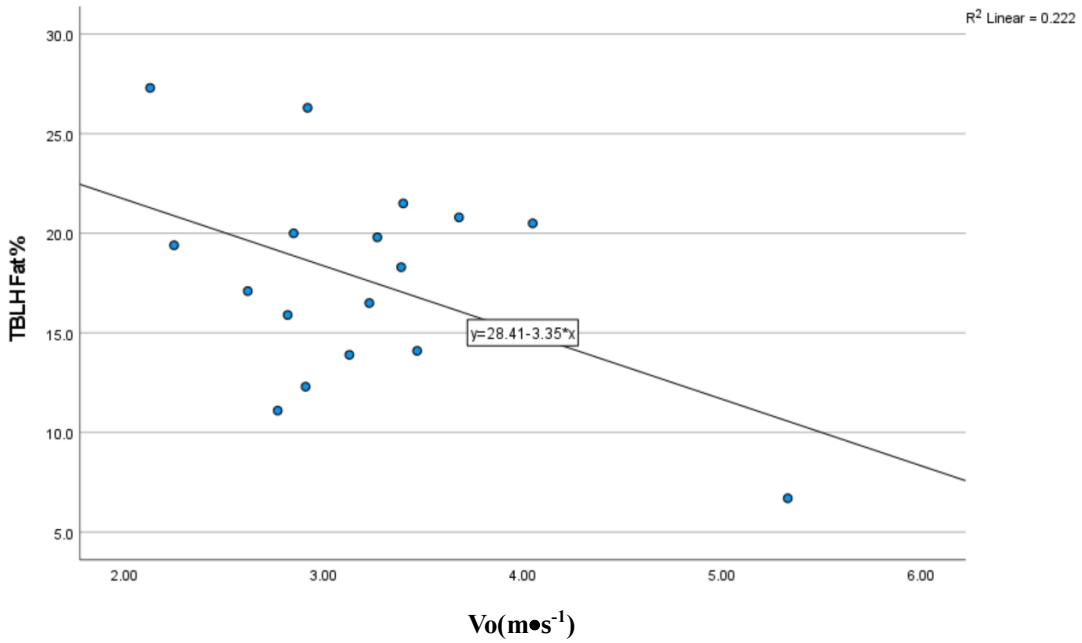



**Figure 8C. Association between theoretical maximal velocity produced (Vo) and TBLH body fat %**

### *4.1.3 Squat jump height under various loading conditions (1kg, 20kg, 40kg, 60kg) and theoretical maximal force-velocity curves*

Table 6 highlights the various mean squat jump heights of all players under various loading conditions and Figure 9 represents the mechanical constraints imposed by the lower extremities' capabilities during the squat jump under various loading conditions. In figure 9, the mean jump height was taken from the four squat jumps of each player (1kg, 20kg, 40kg, 60kg), the orange dashed line (exponential) represents the theoretical maximal velocity ($m \bullet s^{-1}$) of the players and the blue dashed line (polynomial) represents the theoretical maximal force (N/kg**)** of the players. A small association and inverse relationship between theoretical maximal force ($R^2 = 0.2845$), theoretical maximal velocity ($R^2 = 0.2227$) and mean squat jump height can be seen (Figure 9). Displayed in Table 6 and Figure 9, the height of the squat jump becomes smaller due to the increased external load, thus a necessity for greater force is then required to move the greater external load. Furthermore, the velocity increases when the height of the squat jump increases as the load is lighter, so the muscle movement speed is quicker, and a reduced amount of force can be generated.

**Table 6. Mean squat jump heights of all players under various loading conditions.**

| Variables | (Mean ± SD) |
|---|---|
| **Squat Jump height 1kg (m)** | 0.405 ± 0.052 |
| **Squat Jump height 20kg (m)** | 0.328 ± 0.046 |
| **Squat Jump height 40kg (m)** | 0.262 ± 0.046 |
| **Squat Jump height 60kg (m)** | 0.207 ± 0.036 |

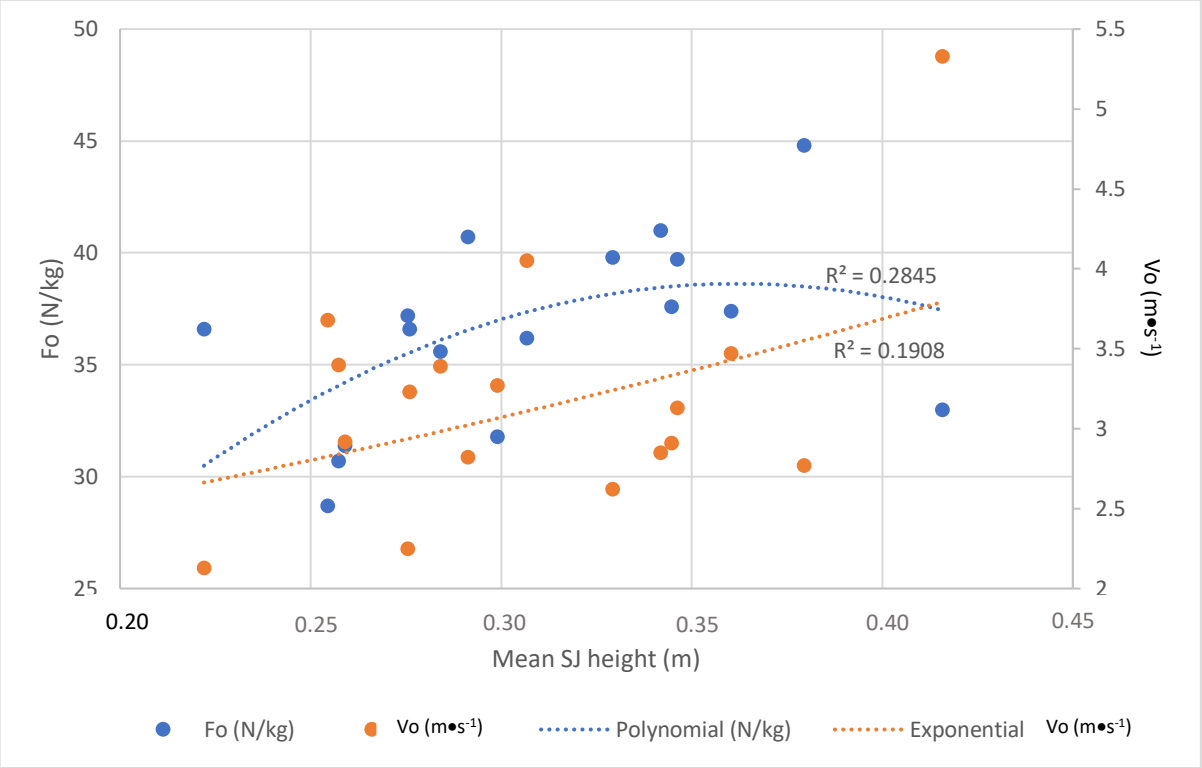



**Figure 9. Theoretical maximal force-velocity curves (Fo and Vo) derived from the mean squat jump heights of each player across various loading conditions (1kg, 20kg, 40kg, 60kg)**

### *4.1.4 Associations between body composition and squat jump height under various loading conditions (1k, 20kg, 40kg, 60kg)*

Singular linear regression analysis was then carried out on the predicting variables: TBLH lean mass (kg), legs lean mass (kg), TBLH body fat %, TBLH fat mass (kg), TBLH mass (kg), theoretical maximal force (N/kg**)** and theoretical maximal velocity ($m \bullet s^{-1}$). They were analysed against the dependant variables squat jump 1kg (Table 7A), squat jump 20kg (Table 7B), squat jump 40kg (Table 7C) and squat jump 60kg (Table 7D). TBLH lean mass (kg), legs lean mass (kg), TBLH mass (kg), theoretical maximal force (N/kg) and theoretical maximal velocity ($m \bullet s^{-1}$) were not seen to be statistically significant for all squat jump loading conditions. TBLH body fat % showed a significant association for jump height performance during the squat jump 20kg (adjusted $r^2 = 0.238$, $f = 6.002$, $p = 0.027$) and squat jump 40kg performance (adjusted $r^2 = 0.207$, $f = 5.166$, $p = 0.038$). These results clearly indicate that there is a direct association of TBLH body fat %. Furthermore, the adjusted $R^2$ for TBLH body fat % during the squat jump 20kg and squat jump 40kg was 0.238 and 0.207 respectively. This depicts that the TBLH body fat % model explains 23.8% and 20.7% of the variance in squat jump height 20kg and squat jump height 40kg.

Singular linear regression analysis was also undertaken on TBLH fat mass (kg) and the dependant variables squat jump 1kg (Table 7A), squat jump 20kg (Table 7B), squat jump 40kg (Table 7C) and squat jump 60kg (Table 7D). TBLH fat mass (kg) significantly predicted jump height for squat jump 1kg ($r^2 = 0.431$, $f = 13.118$, $p = 0.003$), squat jump 20kg ($r^2 = 0.292$ $f = 7.595$, $p = 0.015$) and squat jump 40kg ($r^2 = 0.212$, $f = 5.294$, $p = 0.036$), which indicates that TBLH fat mass (kg) can play a significant part in the shaping of squat jump performance. Moreover, the adjusted $R^2$ for TBLH fat mass (kg) during squat jump height 1kg, squat jump height 20kg and squat jump height 40kg was 0.431, 0.292 and 0.212, respectively. Thus, the model illustrates that there is a 43.1%, 29.2% and 21.2% variance in

jump height for the squat jump 1kg, squat jump 20kg and squat jump 40kg because of TBLH fat mass (kg).

**Table 7A. Singular linear regression analysis between players' independent body composition variables and squat jump height 1kg.**

| Regression Weights | | Beta Coefficient | Adjusted $R^2$ | *F* | *T* | *P* | 95% CI |
|---|---|---|---|---|---|---|---|
| **Squat Jump 1kg** | **TBLH lean mass (kg)** | -0.001 | 0.049 | 0.250 | -0.500 | 0.624 | -0.004 to 0.003 |
| | **Legs lean mass (kg)** | -0.004 | 0.009 | 1.137 | -1.067 | 0.303 | <0.001 to <0.001 |
| | **TBLH body fat %** | -0.006 | 0.328 | 8.808 | -2.968 | 0.100 | -0.010 to -0.002 |
| | **TBLH fat mass (kg)** | -0.006 | 0.431 | 13.118 | -3.622 | 0.003* | <0.001 to <0.001 |
| | **TBLH mass (kg)** | -0.002 | 0.172 | 4.312 | -2.077 | 0.055 | -0.005 to <0.001 |
| | **Theoretical maximal force (N/kg)** | 0.004 | 0.330 | 1.546 | 1.243 | 0.233 | -0.003 to 0.010 |
| | **Theoretical maximal velocity ($m \bullet s^{-1}$)** | 0.190 | 0.014 | 1.220 | 1.105 | 0.287 | -0.180 to 0.057 |

*Correlation is significant at the 0.05 level (2-tailed).

**Table 7B. Singular linear regression analysis between players' independent variables and squat jump height 20kg.**

| Regression Weights | | Beta Coefficient | Adjusted $R^2$ | *F* | *T* | *P* | 95% CI |
|---|---|---|---|---|---|---|---|
| **Squat Jump 20kg** | **TBLH lean mass (kg)** | <0.001 | -0.063 | 0.046 | -0.215 | 0.833 | <0.001 to <0.001 |
| | **Legs lean mass (kg)** | -0.002 | -0.039 | 0.395 | 4.538 | 0.539 | <0.001 to <0.001 |
| | **TBLH body fat %** | -0.005 | 0.238 | 6.002 | -2.450 | 0.027* | -0.009 to -0.001 |
| | **TBLH fat mass (kg)** | -0.005 | 0.292 | 13.118 | -2.756 | 0.015* | <0.001 to <0.001 |
| | **TBLH mass (kg)** | -0.002 | 0.070 | 2.204 | -1.485 | 0.158 | -0.004 to 0.001 |
| | **Theoretical maximal force (N/kg)** | 0.004 | 0.137 | 2.388 | 1.545 | 0.143 | 0.143 to -0.002 |
| | **Theoretical maximal velocity ($m \bullet s^{-1}$)** | 0.006 | -0.058 | 0.128 | 0.358 | 0.725 | -0.029 to 0.400 |

*Correlation is significant at the 0.05 level (2-tailed).

**Table 7C. Singular linear regression analysis between players' independent variables and squat jump height 40kg.**

| Regression Weights | | Beta Coefficient | Adjusted $R^2$ | *F* | *T* | *P* | 95% CI |
|---|---|---|---|---|---|---|---|
| **Squat Jump 40kg** | **TBLH lean mass (kg)** | <0.001 | -0.065 | 0.027 | 0.165 | 0.871 | <0.001 to <0.001 |
| | **Legs lean mass (kg)** | <-0.001 | -0.063 | 0.056 | -0.237 | 0.816 | <0.001 to <0.001 |
| | **TBLH body fat %** | -0.004 | 0.207 | 5.166 | -2.273 | 0.038* | -0.009 to <0.001 |
| | **TBLH fat mass (kg)** | <-0.001 | 0.212 | 5.294 | -2.301 | 0.036* | <0.001 to <0.001 |
| | **TBLH mass (kg)** | <-0.001 | -0.005 | 0.926 | -0.962 | 0.351 | -0.003 to 0.001 |
| | **Theoretical maximal force (N/kg)** | 0.005 | 0.161 | 4.076 | 2.019 | 0.062 | <0.001 to 0.010 |
| | **Theoretical maximal velocity ($m \bullet s^{-1}$)** | -0.002 | -0.065 | 0.021 | -0.144 | 0.887 | -0.037 to 0.032 |

*Correlation is significant at the 0.05 level (2-tailed).

**Table 7D. Singular linear regression analysis between players' independent variables and squat jump height 60kg.**

| Regression Weights | | Beta Coefficient | Adjusted $R^2$ | *F* | *T* | *P* | 95% CI |
|---|---|---|---|---|---|---|---|
| **Squat Jump 60kg** | **TBLH lean mass (kg)** | <0.001 | -0.066 | 0.004 | 2.637 | 0.948 | -0.003 to 0.003 |
| | **Legs lean mass (kg)** | -0.001 | -0.061 | 0.080 | -0.284 | 0.781 | -0.006 to 0.005 |
| | **TBLH body fat %** | -0.003 | 0.146 | 3.736 | -1.933 | 0.072 | -0.006 to 0.000 |
| | **TBLH fat mass (kg)** | -0.003 | 0.147 | 3.763 | -1.940 | 0.071 | -0.008 to -0.001 |
| | **TBLH mass (kg)** | -0.001 | -0.012 | 0.817 | -0.904 | 0.380 | -0.003 to 0.001 |
| | **Theoretical maximal force (N/kg)** | 0.004 | 0.140 | 3.598 | 1.897 | 0.077 | <0.001 to 0.008 |
| | **Theoretical maximal velocity ($m \bullet s^{-1}$)** | -0.005 | -0.053 | 0.190 | -0.436 | 0.669 | -0.032 to 0.021 |

*Correlation is significant at the 0.05 level (2-tailed).

## 5.0 Discussion

This study examined the association of DXA-derived body composition components and jump mechanical performance. Supporting earlier research, analyses conducted in the present study concluded that TBLH body fat % was seen to be statistically significant and had a direct association on countermovement jump 1kg, squat jump 1kg, squat jump 20kg and squat jump 40kg. TBLH fat mass was also seen to be statistically significant and had a direct correlation with the countermovement jump 1kg, squat jump 1kg, squat jump 20kg, squat jump 40kg and theoretical maximal velocity. However, TBLH lean mass, leg lean mass, TBLH mass, theoretical maximal force and theoretical maximal velocity had no statistically significant association with countermovement jump height 1kg or any of the squat jump heights with external loading conditions (1kg, 20kg, 40kg, 60kg).

### *5.1 The association of fat mass variables on countermovement jump and squat jump performance*

Research has reported similar findings to the present study, as body fat mass and body fat % were seen to be inversely linked to countermovement jump performance (Gabbett, 2000; Slinde *et al* 2008; Till *et al,* 2010; Rodríguez-Juan *et al,* 2014). The negative correlation between jump height, TBLH fat mass and TBLH body fat % may be explained because of a potential increase in thermoregulation demands and decrease in power-to-body-mass ratio (Gabbett *et al,* 2008). Players with excess body fat mass may be more likely to have increased levels of thermogenesis as the excess body fat mass will produce heat as a by-product of energy metabolism, which in turn, may decrease jump height due to the increased demands that are placed on the body. Given that strength is the maximum amount of force generated by a muscle at a certain speed and power is the result of velocity (speed) and force

(strength), excess body fat mass could impede muscle activation (Knuttgen and Kraemer, 1987; Moore *et al*, 2020). Furthermore, from the viewpoint of energy supply and demand, energy required from fat mass thermogenesis is backed by fatty acids oxidation and glucose, which suggests that thermogenesis may be an 'energy waste' when it comes to performing exercises due to the working skeletal muscles having to compete with the fat tissue (Zhu *et al*, 2022). It is plausible that the human body may down-regulate the amount of energy provided to the muscles, as more energy substrates and blood are split to fat tissue instead of skeletal muscle, resulting in a negative effect on performance (Zhu *et al*, 2022).

Although, previous research looking at how thermogenesis effects exercise may not be accurate. Many of the studies conducted on thermogenesis involve temperatures around 20$^{o}$C - 22$^{o}$C, which is approximately the thermoneutral zone for clothed human living conditions, however, most of the studies involve mice with their thermoneutral zones sitting around 30$^{o}$C (Cannon and Nedergaard, 2011; Maloney *et al*, 2014). This results in mice being placed under stress due to the thermal conditions, which may have a substantial impact on the physiological activity and thermogenesis within the study (Castillo *et al*, 2011; Qiu *et al*, 2014). Thus, prior studies may not be able to reliably replicate the physiological changes within humans during exercise, who live at their normal thermoneutral zone. There is currently a lack of literature on the effects of thermogenesis on rugby players' performances, especially in the context of ballistic movements. Future research should monitor the room temperature of male rugby players during ballistic movements and analyse body fat mass using DXA scans, or magnetic resonance imaging if available, so standardised comparable human data can be formed, which will allow for the effect of how much thermogenesis impacts performance to be quantified.

Fat mass and body fat % have previously been reported to lead to attenuated calcium signalling and non-optimal muscle shortening, which may influence how much muscle force is produced (Rahemi *et al*, 2015; Tallis *et al*, 2018). Furthermore, the negative association between vertical jump ability and fat mass appears to come from fat not being a contractile tissue, thus it results in a greater load needing to be moved against gravity (Ferreira *et al*, 2010). The different fiber types (type 1, type 2a, type 2d/x and type 2b) contain various isoforms of protein that are a part of relaxation coupling and muscle excitation-contraction (Tallis *et al*, 2018). Fiber types may also differentiate in sarco-endoplasmic reticulum ATPase isoforms, which help re-sequestration occur with calcium back into the sarcoplasmic reticulum to aid relaxation (Gunderson, 2011). This differentiation causes variations in contractile and metabolic function (Berchtold *et al*, 2000). It has also been reported that type 1 fibres have a larger glucose uptake and insulin sensitivity through GLUT4, the glucose transporter, in comparison to fast twitch fibres (Bassel-Duby and Olson, 2006). This suggests that the expression of fiber types is influenced by contractile and metabolic traits of the muscle (Gunderson, 2011; Wyckelsma *et al*, 2017). Additionally, alterations in contractile ability as a result of increased body fat mass or increased body fat % changes, may be related to deviations in troponin isoforms that are involved in facilitating cross-bridge cycling, neuromuscular recruitment, calcium handling and a decrease in myogenesis from muscle satellite cell activation being distorted (Yoshida *et al*, 2012; D'Souza *et al*, 2015; Eshima *et al*, 2017). However, these reactions to increases in body fat mass and body fat % are not necessarily consistent within all muscle groups and experimentally reputable associations between measures and mechanisms of contractility are equivocal in male rugby union players (Tallis *et al*, 2018). Thus, future research needs to assess the association of excess body fat mass on skeletal muscle contractility and how it effects vertical jump performance.

Similarly to the countermovement jump, body fat mass was shown to have a negative association with performance and there was seen to be a strong negative correlation between TBLH fat mass, TBLH body fat % and squat jump height (squat jump height 1kg, squat jump height 20kg, squat jump height 40kg) (Jones *et al*, 2016; Fontana *et al*, 2017; Pasin *et al*, 2017; Brazier *et al*, 2020). This negative relationship was expected again due to the non-force producing nature of fat tissue (Caia *et al*, 2016). Pasin *et al* (2017) analysed the body fat % of 21 elite male rugby players from the Italian Major Rugby League and how it impacted their performance. The results agreed with the present study as they showed a moderate correlation (r= 0.43) between body fat mass and squat jump score. Jones *et al* (2019) also analysed 60 male rugby players who played at various levels of competition (English Premiership and regional leagues) and results showed that body fat mass was negatively correlated with squat jump performance (r= -0.634, p= <0.001). Relatedly to the countermovement jump, this suggests that there may be a lower muscle activation capability with increases of body fat mass, which could cause a decrease in muscle fibre recruitment, resulting in decreased net force generation. In alignment with this theory, Maffiuletti *et al* (2007) previously reported that individuals who were overweight, even with a larger fat-free mass, had lower muscle torques in their quadriceps. Therefore, the greater the individuals' TBLH fat mass and TBLH body fat %, may impede the performance of larger individuals, regardless of the amount of fat-free mass they hold.

Another key factor when it comes to muscle performance and body composition is muscle morphology. Fat tissue has been associated with a larger adipose infiltration of the skeletal muscles, which means players may experience a diminished capacity for power and force production, leading to a low quality of muscle and poor performance (Manini *et al*, 2007; Tuttle *et al*, 2012). Fatty infiltration is where fat cells are located under the perimysium

(amongst muscle fibres) and epimysium (amongst bundles of muscle fibres) (Pagano *et al*, 2018). Supporting this, Yoshida *et al* (2012) reported a moderate negative correlation (r= -0.511, p= 0.005) for reduced activation of the quadricep muscles in older adults with greater amounts of adipose infiltration. It seems that adipose infiltration may not only affect the muscles' ability to generate force but also impede the development of muscle quality that strength and conditioning programmes can help achieve (Addison *et al*, 2014). As the players within the present study have high BMIs, adipose infiltration would be expected to be high (Gallagher *et al*, 2005). Furthermore, as adipose infiltration is between muscle fibres, it is possible that adipose infiltration may interact with muscle fibres through a yet unidentified pathway leading to increased risk of injury and muscle dysfunction, which will inevitably affect jump height and overall performance (Manini *et al*, 2007; Beasley *et al*, 2009). Even though all of the players exhibited relatively average TBLH fat mass and TBLH body fat % scores for male rugby union players, it was not possible to examine adipose infiltration using DXA. Future research should examine the interplay between muscle performance and adipose tissue infiltration in young rugby union players to determine the correlation between muscle shortening and jump height.

The distribution of fat mass throughout the body can also play a pivotal role on how high a player may be able to jump. The players in the study held 18.18% ± 6.45% fat mass in their trunk and 18.15% ± 4.35% in their lower body, which may have been a contributing factor to why their squat jumps were not as high. Thus, it may be more challenging for them to produce greater amounts of power due to having more body fat mass potentially acting as a counterbalance. Supporting this, Acar and Eler (2019) reported that trunk fat % and body fat % were negatively correlated with vertical jump performance.

It is well known that a concentric action can produce greater amounts of peak torque when the movement is preceded by an eccentric contraction (Komi, 2000). Consequently, as the squat jump is commenced from a still position with knee joint flexion at 90°, this eliminates the need for elastic energy to be stored in tendons and muscles as well as the reflex mechanism (Mackala *et al*, 2013). This may considerably affect the activation of the muscles specifically during the concentric part of the squat jump if the player has an excess amount of body fat mass. Interestingly, research has been conflicted with populations of heavier individuals, as it has been suggested that visceral fat mass is linked to an increase in neural drive and excess body fat mass has been linked to a decrease in neural drive (decreased agonist activation capacity) (Tomlinson *et al*, 2014; Moore *et al*, 2020). Although visceral fat was not examined in the present study, future studies should assess the interplay of muscle performance and visceral fat in heavier populations, such as male rugby players, as many significant questions remain between the interactions of visceral adiposity and jump performance.

### *5.1.1 The association of lean mass variables on countermovement jump and squat jump performance*

The present study failed to identify any statistically significant association between TBLH lean mass, legs lean mass, countermovement jump height 1kg and squat jump height (1kg, 20kg, 40kg, 60kg). In contrast to the present study, statistically significant correlations have been reported between lean mass, legs lean mass, countermovement jump height and squat jump height (Colyer *et al*, 2016; Jones *et al*, 2016; Pasin *et al*, 2017; Jones *et al*, 2019; Nunes *et al*, 2020). A determining factor in a player's strength capacity is their muscle cross-sectional area. This represents the combination of the total number and size of efficient units

located within the muscle that aid in supporting endpoint strength and contraction of the muscle (Zamparo *et al*, 2002). Muscular strength and force are also a complex combination of various morphological characteristics of the muscle as well as cross sectional area (Brechue and Abe, 2002). Theoretically, the tension of a muscle is controlled by the force of the muscle per physiological cross-sectional area (Akagi *et al*, 2009). Castro *et al* (1995) and Ikegawa *et al* (2008) reported significantly higher force-to-cross-sectional area ratio in trained male and female athletes, whereas Maughan (1983) and Alway *et al* (1990) found no significant differences between cross-sectional area in trained and untrained male and female athletes. These equivocal results and conflicting research have resulted in an uncertainty as to whether greater peak force can be solely attributed to a greater cross-sectional area (Jones *et al*, 2008). Therefore, when considering the physiological cross-sectional area of a muscle, it is important to understand the cross-sectional area is made up of the muscle volume, fibre pennation angle and muscle length, which all help to make up the total muscle (Ikegawa *et al* 2008). This means that cross-sectional area may not fully explain this potential relationship.

Other sports such as football have seen moderate to strong correlations between lean mass and squat jump height in male athletes (Silvestre *et al*, 2006; Molina-López *et al*, 2020; Ishida *et al*, 2021). Specifically, there has been a lack of research surrounding body composition and the squat jump in male rugby players and this is one of the first studies to examine this. It is interesting to validate that in the current study, the correlation of TBLH lean mass and legs lean mass were not statistically significant with any of the squat jump loading conditions or countermovement jump 1kg, which gives the conclusion that leaner rugby players do not inevitably have a greater countermovement jump or squat jump ability. The current results for TBLH lean mass and legs lean mass were surprising because it would have been anticipated that a greater amount of lean tissue should allow for greater force and

explosive power. However, the current findings show that as there is only a small amount of variance within the population. Future research with a larger sample size is warranted to remove any potential sample bias or skew in the relationship.

It could be postulated that the reason for the players in the present study only demonstrating a negative association with TBLH fat mass and TBLH body fat %, and no association between countermovement jump height and TBLH lean mass, is because they can utilise the amount of TBLH lean mass they currently have. There have been numerous studies that have stated the association between muscle cross-sectional area and force production (Maughan *et al*, 1983; Bruce *et al*, 1997; Wong *et al*, 2016; Suchomel and Stone, 2017). As these players are highly trained sub-elite athletes, they already have a well-established foundation of TBLH lean muscle mass (68.57kg ± 8.33kg) and leg lean mass (25.12kg ± 3.55kg) in comparison to their TBLH mass (87.80kg ± 10.82kg), so the accrual of significant amounts of body fat mass may be more detrimental to their performance due to the power-to-body mass ratio decreasing (Colyer *et al*, 2016). Furthermore, earlier findings have shown that as a result of greater amounts of lean mass, they may be able to recruit more fast twitch muscle fibres (type 2a and type 2b) to aid them in achieving a greater countermovement jump height and improved overall performance (Yamauchi and Ishii, 2007; Waller *et al*, 2013). However, the relative contributions of these factors (cross sectional area, muscle length, type 1 and type 2 fibres and fibre pennation angle) can only be speculated as they were unable to be collected during this study. This suggests that future research needs to investigate these factors further to understand their influence on countermovement jump height, muscle force and velocity.

### *5.1.2 The association of body composition variables, theoretical maximal force and theoretical maximal velocity*

It was hypothesized that body composition may be related to the theoretical maximal force and theoretical maximal velocity profiles of male rugby players. However, there were no statistically significant associations for TBLH fat mass, TBLH body fat % and theoretical maximal force in the current study. Furthermore, TBLH fat mass was seen to be moderately negatively correlated to theoretical maximal velocity and TBLH body fat % was seen to not be statistically significant. Even though there was no statistical significance between TBLH fat mass, TBLH body fat % and theoretical maximal force, there were still trends for moderate negative correlations. Earlier research involving male rugby players has indicated that body fat % and fat mass may have a negative association on the jump velocity and force of rugby players (Bell *et al,* 2012; Jones *et al*, 2016; Jones *et al,* 2019; Nunes *et al*, 2020; Yao *et al*, 2021. Bell *et al* (2012) researched ACTN3 genotypes and body composition in 102 university male rugby union players and how they affected velocity in the countermovement jump. The ACTN3 gene is associated with both speed and power phenotypes in muscles (Pickering and Kiely, 2017). ACTN3 genotypes are constrained largely to type 2b fast twitch muscle fibres, where they enable the generation of glycolytic energy production at fast velocities, which help contribute to speed and power (Bell *et al*, 2012). Results showed that body fat mass (kg) and body fat % negatively affected velocity for all genotypes. Power output was also negatively affected by body fat mass and body fat % for all genotypes.

Power output is a variable that is strongly associated with the production of maximal force in the eccentric and concentric phases of a jump. Jones *et al* (2019) found that male rugby players with a greater body fat mass had a lower squat jump height because they were not able to produce enough relative peak velocity ($r= -0.690$, $p= 0.002$) and relative peak force

(r= -0.437, p= 0.002). Another study by Nunes *et al* (2020) analysed 22 professional male rugby players using DXA and concluded that body fat mass had a very large negative correlation with countermovement jump height (r= -0.65, p= 0.007) and peak power output (r= -0.63, p= 0.010). However, even though power seems to be associated with properties of the nervous system and has elastic elements contributing to it, there appears to be a need for research to explore why there is a neutral and heterogenous component to power when it comes to certain sports, such as rugby (Laffaye *et al,* 2014; Claudino *et al,* 2017). Supporting this, de Campos *et al* (2019) reported that professional male rugby players had a lower jump height in comparison to football and mixed martial arts fighters, despite having a greater landing and push off force. Most of the physical and resistance training that rugby players complete involves exercises that demand maximal strength, which may have resulted in the focus of increasing force and power through sports-specific strategies. Woods *et al* (2015) reported that low skilled male rugby players showed lower power outputs when compared to higher skilled male rugby players and this difference was due to jump velocity, not force.

The inefficient ability to generate power may not only be attributed to greater TBLH fat mass and TBLH body fat %, but it may be associated with the nature of training within the sport causing alterations in performance metrics. Research has indicated that mechanical alterations provided by the movement patterns and exercises of rugby players may impact sports performance, which would undoubtedly decrease jump height, increase energy expenditure and decrease mechanical efficiency (McBride and Snyder, 2012; De Lacey *et al,* 2014). The two crucial mechanical alterations that occur as a result of rugby training are related to the stretch shortening cycle. They are changes in the muscle pre-activation before the exercise is performed and the braking and push-off components of the functional phase of the movement during the ground contact for the leg extensor muscles (Turner *et al,* 2010).

Much more work is still needed to understand these relationships. Future studies should assess the association of the stretch-shortening cycle and body composition on jump performance in male rugby union players, as they are closely related.

Additionally, the results in the current study, alongside previous literature, indicate that male rugby players should incorporate exercises that focus on generating maximal velocity during explosive movements in strength and conditioning sessions, as it may have a marginally greater influence on their overall countermovement jump height. This justifies the importance of players' force-velocity profiles to be analysed, so players can have tailored training programmes to aid them in transitioning from sub-elite athletes to elite athletes. Future studies should aim to look at players' body compositions and force-velocity profiles at different time points over the course of a season, so training plans can be adjusted accordingly to help players continue competing at an optimal level.

### *5.1.3 Body composition and determinants of rugby performance*

TBLH mass was not seen to be statistically significant for the squat jump 1kg, however, there was a small trend for a low to moderate correlation (r= -0.473, p= 0.055, 95% CI= -0.777 - 0.10) and similar findings were reported when singular linear regression analysis was performed (adjusted $R^2$ = 0.172, p = 0.055, 95% CI= -0.005 - <0.001). This suggests that the overall mass of a player may have an association with how high a player can jump vertically during the squat jump, and this has been displayed in previous research (Mitchell *et al*, 2016; Pasin *et al*, 2017; Brazier *et al*, 2020; Posthumus *et al*, 2020). Additionally, even though a greater overall body mass may negatively impact vertical jump height, this does not mean it is not advantageous when performing in other areas of rugby. A greater mass with moderate

levels of body fat mass have been previously reported to provide protection against incoming tackles and injuries, by providing a protective barrier to aid in dealing with the force transferred (Norton, 1996; Brazier *et al*, 2020). Having additional body mass (especially lean mass) may also increase force and power generation, which has the ability to improve the likelihood of players winning tackles, mauls, rucks and scrums (Gabbett *et al*, 2011; Fuller *et al*, 2013). This can be further supported by the success of teams performing in the Rugby World cups between 1987-2007, as the mass of forwards remains to be a key determinant for a team's success (Sedeaud *et al*, 2012). However, it must be taken with caution, that excess body mass primarily made up of fat tissue could impede power-to-body mass ratios and reduce acceleration, resulting in a decreased tackling ability (Gabbett, 2000; Gabbett *et al*, 2008). Ultimately, a greater body mass will have to be carried during the entirety of a game over the total distance travelled, causing an increase in energy expenditure, increase in thermoregulatory stress and decreased aerobic capacity (Gabbett *et al*, 2008; Fuller *et al*, 2013). Nevertheless, there were no statistically significant findings between TBLH mass in the current study for any of the performance measures (theoretical maximal force, theoretical maximal velocity and jump height), but future research should aim to examine the impact between a player's body mass, energy expenditure, distance travelled, and force generated in the horizontal plain.

The players in the present study appeared to display large amounts of TBLH lean mass (68.57kg ± 8.33kg) in comparison to overall TBLH mass (87.80kg ± 10.82kg). Furthermore, the analysis of the results revealed a similar trend throughout, whereby TBLH body fat % and TBLH fat mass (kg) had a greater association with negatively impacting the performance measures compared to lean mass variables. These results would suggest that it is advantageous for players to maintain a body mass that is favourable towards maintaining a

greater amount of lean mass to aid in the production of muscular power (Duthie *et al*, 2006; Posthumus *et al*, 2020). Although the potential benefits of increased body fat mass and tackle force absorption have been reported (Brazier *et al*, 2020), excess body fat mass has also been correlated to a poorer tackling ability in senior male rugby players (Gabbett *et al*, 2010; Gabbett *et al*, 2011). These conflicting equivocal findings, display that it may be difficult to find the 'ideal' or 'optimal' amount of lean body mass and body fat mass, as different positions may necessitate different demands. An example of this can be seen through some forwards being used for the sole purpose of taking impact, whereas other positions may be expected to play for greater periods of time, so they are unable to hold the same amount of body mass (Waldron *et al*, 2013). It could be argued that rugby union players may not necessarily exhibit homogeneous body composition profiles and anthropometric profiles across differing positions unlike other team sports, such as football (Iga *et al*, 2014). This suggests that future research should take a multifaceted approach when looking at the key determinants of performance in male rugby union players as body composition needs to be assessed alongside numerous important performance indicators to allow for a holistic overview on what contributes to a player's optimal performance.

### *5.1.4 Squat jump height under various loading conditions –singular linear regression analysis*

The findings from the singular linear regression analysis indicate that TBLH fat mass and TBLH body fat % explained more of the variance in results when compared to TBLH lean mass and legs lean mass. Furthermore, as the loading conditions increased for the squat jumps, theoretical maximal force became increasingly more statistically significant in changing squat jump height, which could be due to the excess mass being made up of

primarily body fat mass, meaning less force could be generated. Pasin *et al* (2017) supported this idea, as they noted that lean mass was largely correlated to bodyweight squat jump height and 70kg jump squat jump height. Fat mass also had a moderate negative correlation to bodyweight jump squat height and 70kg jump squat height. Jones *et al* (2019) reported similar findings, as elite male back players had greater squat jump heights and greater relative peak force when lower skinfolds (sum of 8 sites) were observed in comparison to forwards who had higher skinfolds (sum of 8 site) and lower squat jump heights.

As the loading conditions of a squat jump increase, the acceleration of mass decreases (McBride *et al* ,2002). The shape of the force-time, velocity-time and power-time curve may include marked declines in gradient of the curves, which causes a decrease in peak velocity, force and power of the players' jump. Therefore, in the present study, the amount of variance from TBLH fat mass and TBLH body fat % affecting the differing squat jump loading conditions may be attributed to fat being less metabolically active compared to lean mass, resulting in less power and force being generated (Hargreaves and Spriet, 2020). An unloaded squat jump may cause an increase in firing frequency in the muscle, specific motor unit recruitment and synchronisation of working motor units to a larger degree in contrast to squat jumps with greater loads (Van Cutsem *et al*, 1998; Kyröläinen *et al,* 2005). This is why TBLH fat mass, TBLH body fat % and theoretical maximal force were still showing trends at heavier squat jump loads (Moritani, 1993; Van Cutsem *et al*, 1998; Kyröläinen *et al*, 2005).

In the present study, a small association and inverse relationship between theoretical maximal force ($R^2 = 0.284$), theoretical maximal velocity ($R^2 = 0.2227$) and mean squat jump height can be seen in Figure 9. Furthermore, in Table 6, as the weight of the squat jump increases a decrease in mean jump height can be seen: squat jump height 1kg (0.405m ± 0.519m), squat

jump height 20kg (0.328m ± 0.460m), squat jump height 40kg (0.262m ± 0.460m), squat jump height 60kg (0.207m ± 0.358m). Since the seminal work of Hill (1938), there have been numerous studies analysing the necessity of muscle force upon its velocity and the hyperbolic shape the relationship has during vertical jumps (Vandewalle *et al*, 1987; Samozino *et al*, 2012; Cuk *et al*, 2014; Jiménez-Reyes *et al*, 2018). In alignment with previous findings, the present study shows the polynomial curve of theoretical maximal force decreasing as the jump height increases (external loads decreasing) and the exponential trendline of theoretical maximal velocity increasing (Figure 9). This highlights the inverse relationship that occurs between the force-velocity curves and suggests that there may be a greater demand on the players to produce velocity during squat jumps with a lighter load compared to squat jumps with a heavier load, which may necessitate more force to be produced. It has been hypothesised that the gradient of the velocity curve is higher during vertical jumps with lighter loads due to the increased acceleration of the concentric muscles (Cormie *et al*, 2011). Therefore, it would be expected that the acceleration of mass during squat jumps declines as the load of the squat jumps increases, which can be seen in the present study, supporting previous literature (McBride *et al*, 2002; Cormie *et al*, 2008; Jiménez *et al*, 2014). Future research should explore the effects of velocity decreasing as squat jump loads increase because the stimulus given to the neuromuscular system may result in specific motor unit recruitment, synchronisation of active motor units to a larger degree and improved firing frequency.

Another consideration for future research, is to potentially employ optimal external loads for players performing vertical jumps. A crucial point for determining the load that maximises mechanical force and velocity is whether body mass should be incorporated into the power equation (force x velocity). Currently, there is a lot of scrutiny around the measurement and

calculation of this equation as a result of the numerous methodological differences amongst the research. There appears to be a large scope of literature and data based around a player's one repetition maximum squat strength for determining the optimal external load during the squat jump (10% - 90% of one repetition maximum) (Izquierdo *et al*, 2002; Stone *et al*, 2003; Kawamori and Haff, 2004; Loturco *et al*, 2016). Including body mass would add to the total mass values for calculating force, thus leading to an increase in power values (Smilios *et al*, 2013). This effect would then be greater in the power and velocity outputs with lighter loads because of the increased influence of body mass to the overall mass used in the calculation of force, compared to the power and velocity outputs that would be generated at heavier loads (Dugan *et al*, 2004). Therefore, the force-velocity and load-power relationships will inevitably change, resulting in the load that can aid in maximising mechanical force, velocity and power of the players to also change. Even though the present study did not need to implement relative external loads when calculating the force-velocity profiles of the players, due to the work of Morin and Samozino (2017), future studies may want to include body mass when calculating the theoretical maximal force, theoretical maximal velocity and power curves of players. This is because their mass also has to be accelerated vertically alongside the bar and the neuromuscular system has to augment the suitable amount of force to prevail over the players' body mass, not just the bar mass (Smilios *et al*, 2013).

### *5.1.5 Post activation potentiation and jump performance*

Post activation potentiation increases muscle twitch and tetanic force after a 'conditioning' contractile exercise is performed (Sale, 2002). It has been indicated that a player's ability to demonstrate voluntary post activation potentiation is affected by the intensity, amount of 'conditioning' activity and the amount of rest administered between performing the exercise

and ‘conditioning’ activity (Wilson *et al*, 2013). As the players had already taken part in a warmup and completed numerous squat jumps under different loading conditions, post activation potentiation may have impacted the results. This may have occurred because of the players recruiting more type 2 muscle fibres, and the increased rate of force at greater frequencies are factors that could potentially increase acceleration (Tillin and Bishop, 2009; Arabatzi *et al*, 2014). Thus, velocities reached with loads between the extremities of the maximum shortening cycle and maximum isometric force, would cause the load-velocity relationship to become less concave (Sale, 2002).

As the loading conditions became increasingly heavier TBLH fat mass, TBLH body fat % and theoretical maximal force may have explained the variance in results. Furthermore, excess fat mass has been shown to not contribute to the production of force as much as TBLH lean mass and legs lean mass in the squat jump (Brazier *er al*, 2020). Post activation potentiation may be more elicited in players with a greater amount of type 2 muscle fibres, as suggested by the strong relationship between post activation potentiation magnitude and the amount of type 2 muscle fibres (Hamada *et al*, 2003).

Post activation potentiation has also been reported to have an increase in myosin regulatory light chain phosphorylation in response to ‘conditioning’ activity. This development is most significant in fibres with a larger amount of type 2 myosin heavy chain isoforms (Moore and Stull, 1984; Stull *et al*, 2011). However, this relationship is primarily observed in animal models, and the correlation between post activation potentiation and type 2 myosin heavy chain isoforms has not always been seen in human muscle. This suggests that there is a need for muscle biopsy analysis in future research to establish if post activation potentiation

influences the amount of force lean mass can generate during squat jumps under different loading conditions.

There has also been a large body of literature suggesting that stronger individuals can potentially produce greater voluntary post activation potentiation (Robbins *et* al, 2005; Kilduff *et al*, 2007; Seitz *et al*, 2014; 2015). Stronger individuals generally possess a greater percentage of type 2 muscle fibres, which suggests they are more likely to display a larger increase in myosin light chain phosphorylation after a warmup or 'conditioning' activity has been performed (Aagaard and Andersen, 1998). Given the results of the present study, this sample may be able to generate more force during the squat jump under various loading conditions if they reduce their TBLH fat mass and TBLH body fat %. This finding is important for players as well as researchers, as it suggests that leaner players will be able to generate more force. Training sessions can then be tailored for heavier players with excess body fat mass, focussing on exercises that are force dominant whilst they aim to achieve a more optimal body composition. Future studies can then examine if leaner players' jump height performance will correlate to an overall improved performance.

### *5.1.6 Limitations*

Although this is the first study to look at how body composition impacts jump mechanical performance on male university rugby union players, with a particular interest on theoretical maximal force and theoretical maximal velocity, this study does have its limitations that should be discussed. Firstly, the participant recruitment within the study led to the sample (n=17) being combined instead of being separated into forward players and back players. This may have influenced the results, as there were 11 back players in the study and only 6

forward players. Back players are also generally leaner and have a lighter body mass than forward players, which may have caused variables, such as theoretical maximal velocity, to not impact squat jump height as much as it was hypothesised. Future studies should focus on recruiting a larger sample size with an equal distribution of backs and forwards to get a better understanding of this specific population. This will allow for players to be separated into sub-groups, which means results should not be affected as much by other potentially confounding variables.

Another limitation in the present study is that a longitudinal approach was not implemented. As this study was cross-sectional it only allowed for the players to be observed at one moment in time (start of season). Thus, there was no opportunity to see how performance may change over the course of a season or if a tailored training programme would have any influence on the players' countermovement jump or squat jump performance. For example, if a player was monitored at three time points over the course of a season (preseason, middle of the season and end of season), it would give a better indication as to whether an improvement in body composition (increase in lean mass and decrease in fat mass) allows for players to generate more force and velocity. Furthermore, body composition and performance have been shown to fluctuate over a season, so the time at which a study is conducted may significantly influence the findings (Harley *et al*, 2011; Mitchell *et al*, 2016; Lees *et al*, 2017; Zabaloy *et al*, 2022). As the present study was conducted at the start of a season, players in previous studies have been shown to have less body fat mass at the beginning of a season and are well-rested from the break in competition when compared to players at the end of a season (Harley *et al*, 2011; Lees *et al*, 2017). Therefore, theoretically, data gathered in studies where force production is assessed in the latter stages of a season may be attenuated

as a result of the increases in body fat mass without a subsequent increase in muscle force, resulting in a decrease in acceleration (Duthie, 2006; Higham *et al*, 2014).

The main focus of the study was also to investigate body composition analysis on a whole-body level rather than a regional level. This meant that certain features of body composition (trunk lean mass, visceral fat, bone mineral density, etc…) were not analysed individually. Regional body composition may demonstrate a significant impact on the players' performances in the present study compared to the body composition variables selected. Furthermore, even though other regional body composition variables may not be as closely related to the focus of the study, they can provide pathways for future studies to explore what other factors may affect jump height, theoretical maximal force and theoretical maximal velocity. Incorporating muscle biopsy analysis alongside this would also allow for the influence of post activation potentiation on jump height to be analysed, so it can be determined if it has an influence on the amount of force lean mass can generate during different vertical jumps.

### *5.1.7 Practical applications*

The body composition and jump mechanical performance of university male rugby union players has not been extensively studied. The findings in the present study will help future research expand our knowledge of body composition and the associations that strength, power, force and velocity have on the countermovement jump and squat jump in this specific population. Furthermore, the findings show that TBLH lean mass and legs lean mass are not as influential to a player's countermovement jump and squat jump performance when compared to TBLH fat mass and TBLH body fat %. This suggests that it is advantageous for

players to obtain a leaner physique as fat mass is detrimental to jump performance. However, excess mass appears to negatively affect jump performance, regardless of the excess mass being made up of fat mass or lean mass. These observations are probably due to the lack of force producing capabilities that excess mass, TBLH fat mass and TBLH body fat % have on the countermovement jump and squat jump. The significance of modifying a resistance training programme for players to develop their power and strength by focussing on the force-velocity profile (theoretical maximal force and theoretical maximal velocity) is highlighted within the present study, as theoretical maximal force was seen to cause a variance in the results of squat jump height for heavier loads, however, it may have remained undetected with other forms of assessment.

By individualising training programmes, deficiencies in force or velocity can be addressed by implementing various exercises that incorporate differing intensities, velocities and forces during different phases of a player's training cycle. Therefore, a personalised programme can be produced to signify the performance requirements for each individual player. For example, force-velocity curves give crucial information when it comes to analysing a player's lower body explosive capabilities. Furthermore, the force-velocity slope can help distinguish specific parts of a player's mechanical weaknesses. Velocity-deficient players should, therefore, train at a greater velocity and with a lighter weight, whereas force-deficient players should perform exercises with a heavier load and focus on improving power output (Jiménez-Reyes *et al*, 2017). Nevertheless, this style of training demands progression that is technique-driven to guarantee the exercises are performed with the appropriate velocity and suitable load. Coaches should progress, design, and if required, regress individualised training programmes to meet adaptations caused by training and optimise their players' performances on the pitch. More research is still needed to better understand how to implement force-

velocity training into training programmes over longer periods of time to see what potential positive effects it can have on a player's performance and how this may aid them in progressing from a sub-elite athlete to an elite athlete.

Future studies can use this preliminary data to develop larger investigations to address remaining research questions, such as what other mechanical characteristics may affect countermovement jump height and squat jump height other than body composition, theoretical maximal force and theoretical maximal velocity. Additionally, it is important to examine if an optimal force-velocity profile would be correlated with an improved performance for other maximal effort contexts, such as running or sprint cycling. This would allow for a step towards a greater understanding of force and velocity-based training, so insights can be developed into emerging strength and conditioning practices.

## 6.0 Conclusion

To conclude, the data obtained from the current study revealed that there were statistically significant associations between TBLH fat mass, TBLH fat %, and lower jump heights for the countermovement jump height 1kg and squat jump heights under various loading conditions (1kg, 20kg, 40kg). Furthermore, across the loaded squat jumps it appeared that TBLH fat mass and TBLH fat % had a larger negative association with theoretical maximal force production when compared to theoretical maximal velocity. However, a surprising finding was that TBLH lean mass and legs lean mass was not seen to be statistically significant for any variables. This signifies that players who carry excess mass, regardless of the mass being primarily lean mass, may not necessarily be able to jump higher or produce more force and velocity. The practical application of this work supports players' needs for individualised training programmes to help improve the amount of force and velocity they produce. It also highlights the importance of monitoring players' body compositions, so that they can be adjusted through nutrition strategies and training programmes throughout the season to allow them to play at optimal levels continuously.

## 7.0 Appendices

### A) Challenges of the study

Over the course of my thesis, I faced numerous challenges along the way that I had to overcome. At the beginning of the project, Covid-19 was still causing massive disruption when it came to social distancing and working with large groups of people as the virus was spreading rapidly around Durham. This led to sessions that were organised for data collection with the Durham University rugby team to be cancelled and rearranged constantly which caused the collection of data and interpretation of the results to be delayed enormously. Furthermore, as the season progressed, it caused worry as to whether the study would still be feasible as the schedule of the rugby team became increasingly busier so trying to organise testing sessions between training and games became extremely difficult. Alongside Covid-19, during the first two testing sessions, which later turned into practice sessions, the OptoJump became faulty which caused the data of the participants to not be recorded properly and thus the sessions were not optimal for data collection. This also occurred on the actual day of testing (the data used within this study) so we had to prioritise getting the players who we considered to be most valuable through the countermovement jumps and squat jumps. Unfortunately, this meant the sample size was significantly reduced as it was not possible to get more players through the testing procedure in the allocated time that was given.

As my deadline approached, both my original supervisors also left the university which caused massive amounts of stress and worry. This led to me needing a large extension on my thesis submission as I had not received any feedback or support on my thesis in months so I was unsure at the current quality of my work and thus was not willing to submit my work at a level I did not deem good enough. However, since my new supervisors took over, they filled

me with confidence as they constantly reassured me that I was going in the right direction and provided me with lots of support throughout.

**B)**

## 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: DXA-derived body composition and jump mechanical performance in sub-elite rugby union players**

**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, at the beginning of rugby union season.

**Body Composition Test**
Your body composition will be measured using dual x-ray absorptiometry. This will take less than 20 minutes. You will be asked to lay down on the dual x-ray absorptiometry machine and maintain the position you are told to by one of the researchers. Two x-ray beams of differing energies that differently attenuate bone mass and tissue will travel through your body to provide an estimate of your body composition, you will not feel this.

***Strength and Power Testing***

**Countermovement Jump:**

The countermovement jump is a routinely used test for monitoring neuromuscular status in individual and team sport players. The test provides an objective assessment of explosive lower-body muscular power, neuromuscular fatigue and supercompensation. The countermovement jump can be conducted with or without an arm-swing, however as the arm-swing has been found to improve performance by 10% or more this has been omitted from the test protocol in an attempt to precisely measure the performance output of the lower limbs in isolation. Players performed 3 maximal countermovement jumps under 1 sub-maximal loading condition (1kg). Before each jump, players were told to stand up straight and still within the testing area with their hands placed on a dowel (1kg); this hand position remained the same during the entirety of the movement and the players were told to keep the dowel in high bar back squat position. At this point, players initiated a downwards movement into a squatting position with a knee angle of 90° (this differed between players), followed instantly by a maximal jump in a vertical direction (Figure 4). It was important to let the players choose a self-selected depth when performing the countermovement jump and squat jump as research indicates that trained players will automatically modify their squat depth so they can perform at an optimal level when they are performing movements that involve jumping.

**Squat Jump:**

The players performed 3 maximal squat jumps (the greatest jump was recorded) under 4 different sub-maximal loading conditions (1kg, 20kg, 40kg and 60kg). When instructed to perform the jumps, the players were told to keep constant downwards pressure on the barbell so it did not move from the trapezius whilst the movement was being performed. During testing players were told to squat down to a knee angle of about 90° (this differed between the players self-selected depth), followed by a 2 second pause before being instructed to then perform a maximal jump in a vertical direction. A 5-15 second rest was administered between each jump repetition. An approximate 2-minute rest was implemented after each loading condition due to the time constraints.

**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 dual x-ray absorptiometry 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 a MRes thesis submission 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:**

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

**Supervisor names: Dr Katie Di Sebastiano and Mr Rob Cramb**

**Email: kathleen.di-sebastiano@durham.ac.uk or r.k.cramb@durham.ac.uk**

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

**C)**

## Consent Form

**Project title**: DXA-derived body composition and jump mechanical performance in sub-elite rugby union players
**Researcher(s)**: Mark Christie
**Department:** Sport and Exercise Sciences
**Supervisor name**: Kathleen Di-sebastiano
**Supervisor contact details:** kathleen.di-sebastiano@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. | X |
| 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. | X |
| 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. | X |
| I agree to follow the Covid-secure protocols | X |
| I agree to take part in the above project, including:<br>1. Body Composition Test<br>2. Performance Testing | X |
| I understand that my participation is entirely voluntary and that I am free to withdraw at any time without giving a reason. | X |

Researcher's Signature__ M. C____ Date__12/10/2021_____

(NAME IN BLOCK LETTERS)___MARK CHRISTIE_____

**D)**

## Debriefing Sheet

**Project title: DXA-derived body composition and jump mechanical performance in sub-elite rugby union players.**

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 association this may have with 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 anonymized data will be presented in Master 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:**

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

**E)**

Privacy Notice

Durham University

## PART 1 – GENERIC PRIVACY NOTICE

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

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

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

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

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

**Data Controller**

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

Telephone: (0191 33) 46246 or 46103

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

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

**Data Protection Officer**

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

Jennifer Sewel
University Secretary
Telephone: (0191 33) 46144

E-mail: university.secretary@durham.ac.uk

**Your rights in relation to your personal data**:

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

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

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

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

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

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

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

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

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

- You believe that the data is inaccurate and you want us to restrict processing until we determine whether it is indeed inaccurate

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

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

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

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

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

Telephone: 0303 123 1113

Website: Information Commissioner's Office

**PART 2 – PROJECT-SPECIFIC PRIVACY NOTICE**

**Project Title: DXA-derived body composition and jump mechanical performance in sub-elite rugby union players.**
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 Katie Di-Sebastiano (kathleen.di-sebastiano@durham.ac.uk).

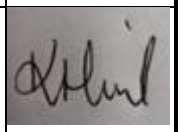
**F)**

# Task/Activity Risk Assessment

| **Description of Task or Activity:** *(to include enough information to establish the foreseeable hazards)* | **Location(s):** *(where will the activity or task take place?)* | **Date:** |
|---|---|---|
| Countermovement jump (athletes will be asked to jump as high as they can whilst keeping their hands on their hips) and squat jump (athletes must squat down, pause for 2 seconds under loaded/unloaded conditions and then jump as high as possible). | Maiden Castle Gym, Durham | 12/10/2021 |
| **Most significant risk(s):** | **Equipment required** *(including PPE, tools, chemicals etc.)* | |
| **Muscle injury** | **Squat rack, Olympic Bench, Olympic barbell, Weights,** | |

| **Those at risk** *(people who could be harmed)* | **How could they be harmed?** *(nature of injuries, damage that could result)* | **Uncontrolled risk level** *(level of risk without control)* | **Required controls** *(how the risk can be removed or reduced by for example engineered methods, safe systems of work, training and/ or personal protective equipment)* | **Controlled risk level** *(level of risk remaining when controls are in place)* |
|---|---|---|---|---|
| **Participants – Trained rugby players** | **- Muscular injury**<br><br>**- Weights falling and hitting an athlete**<br><br>**- Rolling an ankle from the countermovement jump/drop jump** | **Medium** | **A moderate intensity warm-up and dynamic stretching will be completed prior to the test.**<br><br>**All participants are highly trained experienced athletes, familiar with sub maximal and maximal testing, and will be briefed of the protocol before testing starts**<br><br>**Testing will be performed in the gym at Maiden Castle which is approved for this purpose.**<br><br>**An accredited strength and conditioning coach will be supervising testing, ensuring correct and safe technique.**<br><br>**All athletes will be required to wear appropriate footwear and clothing.**<br><br>**There will be a first aider within Maiden Castle if medical attention is needed.** | **Low** |

| | |
|---|---|
| **Internal Guidance/Linked Documents:** | |
| **Competence Requirements:** | |
| **Supervisor/Manager Review and Comment:** | **The exercise tests will be performed by trained athletes, in a supervised setting with S&C qualified practitioner, and in a suitable and safe environment.** |

| **Assessment Prepared by** | | **Supervisor/Manager acceptance** | |
|---|---|---|---|
| Name: | Mark Christie | Name: | Dr Karen Hind |
| Signature: |  | Signature: |  |
| Date: | 11/10/2021 | Date: | 11/10/2021 |
| **This risk assessment should be read by those performing and supervising the work in conjunction with all relevant documentation including method statements and safe systems of work** | | | |

**G)**

## Health and Safety Risk Matrix

| | | | Probability/ likelihood of risk realisation | | | | |
|---|---|---|---|---|---|---|---|
| | | | Almost Impossible (1) | Not Likely to occur (2) | Could occur (3) | Known to occur (4) | Common occurrence (5) |
| | | Health and Safety | A freak combination of factors would be required for risk to be realised | A rare combination of factors would be required for risk to be realised | Could happen when additional factors are present otherwise unlikely to occur | Not certain to happen but an additional factor may result in risk being realised | Almost inevitable that risk will be realised |
| Potential Consequences | Severe (5) | One or more fatalities. Irreversible health problems | 5 | 10 | 15 | 20 | 25 |
| | Major (4) | Partial or medium-term, disabilities or major health problems | 4 | 8 | 12 | 16 | 20 |
| | Moderate (3) | Lost-time injuries or potential medium-term health problems | 3 | 6 | 9 | 12 | 15 |
| | Minor (2) | Minor, very short-term health concerns on recordable injury cases. | 2 | 4 | 6 | 8 | 10 |
| | Insignificant (1) | Inherently safe, unlikely to cause health problems or injuries | 1 | 2 | 3 | 4 | 5 |

| Extreme risk | High risk | Medium risk | Low risk |
|---|---|---|---|

## H) IRAS NHS ethics application: IRAS approval reference number - IRAS Project ID: 308072 and Durham approval reference number: SPORT-2022-05-28T09_56_39-hwhs25

**Welcome to the Integrated Research Application System**

**IRAS Project Filter**

The integrated dataset required for your project will be created from the answers you give to the following questions. The system will generate only those questions and sections which (a) apply to your study type and (b) are required by the bodies reviewing your study. Please ensure you answer all the questions before proceeding with your applications.

Please complete the questions in order. If you change the response to a question, please select 'Save' and review all the questions as your change may have affected subsequent questions.

**Please enter a short title for this project** (maximum 70 characters)
Fatigue and Recovery in Elite and Sub-Elite Rugby Union Players

**1. Is your project research?**

(●) Yes ( ) No

**2. Select one category from the list below:**

( ) Clinical trial of an investigational medicinal product
( ) Combined trial of an investigational medicinal product and an investigational medical device
( ) Clinical investigation or other study of a medical device
( ) Other clinical trial to study a novel intervention or randomised clinical trial to compare interventions in clinical practice
(●) Basic science study involving procedures with human participants
( ) Study administering questionnaires/interviews for quantitative analysis, or using mixed quantitative/qualitative methodology
( ) Study involving qualitative methods only
( ) Study limited to working with human tissue samples (or other human biological samples) and data (specific project only)
( ) Study limited to working with data (specific project only)
( ) Research tissue bank
( ) Research database

**If your work does not fit any of these categories, select the option below:**

( ) Other study

**2a. Will the study involve the use of any medical device without a UKCA/CE UKNI/CE Mark, or a UKCA/CE UKNI/CE marked device which has been modified or will be used outside its intended purposes?**

○ Yes ◉ No

**2b. Please answer the following question(s):**

a) Does the study involve the use of any ionising radiation? ◉ Yes ○ No

• Enter your combined review IRAS ID from the new part of IRAS:

• Does the study involve exposure to radioactive materials? ○ Yes ◉ No

b) Will you be taking new human tissue samples (or other human biological samples)? ○ Yes ◉ No

c) Will you be using existing human tissue samples (or other human biological samples)? ○ Yes ◉ No

d) Will the study involve any other clinical procedures with participants (e.g. MRI, ultrasound, physical examination)? ◉ Yes ○ No

**3. In which countries of the UK will the research sites be located?** *(Tick all that apply)*

☑ England
☐ Scotland
☐ Wales
☐ Northern Ireland

**3a. In which country of the UK will the lead NHS R&D office be located:**

○ England
○ Scotland
○ Wales
○ Northern Ireland
◉ This study does not involve the NHS

**4. Which applications do you require?**

☐ NHS/HSC Research and Development offices
☐ Social Care Research Ethics Committee
☑ Research Ethics CommitteeIonising Radiation for combined review Form
☐ Confidentiality Advisory Group (CAG)
☐ Her Majesty's Prison and Probation Service (HMPPS)

**5. Will any research sites in this study be NHS organisations?**

○ Yes ◉ No

**6. Do you plan to include any participants who are children?**

○ Yes ◉ No

**7. Do you plan at any stage of the project to undertake intrusive research involving adults lacking capacity to consent for themselves?**

○ Yes ◉ No

*Answer Yes if you plan to recruit living participants aged 16 or over who lack capacity, or to retain them in the study following loss of capacity. Intrusive research means any research with the living requiring consent in law. This includes use of identifiable tissue samples or personal information, except where application is being made to the Confidentiality Advisory Group to set aside the common law duty of confidentiality in England and Wales. Please consult the guidance notes for further information on the legal frameworks for research involving adults lacking capacity in the UK.*

**8. Do you plan to include any participants who are prisoners or young offenders in the custody of HM Prison Service or who are offenders supervised by the probation service in England or Wales?**

○ Yes ◉ No

**9. Is the study or any part of it being undertaken as an educational project?**

◉ Yes ○ No

Please describe briefly the involvement of the student(s):
Data from the project will be used in part toward a Doctorate (Lewis Williams)

**9a. Is the project being undertaken in part fulfilment of a PhD or other doctorate?**

◉ Yes ○ No

**10. Will this research be financially supported by the United States Department of Health and Human Services or any of its divisions, agencies or programs?**

○ Yes ◉ No

**11. Will identifiable patient data be accessed outside the care team without prior consent at any stage of the project (including identification of potential participants)?**

○ Yes ◉ No

**Integrated Research Application System**
**Application Form for Basic science study involving procedures with human participants**

NHS
Health Research Authority

## Application to NHS/HSC Research Ethics Committee

The Chief Investigator should complete this form. Guidance on the questions is available wherever you see this symbol displayed. We recommend reading the guidance first. The complete guidance and a glossary are available by selecting Help.

Please define any terms or acronyms that might not be familar to lay reviewers of the application.

**Short title and version number:** (maximum 70 characters - this will be inserted as header on all forms)
Fatigue and Recovery in Elite and Sub-Elite Rugby Union Players

*Please complete these details after you have booked the REC application for review.*

**REC Name:**

**REC Reference Number:** **Submission date:**

## PART A: Core study information

### 1. ADMINISTRATIVE DETAILS

**A1. Full title of the research:**

Global Markers of Fatigue and Recovery in Elite and Sub-Elite Rugby Union Players

**A2-1. Educational projects**

Name and contact details of student(s):

**Student 1**

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Mr | Lewis | Williams |
| Address | Department of Sport & Exercise Sciences | | |
| | Maiden Castle Sports & Wellbeing Park | | |
| | Durham University | | |
| Post Code | DH1 3SE | | |
| E-mail | Lewis.d.williams@durham.ac.uk | | |
| Telephone | | | |
| Fax | | | |

Give details of the educational course or degree for which this research is being undertaken:

Name and level of course/ degree:
PhD

Name of educational establishment:
Durham University

Name and contact details of academic supervisor(s):

**Academic supervisor 1**

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Dr | Karen | Hind |
| Address | Department of Sport & Exercise Sciences | | |
| | Maiden Castle Sports & Wellbeing Park | | |
| | Durham University | | |
| Post Code | DH1 3SE | | |
| E-mail | karen.hind@durham.ac.uk | | |
| Telephone | | | |
| Fax | | | |

**Academic supervisor 2**

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Dr | Shaun | MacLaren |
| Address | Department of Sport & Exercise Sciences | | |
| | Maiden Castle Sports & Wellbeing Park | | |
| | Durham University | | |
| Post Code | DH1 3SE | | |
| E-mail | shaun.maclaren@durham.ac.uk | | |
| Telephone | | | |
| Fax | | | |

**Academic supervisor 3**

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Dr | Katie | Di Sebastiano |
| Address | Department of Sports & Exercise Sciences | | |
| | Maiden Castle Sports & Wellbeing Park | | |
| | Durham University | | |
| Post Code | DH1 3SE | | |
| E-mail | | | |
| Telephone | | | |
| Fax | | | |

Please state which academic supervisor(s) has responsibility for which student(s):
*Please click "Save now" before completing this table. This will ensure that all of the student and academic supervisor details are shown correctly.*

| **Student(s)** | **Academic supervisor(s)** |
|---|---|
| **Student 1** Mr Lewis Williams | ☐ Dr Karen Hind<br>☐ Dr Shaun MacLaren |

☐ Dr Katie Di Sebastiano

*A copy of a current CV for the student and the academic supervisor (maximum 2 pages of A4) must be submitted with the application.*

**A2-2. Who will act as Chief Investigator for this study?**

◉ Student
○ Academic supervisor
○ Other

**A3-1. Chief Investigator:**

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Mr | Lewis | Williams |
| Post | PhD Candidate | | |
| Qualifications | BSc (Hons) | | |
| ORCID ID | 0000 0000 0000 0000 | | |
| Employer | Durham University | | |
| Work Address | Department of Sport & Exercise Sciences | | |
| | Maiden Castle Sports & Wellbeing Park | | |
| | Durham University | | |
| Post Code | DH1 3SE | | |
| Work E-mail | Lewis.d.williams@durham.ac.uk | | |
| * Personal E-mail | Lewis.d.williams@durham.ac.uk | | |
| Work Telephone | 000000000000000 | | |
| * Personal Telephone/Mobile | 07572415893 | | |
| Fax | 000000000000000 | | |

** This information is optional. It will not be placed in the public domain or disclosed to any other third party without prior consent.*
*A copy of a current CV (maximum 2 pages of A4) for the Chief Investigator must be submitted with the application.*

**A4. Who is the contact on behalf of the sponsor for all correspondence relating to applications for this project?**
*This contact will receive copies of all correspondence from REC and HRA/R&D reviewers that is sent to the CI.*

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Mr | Niall | O'Loughlin |
| Address | RIS, Maple Wing, Mountjoy Centre, Stockton Road | | |
| | Durham | | |
| Post Code | DH1 3LE | | |
| E-mail | niall.c.o'loughlin@durham.ac.uk | | |
| Telephone | 01913344623 | | |
| Fax | | | |

**A5-1. Research reference numbers.** *Please give any relevant references for your study:*

| | |
|---|---|
| Applicant's/organisation's own reference number, e.g. R & D (if available): | n/a |
| Sponsor's/protocol number: | n/a |
| Protocol Version: | 1.0 |
| Protocol Date: | 10/12/2021 |
| Funder's reference number (enter the reference number or state not applicable): | n/a |
| Project website: | n/a |

**Registry reference number(s):**
*The UK Policy Framework for Health and Social Care Research sets out the principle of making information about research publicly available. Furthermore: Article 19 of the World Medical Association Declaration of Helsinki adopted in 2008 states that "every clinical trial must be registered on a publicly accessible database before recruitment of the first subject"; and the International Committee of Medical Journal Editors (ICMJE) will consider a clinical trial for publication only if it has been registered in an appropriate registry. Please see guidance for more information.*

International Standard Randomised Controlled Trial Number (ISRCTN):
ClinicalTrials.gov Identifier (NCT number):

**Additional reference number(s):**

| Ref Number Description | Reference Number |
|---|---|

**A5-2. Is this application linked to a previous study or another current application?**

◯ Yes ◉ No

*Please give brief details and reference numbers.*

## 2. OVERVIEW OF THE RESEARCH

***To provide all the information required by review bodies and research information systems, we ask a number of specific questions. This section invites you to give an overview using language comprehensible to lay reviewers and members of the public. Please read the guidance notes for advice on this section.***

**A6-1. Summary of the study.** *Please provide a brief summary of the research (maximum 300 words) using language easily understood by lay reviewers and members of the public. Where the research is reviewed by a REC within the UK Health Departments' Research Ethics Service, this summary will be published on the Health Research Authority (HRA) website following the ethical review. Please refer to the question specific guidance for this question.*

The overall aim of this research is to characterise global player loads in relation to fatigue and recovery responses, in high performance rugby players. Rugby players are exposed to multiple forms of collision which increases the risk of injury and heightened fatigue. Understanding human responses to loading in rugby is integral to the avoidance of burnout in rugby players and to support overall player welfare. Fatigue is a complex and multifaceted phenomenon that has a variety of possible mechanisms and associated recovery responses, not only in matches but also from training. Despite much research on the performance of rugby players, there is a lack of evidence on fatigue. Those studies which have investigated fatigue, are limited in that they have only used measures in isolation, over a short time period and/or with few participants. In addition, no study has included head impact data which give an additional and crucial insight into the global loads sustained by the elite / sub-elite rugby player.

Participants will be rugby players performing at elite or sub-elite level in North East England. Testing will take place at Newcastle Rugby Club, Kingston Park Stadium or Durham University Sports and Wellbeing Park. Players will wear Global Positioning Units and Instrumented Mouthguards during contact training and matches to give a quantification of locomotive activity and impact data. Performance tests, subjective wellness scores, DXA and cognitive tests will provide information about the relationship between load, fatigue and recovery.

**A6-2. Summary of main issues.** *Please summarise the main ethical, legal, or management issues arising from your study*

*and say how you have addressed them.*

*Not all studies raise significant issues. Some studies may have straightforward ethical or other issues that can be identified and managed routinely. Others may present significant issues requiring further consideration by a REC, R&D office or other review body (as appropriate to the issue). Studies that present a minimal risk to participants may raise complex organisational or legal issues. You should try to consider all the types of issues that the different reviewers may need to consider.*

The main ethical considerations for this study are the use of dual energy X-ray absorptiometry (DXA) and the collection, analysis and storage of data from professional and sub-elite rugby players. Covid protocols at the University will be followed at all times and information about precautions is provided in the Participant Information Sheet.

DXA
Each participant will receive a maximum of 5 total body and 2 hip and spine DXA assessments from January 2022 and June 2023 (or when the end of the 2022-23 season occurs).

Total Body: The total body scans are important to investigate changes in visceral fat, subcutaneous fat and lean mass over the duration of the study. Our previous research has found increases in visceral fat and decreases in subcutaneous fat over the season in professional rugby players, which may reflect a change in player loads and increase cardiometabolic risk (McHugh et al., 2021). We have also found reductions in lean mass in professional players over the season (Harley et al., 2009) which may reflect fatigue and overtraining. This current research is important to investigate such changes and explore associations with training and match loads, recovery markers and self reported wellbeing. There will be 5 total body scans (2021-22: mid season and end season; 2022-23: pre season, mid season and end of season). The total body less head scan (TBLH) will be used instead of the total body scan which includes the head. The TBLH scan brings a lower dose of ionising radiation than the standard total body scan due to the exclusion of the head region and reduced scan time.

Hip and Spine Bone Density: The bone density assessments will be included at pre-season and end-season 2022-23 to allow exploration of adaptation of bone strength to physical loading over one season of professional rugby union and associations with body composition changes and skeletal injury. Our research has found that fractures are common injuries in rugby (Hind et al., 2020).

Review and mitigation of risk:
- The total effective dose to each participant for the scans included in this study, has been reviewed and approved by the Medical Physics Expert and the Clinical Radiation Expert.
- The study at present, includes only male rugby players due to our existing network with the local professional club. Should it become possible to recruit female rugby players, we will submit an amendment to this ethics application and this will include the necessary safeguards in place concerning pregnancy and DXA.

DATA
The collection and storage of participant data will be governed by the the GDPR. Data will be stored on the DXA system and a University PC or laptop, all of which are password protected. The DXA imaging suite is locked and the code to enter the suite is only known by the laboratory manager, laboratory technician, security and the research team. Data inputted into electronic spreadsheets will be coded. The DXA data will be stored for 10 years and the anonymised data thereafter will be stored on the Durham University Repository to enable data sharing where relevant and permitted.

It is also important to note that player participation in this research is entirely voluntary and this is made clear in the Information Sheet and Consent form.

## 3. PURPOSE AND DESIGN OF THE RESEARCH

**A7. Select the appropriate methodology description for this research.** *Please tick all that apply:*

- ☐ Case series/ case note review
- ☐ Case control
- ☑ Cohort observation
- ☐ Controlled trial without randomisation
- ☐ Cross-sectional study
- ☐ Database analysis
- ☐ Epidemiology

- ☐ Feasibility/ pilot study
- ☐ Laboratory study
- ☐ Metanalysis
- ☐ Qualitative research
- ☑ Questionnaire, interview or observation study
- ☐ Randomised controlled trial
- ☑ Other (please specify)

Longitudinal study including multiple measures of load and fatigue in rugby players.

**A10. What is the principal research question/objective?** *Please put this in language comprehensible to a lay person.*

The primary research questions are:
1) What are the global loads sustained by players on a weekly basis and across the season?
2) What are the global indicators of fatigue in elite and sub-elite rugby players?
3) How does load and fatigue vary across the high performance rugby season?

**A11. What are the secondary research questions/objectives if applicable?** *Please put this in language comprehensible to a lay person.*

The secondary research questions are
1) Are changes in body composition (including visceral fat) of rugby players associated with training and match loads and player fatigue?
2) Are there changes in cognition scores across the season and are there associations with head impact data and wellbeing?
3) Are there changes in bone strength over one season and are there any associations with GPS-derived workload and injury?

**A12. What is the scientific justification for the research?** *Please put this in language comprehensible to a lay person.*

This study will be the first to develop a model of global player load in high performance rugby. This study will also be the first to incorporate consideration of head impacts in addition to the usual player load quantified by Global Positioning Systems (GPS). Given the increasing emphasis and concern about player welfare in rugby, this study is timely and relevant. The study will explore the relationship between global player load during matches and training, and fatigue and recovery. In addition to furthering the scientific knowledge in this field, the results will be of practical interest to backroom staff, including strength and conditioning coaches, sport scientists and medical staff, in terms of incorporating recovery into training programmes and planning appropriate training loads for players to make sure they are recovered well and ready to return to training post matches, with a view to ensuring player safety, reducing the incidence of injury and improving player wellbeing.

The importance of understanding fatigue and associated recovery has been attempted in research but is multifaceted and complex (Halson 2014). Currently studies have examined blood markers in response to matches (Banfi et al. 2006), hormonal responses (Tiernan et al. 2020), self-reported wellness (Hills & Rogerson 2018) and physiological and neuromuscular function (Twist and Highton 2013). Whilst these studies provide informative insights into the fatigue associated with matches, these studies are in isolation, over a smaller period of the season, with smaller numbers of participants or not at elite level.

In this current study, in order to achieve a deeper understanding of the match and training demands, global impact data will be measured given that players are frequently exposed to significant physical collisions (Jones et al. 2015). This study will include the measurement of head impact forces using validated Instrumented Mouthguards (IMG's) (Tierney et al. 2021), alongside GPS data to give a more informative overall measurement of match load. Over the course of a season, this allows for the quantification of both impact loads to the brain and locomotive activity, which is currently lacking in research.

Rugby players have a high exposure to impacts and subconcussive impacts (King et al. 2017) through tackling, rucking and mauling (Jones et al. 2015). A subconcussive impact is defined as any impact that does not result in a concussion diagnosis, does not result in time-loss of participation in practice or games and does not result in concussion-related symptoms that linger for a prolonged period of time (King et al. 2015). Whilst these impacts may not have the magnitude to result in a concussion, these cumulative subconcussive impacts should not be ignored (Kieffer et al. 2020). This information is essential for backroom club to be able to return players safely and accurately to

training and matches as these impacts can cause cognitive fatigue, including concentration, memory, orientation, and saccadic eye movements (King et al. 2015) and physical fatigue.

The benefits of this research include the provision of new information on the global loads sustained by high performance players. High athlete workload without adequate recovery and poor load management, is a major risk for injury occurrence (Soligard et al. 2016). Having both data from IMG's and GPS would quantify that workload, which would lead to inventions on recovery from backroom staff with a view to preventing injuries and improving player wellbeing.
This two-factored workload measure will then be compared to player outcomes from cognitive assessment (Cognetivity and King-Devick), subjective wellness questionnaires (including sleep) and and neuromuscular performance tests (countermovement jump). This will help identify what type of fatigue a player is experiencing post-match, relationship to global player load and how this changes throughout the duration of a season. It will also allow the investigation of relationships between aspects of load and fatigue outcomes.

**A13. Please summarise your design and methodology.** *It should be clear exactly what will happen to the research participant, how many times and in what order. Please complete this section in language comprehensible to the lay person. Do not simply reproduce or refer to the protocol. Further guidance is available in the guidance notes.*

STUDY DESIGN
A longitudinal study design has been chosen because this allows for the investigation of cumulative load and of changes in the key variables of interest. This design also is most suited to the primary research question which seeks to identify indicators of fatigue and recovery in rugby union players over a period of time.

TIMELINE
The study will start in January 2022 and there will be PhD supervisory meetings at least monthly until the final report is completed. The final report for the entire study is expected by March 2024.

STUDY SAMPLE AND RECRUITMENT
Elite and sub-elite male rugby players will be recruited to the study by the lead PhD researcher. This cohort has been identified due to their participation in a full-contact sport to a high performance level, involving high volume and intensity training and demanding match schedules. Elite players will be engaged on a professional contract with the local professional rugby club. Sub-elite players will be on the performance pathway within the local professional rugby club or Durham University. All participants will be aged between 18 and 40 years.
The sample size is determined by the maximum number of players in the squad and all players in the squad will be invited to participate. At elite level, the sample will comprise of approximately 50 players and at the sub-elite level, the sample will comprise of approximately 30-50 players.
It will be made clear to players, both verbally and in the Information Sheet, that they do not have to take part in the research and that it is their decision.
It is possible that a minority of participants will move clubs during the study. Any movement would occur between seasons and thus not impacting on a full season of data collection. If a participant moves club, their involvement in the study will stop at their last time point of testing. Only participants with one full season of data will be included in the final analysis.

METHODOLOGY

ROUTINE DATA:
Routine (daily/weekly) data, collected by the club, will be collated and used in the analysis. This includes training and match GPS data, player wellbeing scores and performance test scores. The reason for the inclusion of this secondary data, is to avoid replication of tests already completed and to avoid over burdening participants. The data is essential to answer the study primary and secondary questions.

Participants will be asked permission for their club data to be included in this research study via the Consent Form. The data will be stored securely using participant codes and not names.

GLOBAL POSITIONING SYSTEMS (GPS):
Participants will be asked to wear GPS (Catapult Vector Unit, Melbourne, Australia) during each training and match from January 2022 to the end of 2022-23 season. Catapult Vector units have a 10 Hz Sampling rate and in-built 100 Hz tri-axial accelerometers which can determine individuals' locomotion and external forces. Participants will be given their own GPS device, which is switched on 20 minutes before a session and turned off immediately post session. Data can then be downloaded via Catapult software (Catapult Openfield, Catapult Sports, Melbourne, Australia)for analysis.

PERFORMANCE RECOVERY TEST MEASURES: COUNTERMOVEMENT JUMP (CMJ):
Participants will be asked to perform three countermovement jumps with an external load of 40kg (20kg Olympic Bar +

20kg Load) to measure lower body power (48hrs post match), all participants will be familiar with this method. Linear velocity transducer (LVT) technology (GymAware, Kinetic Performance Technology, Canberra, Australia) allows for various metrics to be collected during the weighted countermovement jump, via GymAware App and then stored under password for later analysis through GymAware Cloud.

PLAYER WELLBEING SCORES:
Participants will be asked to self-rate their wellness using a likert scale response to questions about their sleep quality, lower body soreness, upper body soreness, mood and motivation. Participants submit their responses via their own mobile phones via a google forms link, this data is only accessed by the clubs Head of Performance and Head of Physiotherapy.

IMPACT MONITORING MOUTHGUARDS:
Participants will be asked to wear an impact measurement mouthguard (Protect Biometric, MN, USA) during contact training sessions and matches from January 2022 to the end of the 2022-2023 season. This mouthguard contains an accelerometer which counts and measures impact forces to the head, and a proximity sensor, which identifies the location of an impact. Participants will be given their own mouthguard and this will not be used by anyone else. After each session, participants will sanitise and return their mouthguard to its own personal case, labelled with their name and jersey number. The case will then be slotted into the charging case and stored by the lead researcher, until the next session or match. Data from the sensors is transferred to the cloud via bluetooth.

DXA & COGNITION - DURHAM UNIVERSITY:
DXA and cognition data will be collected at 5 time points starting from January 2022.

| | Pre-season ~September | Mid-season ~January | End-season ~May/June |
|---|---|---|---|
| 2021-22 | n/a | X | X |
| 2022-23 | X | X | X |

i) DXA body composition including visceral fat mass at each time point;
ii) Cognitive testing using the validated Cognetivity test (5 minutes) and the validated King Devick visual screening test (<5 minutes), at each time point;
iii) DXA bone mineral density (2022-23 pre and end-season).

The above tests will take place during one appointment at each time point, at Maiden Castle Sports and Wellbeing Park, Durham University. Each appointment will last no longer than 60 minutes and free, onsite parking will be available for all participants.

Participants will be asked to follow the pre-DXA scan protocol which reduces the risk of biological error and is important for longitudinal monitoring:
a) overnight fast (if the appointment is in the morning) or following a 5 hours fast (if the appointment is 11am or later); b) drink 500ml of water 2 hours before the appointment, c) no moderate-vigorous exercise within the last 12 hours, d) no caffeine within the last 5 hours and e) no alcohol within the last 24 hours. Participants will be asked to void their bladder before the scan. Participants will receive written guidance (please see supporting documents with this ethics application).

For the DXA scan, participants will remove jewellery and will be measured in lightweight clothing that does not contain metal or plastic (for example, lightweight shorts and vest). Body mass will be measured to the nearest gram using calibrated electronic scales and height will be measured to the nearest cm using a freestanding stadiometer. (SECA, Birmingham, UK).

DXA scans will be performed using a GE Lunar iDXA (GE Healthcare, Madison, WI) with Encore software version 18.0. The DXA operator will be trained (training provided by the supervisor who has over 15 years experience in DXA scanning, is a an ISCD training course provider, and is Chair of the Body Composition Education Committee for the ISCD) and will have a valid and up to date IRMER training certificate.
DXA scans are performed with the participant lying supine ensuring comfort at all times. At each time point, participants will receive one total body less head scan. Unlike the standard total body scan, this scan does not include the head region and so there is a reduction in scan time and a reduction in dose. On an annual basis over the three year study duration, participants will also receive a DXA bone density assessment at the lumbar spine and total hip.

All participants will be offered a copy of their DXA results. If bone density results indicate low bone density, participants will be advised to make an appointment with their GP.

Following their DXA scan, participants will be offered a drink of water and a light snack (banana or cereal/protein bar). The cognitive testing will take place after the participant has eaten.

The cognitive testing will take place in a quiet room, using an iPad and with a total duration of 10-15 minutes. The first test is the Cognetivity ICA (Cognetivty, UK) whereby participants are asked to click on either the left or right side of the iPad screen to indicate if the image that appears is an animal or an object. There are 50 images included in this test. The duration of this test is 5 minutes. The second test is the King Devick Test (MayoClinic, UK). This test involves reading out loud a series of numbers from left to right and the time taken to do so, is the overall score for the test. Both tests have been validated.

**A14-1. In which aspects of the research process have you actively involved, or will you involve, patients, service users, and/or their carers, or members of the public?**

- [x] Design of the research
- [x] Management of the research
- [x] Undertaking the research
- [x] Analysis of results
- [x] Dissemination of findings
- [ ] None of the above

*Give details of involvement, or if none please justify the absence of involvement.*
The lead PhD student investigator is also a member of the coaching team at the rugby union club, involved in all stages of the research.

## 4. RISKS AND ETHICAL ISSUES

### RESEARCH PARTICIPANTS

**A17-1. Please list the principal inclusion criteria (list the most important, max 5000 characters).**

The inclusion criteria are as follows:
- Aged 18 to 40 years;
- Elite (professional contract) male rugby player at the local professional rugby club;
- Sub-elite (performance pathway) male rugby player at the local professional rugby club or Durham University rugby first team squad.

**A17-2. Please list the principal exclusion criteria (list the most important, max 5000 characters).**

Currently, this study will only research male rugby players. Should the opportunity arise to include female rugby players, an amendment to the ethics application will be made.

### RESEARCH PROCEDURES, RISKS AND BENEFITS

**A18. Give details of all non-clinical intervention(s) or procedure(s) that will be received by participants as part of the research protocol.** *These include seeking consent, interviews, non-clinical observations and use of questionnaires.*

Please complete the columns for each intervention/procedure as follows:

1. Total number of interventions/procedures to be received by each participant as part of the research protocol.
2. If this intervention/procedure would be routinely given to participants as part of their care outside the research, how many of the total would be routine?
3. Average time taken per intervention/procedure (minutes, hours or days)
4. Details of who will conduct the intervention/procedure, and where it will take place.

| Intervention or procedure | 1 | 2 | 3 | 4 |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Providing consent to participate in the research after reading the information sheet. | 1 | | 5 minutes | Lead PhD researcher (LW) at either the rugby union club or Durham University. |
| Standing height measurement | 5 | | 1 minute | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |
| Body mass measurement | 5 | 5 | 1 minute | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |
| King Devick test | 5 | | 5 minutes | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |
| Waist circumference | 5 | | 1 minute | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |
| Cognetivity ICA test | 5 | | 5 minutes | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |
| Impact monitoring mouthguards worn during contact training and matches. Participants are familiar with wearing mouthguards. | 1 | 1 | 6 Hours/ Week | Lewis Williams |

**A19. Give details of any clinical intervention(s) or procedure(s) to be received by participants as part of the research protocol.** *These include uses of medicinal products or devices, other medical treatments or assessments, mental health interventions, imaging investigations and taking samples of human biological material. Include procedures which might be received as routine clinical care outside of the research.*

Please complete the columns for each intervention/procedure as follows:

1. Total number of interventions/procedures to be received by each participant as part of the research protocol.
2. If this intervention/procedure would be routinely given to participants as part of their care outside the research, how many of the total would be routine?
3. Average time taken per intervention/procedure (minutes, hours or days).
4. Details of who will conduct the intervention/procedure, and where it will take place.

| Intervention or procedure | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| DXA total body less head scan | 5 | | 7 to 14 minutes | Lewis Williams, Dr Karen Hind, Dr Katie Di Sebastiano |
| DXA lumbar spine scan | 2 | | 1 minute | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |
| DXA left or right femur scan | 2 | | 1 minute | Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren, Dr Katie Di Sebastiano |

**A21. How long do you expect each participant to be in the study in total?**

From the provision of consent, the participants will be involved in the study for 18 months (January 2022 to ~June 2023- end of the season).

**A22. What are the potential risks and burdens for research participants and how will you minimise them?**

*For all studies, describe any potential adverse effects, pain, discomfort, distress, intrusion, inconvenience or changes to lifestyle. Only describe risks or burdens that could occur as a result of participation in the research. Say what steps would be taken to minimise risks and burdens as far as possible.*

DXA scan for the measurement of total body composition and bone density:
Participants will be exposed to low levels of ionising radiation. The equivalent dose comparisons have been made by the Medical Physics Expert and Clinical Radiation Expert, and are considered acceptable for the study. All DXA activities are performed under the facility local rules, IRR17 and IRMER, under the supervision of Dr Karen Hind who has 18 years experience in DXA and is a certified clinical densitometrist (ISCD), and overseen by the Radiation Protection Supervisor and the Radiation Protection Advisor. All scans are performed with the participant lying supine, ensuring comfort at all times.

There are no risks or burdens associated with the cognition tests. Each take less than 5 minutes to complete.

Note on secondary data: GPS load data from training and matches, data from a player wellbeing questionnaire, and data from performance/recovery tests are routinely carried out by the rugby club and therefore these tests will not be repeated to avoid overburdening participants. Participants will be asked their permission for their data from the club, to be used in this study.

Confidentiality: The confidentiality and privacy of the participants will be maintained by the coding of information entered into data sheets and by protection of the DXA PC via password and security of the imaging suite within Maiden Castle. Any electronic data will be stored on a password protected computer or on an encrypted memory stick. Any paper format data will be stored securely in a locked filing cabinet, in a restricted access and lockable room in Durham University.

**A24. What is the potential for benefit to research participants?**

Participants will be offered their own results from the DXA scans. DXA is considered the gold standard method for measuring both bone density and body composition, with a high degree of accuracy and precision. This information will inform participants on their bone mass (incl change in bone density from the start to end of the season), fat mass, lean mass and visceral fat. This information is helpful for health, injury prevention and performance reasons.

In addition, the overall results from the study will be fed back to the players and coaching staff (anonymous format) so that strategies can be identified for reducing fatigue and injury risk, and for advancing player welfare.

## RECRUITMENT AND INFORMED CONSENT

***In this section we ask you to describe the recruitment procedures for the study. Please give separate details for different study groups where appropriate.***

**A27-1. How will potential participants, records or samples be identified? Who will carry this out and what resources will be used?** *For example, identification may involve a disease register, computerised search of GP records, or review of medical records. Indicate whether this will be done by the direct healthcare team or by researchers acting under arrangements with the responsible care organisation(s).*

Participants will be recruited from the local professional rugby club and from Durham University rugby first team squad. The lead PhD researcher will recruit participants through his position on the coaching team of the rugby club. It will be clearly communicated to players that it is not mandatory for them to take part and it is completely their decision. This will be conveyed to them verbally and via the Participant Information Sheet.

**A27-2. Will the identification of potential participants involve reviewing or screening the identifiable personal information of patients, service users or any other person?**

○ Yes ◉ No

*Please give details below:*

**A28. Will any participants be recruited by publicity through posters, leaflets, adverts or websites?**

○ Yes ◉ No

**A29. How and by whom will potential participants first be approached?**

Potential participants will be approached by Lewis Williams who is the PhD student on this project and who is also on the coaching team for the professional rugby club. Participation in the project is entirely voluntary and no one will be coerced to participate against his will. The researcher will not place any pressure or undue influence when approaching potential participants. It has been made clear in the information sheet that no sanctions will follow if the participant decides to leave the research at any time.

**A30-1. Will you obtain informed consent from or on behalf of research participants?**

(●) Yes ( ) No

*If you will be obtaining consent from adult participants, please give details of who will take consent and how it will be done, with details of any steps to provide information (a written information sheet, videos, or interactive material). Arrangements for adults unable to consent for themselves should be described separately in Part B Section 6, and for children in Part B Section 7.*

*If you plan to seek informed consent from vulnerable groups, say how you will ensure that consent is voluntary and fully informed.*

The study aims, procedures, risks and benefits will be explained in a written Participant Information Sheet. Lewis Williams, Dr Karen Hind, Dr Shaun Maclaren and Dr Katie Di Sebastiano will answer questions from potential participants. Potential participants will be given a consent form which they will complete and sign if they are happy to take part in the research. This consent form will specifically ask if they are happy for their routine data collected by the club, to be shared with the research team and used in the analysis.

*If you are not obtaining consent, please explain why not.*

*Please enclose a copy of the information sheet(s) and consent form(s).*

**A30-2. Will you record informed consent (or advice from consultees) in writing?**

(●) Yes ( ) No

**A31. How long will you allow potential participants to decide whether or not to take part?**

Potential participants will have as long as they need to decide whether or not they want to take part. They will be asked to take a minimum of 7 days to consider their decision (from reading the information sheet to signing the consent form).

**A32. Will you recruit any participants who are involved in current research or have recently been involved in any research prior to recruitment?**

( ) Yes
(●) No
( ) Not Known

**A33-1. What arrangements have been made for persons who might not adequately understand verbal explanations or written information given in English, or who have special communication needs?** *(e.g. translation, use of interpreters)*

Individuals who are unable to understand the verbal explanations or written explanations in English, will not be permitted to take part in the study. This decision is because there is no financial resource to support the involvement of translators/interpreters to assist with communication between the researcher and the participants. For this reason, it would not be ethical to obtain consent without it being fully informed and it would be a risk to the individual to take part in the study without knowledge and understanding of what is required.

**A35. What steps would you take if a participant, who has given informed consent, loses capacity to consent during the study?** *Tick one option only.*

○ The participant and all identifiable data or tissue collected would be withdrawn from the study. Data or tissue which is not identifiable to the research team may be retained.

◉ The participant would be withdrawn from the study. Identifiable data or tissue already collected with consent would be retained and used in the study. No further data or tissue would be collected or any other research procedures carried out on or in relation to the participant.

○ The participant would continue to be included in the study.

○ Not applicable – informed consent will not be sought from any participants in this research.

○ Not applicable – it is not practicable for the research team to monitor capacity and continued capacity will be assumed.

*Further details:*

*If you plan to retain and make further use of identifiable data/tissue following loss of capacity, you should inform participants about this when seeking their consent initially.*

## CONFIDENTIALITY

**In this section, personal data means any data relating to a participant who could potentially be identified. It includes pseudonymized data capable of being linked to a participant through a unique code number.**

### Storage and use of personal data during the study

**A36. Will you be undertaking any of the following activities at any stage (including in the identification of potential participants)?** *(Tick as appropriate)*

- ☐ Access to medical records by those outside the direct healthcare team
- ☐ Access to social care records by those outside the direct social care team
- ☐ Electronic transfer by magnetic or optical media, email or computer networks
- ☐ Sharing of personal data with other organisations
- ☐ Export of personal data outside the EEA
- ☑ Use of personal addresses, postcodes, faxes, emails or telephone numbers
- ☐ Publication of direct quotations from respondents
- ☐ Publication of data that might allow identification of individuals
- ☐ Use of audio/visual recording devices
- ☐ Storage of personal data on any of the following:
  - ☑ Manual files (includes paper or film)
  - ☐ NHS computers
  - ☐ Social Care Service computers
  - ☐ Home or other personal computers
  - ☑ University computers
  - ☐ Private company computers
  - ☑ Laptop computers

*Further details:*
Personal information will only be used to contact the participants, for example to send the Information Sheet.

**A38. How will you ensure the confidentiality of personal data?** *Please provide a general statement of the policy and procedures for ensuring confidentiality, e.g. anonymisation or pseudonymisation of data.*

Data will be coded from the outset, for storage, processing and analysis to ensure confidentiality. Anonymised data will be stored for 20 years. Individual participants will not be identifiable from any publication or other output arising from the research. It is possible that the club will be identifiable given their locality to Durham University and involvement of one of the coaching team on this project as lead PhD researcher. Agreement from the club has been provided in writing for the study (please see supporting documents attached to this ethics application) to go ahead with the understanding that the club may be identified given the PhD researcher affiliation.
https://www.dur.ac.uk/research.innovation/outputs/data.management /archive/

**A40. Who will have access to participants' personal data during the study?** *Where access is by individuals outside the direct care team, please justify and say whether consent will be sought.*

Lewis Williams (PhD candidate), Dr Karen Hind, Dr Shaun Maclaren and Dr Katie Di Sebastiano are the only individuals who will have complete access to all participant data. Any data shared outside of the research team will be anonymised.

**Storage and use of data after the end of the study**

**A43. How long will personal data be stored or accessed after the study has ended?**

- ○ Less than 3 months
- ○ 3 – 6 months
- ○ 6 – 12 months
- ○ 12 months – 3 years
- ◉ Over 3 years

*If longer than 12 months, please justify:*
Personal data (name, email address and participant code) will be stored for 10 years. This is because participants may wish to access their DXA results over this time,

**INCENTIVES AND PAYMENTS**

**A46. Will research participants receive any payments, reimbursement of expenses or any other benefits or incentives for taking part in this research?**

○ Yes ◉ No

**A47. Will individual researchers receive any personal payment over and above normal salary, or any other benefits or incentives, for taking part in this research?**

○ Yes ◉ No

**A48. Does the Chief Investigator or any other investigator/collaborator have any direct personal involvement (e.g. financial, share holding, personal relationship etc.) in the organisations sponsoring or funding the research that may give rise to a possible conflict of interest?**

◉ Yes ○ No

*If yes, please give details including the amount of any monetary payment or the basis on which this will be calculated:*
The lead PhD researcher, Lewis Williams is an employed member of the coaching team for the local professional rugby club where players will be recruited from. This is common in sports science research where applied practitioners will undertake a PhD. Dr Shaun Maclaren, co-supervisor, is employed by both Durham University and the local professional rugby club (Academy coaching team). Again, this is common place in sport science research where

it is important for students to be taught by those who have applied expertise of the field. The club are not sponsoring the research and have not provided any monetary contributions. The overall findings of the research will be fed-back to the club to identify avenues to support player welfare in terms of reducing fatigue.

## NOTIFICATION OF OTHER PROFESSIONALS

**A49-1. Will you inform the participants' General Practitioners (and/or any other health or care professional responsible for their care) that they are taking part in the study?**

○ Yes ◉ No

*If Yes, please enclose a copy of the information sheet/letter for the GP/health professional with a version number and date.*

## PUBLICATION AND DISSEMINATION

**A50. Will the research be registered on a public database?**

*The UK Policy Framework for Health and Social Care Research sets out the principle of making information about research publicly available. Furthermore: Article 19 of the World Medical Association Declaration of Helsinki adopted in 2008 states that "every clinical trial must be registered on a publicly accessible database before recruitment of the first subject"; and the International Committee of Medical Journal Editors (ICMJE) will consider a clinical trial for publication only if it has been registered in an appropriate registry. Please see guidance for more information.*

○ Yes ◉ No

*Please give details, or justify if not registering the research.*
The study is not a clinical trial.

*Please ensure that you have entered registry reference number(s) in question A5-1.*

**A51. How do you intend to report and disseminate the results of the study?** *Tick as appropriate:*

- ☑ Peer reviewed scientific journals
- ☑ Internal report
- ☑ Conference presentation
- ☐ Publication on website
- ☑ Other publication
- ☐ Submission to regulatory authorities
- ☐ Access to raw data and right to publish freely by all investigators in study or by Independent Steering Committee on behalf of all investigators
- ☐ No plans to report or disseminate the results
- ☐ Other (please specify)

**A53. How and when will you inform participants of the study results?**

*If there will be no arrangements in place to inform participants please justify this.*
Participants will receive their own DXA results and will be asked if they would like to receive a copy of the overall project results. The overall project results will be in the form of a short summary document with bullet points of the key findings. This will be shared to interested participants via email.

## 5. Scientific and Statistical Review

**A54. How has the scientific quality of the research been assessed?** *Tick as appropriate:*

- [ ] Independent external review
- [ ] Review within a company
- [ ] Review within a multi-centre research group
- [x] Review within the Chief Investigator's institution or host organisation
- [x] Review within the research team
- [x] Review by educational supervisor
- [ ] Other

*Justify and describe the review process and outcome. If the review has been undertaken but not seen by the researcher, give details of the body which has undertaken the review:*
All supervisors have reviewed and approved the project design and protocol. Supervisors are experienced in the design, conduct, statistical analysis, scientific interpretation and dissemination of research.

*For all studies except non-doctoral student research, please enclose a copy of any available scientific critique reports, together with any related correspondence.*

*For non-doctoral student research, please enclose a copy of the assessment from your educational supervisor/ institution.*

**A56. How have the statistical aspects of the research been reviewed?** *Tick as appropriate:*

- [ ] Review by independent statistician commissioned by funder or sponsor
- [ ] Other review by independent statistician
- [ ] Review by company statistician
- [ ] Review by a statistician within the Chief Investigator's institution
- [ ] Review by a statistician within the research team or multi-centre group
- [ ] Review by educational supervisor
- [ ] Other review by individual with relevant statistical expertise
- [x] No review necessary as only frequencies and associations will be assessed – details of statistical input not required

*In all cases please give details below of the individual responsible for reviewing the statistical aspects. If advice has been provided in confidence, give details of the department and institution concerned.*

| | Title Forename/Initials Surname |
|---|---|
| | Dr Shaun MacLaren |
| Department | Department of Sport & Exercise Sciences |
| Institution | Durham University |
| Work Address | Department of Sport & Exercise Sciences |
| | Maiden Castle Sports & Wellbeing Park |
| | Durham University |
| Post Code | DH1 3SE |
| Telephone | |
| Fax | |
| Mobile | |
| E-mail | shaun.maclaren@durham.ac.uk |

*Please enclose a copy of any available comments or reports from a statistician.*

**A57. What is the primary outcome measure for the study?**

The primary outcome measures for the project are load and fatigue.
Load is quantified using the GPS and instrumented mouthguards.
Fatigue is quantified as:
Subjective: Overall player wellbeing score for the season
Objective: Performance test score fluctuation from pre-season

**A58. What are the secondary outcome measures?** *(if any)*

The secondary outcome measures of the project are:
- Seasonal changes in lean mass
- Seasonal changes in fat mass
- Seasonal changes in visceral fat mass
- Seasonal changes in cognitive scores
- Change in bone density by end of the study

Each of these outcomes represent 'response' to load.

**A59. What is the sample size for the research?** *How many participants/samples/data records do you plan to study in total? If there is more than one group, please give further details below.*

| | |
|---|---|
| Total UK sample size: | 120 |
| Total international sample size (including UK): | 120 |
| Total in European Economic Area: | 0 |

*Further details:*
This is the planned 'maximum' number of participants. All participants will be recruited from the UK.

**A60. How was the sample size decided upon?** *If a formal sample size calculation was used, indicate how this was done, giving sufficient information to justify and reproduce the calculation.*

The sample size is based on what is 'maximally feasible' in terms of the participant population (limited to elite and sub-elite players from specific clubs) and the time and resources to perform the study.

**A61. Will participants be allocated to groups at random?**

○ Yes ◉ No

**A62. Please describe the methods of analysis (statistical or other appropriate methods, e.g. for qualitative research) by which the data will be evaluated to meet the study objectives.**

The project dependant variables shall include measures of training response such as, subjective wellness, cognitive function, sleep characteristics, lower body muscular power measures, bone and body composition and also athlete health including injury and concussion.

The primary independent variables shall be measures of training load, including impact sensor mouthguard data and locomotive GPS data. Additional variables that may be used as secondary independent variables or moderating/ confounding variables may include fitness and strength levels, playing position, body composition and neck strength.

The overall aim of analyses is to examine associations between independent variables on dependent variables, while accounting for or specifying the additional effect of moderating variables. Statistics used to describe these effects could mean differences or associations (correlations), for example. All statistics will be presented with confidence (compatibility) limits (CL) as markers of uncertainty in the estimates (Greenland, 2019).

Since each player shall have repeated measures on both dependent and independent variables, data analysed using

mixed effects linear models. This helps account for the 'nested' design by specifying players as random effects (Hopkins et al., 2009). A benefit of this approach is to properly account for different sources of variance and to provide an accurate estimate of CL, which is vital for statistical inference and scientific conclusions (Cnaan et al., 1997). A further benefit is the ability to examine interindividual differences (Hopkins et al., 2009).

Approach to Inference: Traditional null hypothesis significance testing has been extensively criticized (McShane et a., 2019; Amrhein et al., 2019) and will therefore not be used to make conclusions on the main results. Instead, progressive frequentist approaches, such as Minimum Effects Testing and Equivalence Testing, shall be used to describe the practical significance of results (Lakens, 2019). Briefly, these methods provide a probabilistic interpretation of the effect CL in relation to threshold values representing real-world importance.

## 6. MANAGEMENT OF THE RESEARCH

**A63. Other key investigators/collaborators.** *Please include all grant co-applicants, protocol co-authors and other key members of the Chief Investigator's team, including non-doctoral student researchers.*

Title Forename/Initials Surname

Post
Qualifications
Employer
Work Address

Post Code
Telephone
Fax
Mobile
Work Email

## A64. Details of research sponsor(s)

**A64-1. Sponsor**

**Lead Sponsor**

Status:
- ○ NHS or HSC care organisation
- ◉ Academic
- ○ Pharmaceutical industry
- ○ Medical device industry
- ○ Local Authority
- ○ Other social care provider (including voluntary sector or private organisation)
- ○ Other

Commercial status: Non-Commercial

*If Other, please specify:*

**Contact person**

| | |
|---|---|
| Name of organisation | Durham University |
| Given name | Niall |
| Family name | O'Loughlin |
| Address | RIS, Maple Wing, Mountjoy Centre, Stockton Road |
| Town/city | Durham |
| Post code | DH1 3LE |
| Country | United Kingdom |
| Telephone | 01913344623 |
| Fax | |
| E-mail | niall.c.o'loughlin@durham.ac.uk |

**Legal representative for clinical investigation of medical device (studies involving Northern Ireland only)**
*Clinical Investigations of Medical Devices that take place in Northern Ireland must have a legal representative of the sponsor that is based in Northern Ireland or the EU*

**Contact person**

| | |
|---|---|
| Name of organisation | |
| Given name | |
| Family name | |
| Address | |
| Town/city | |
| Post code | |
| Country | |
| Telephone | |
| Fax | |
| E-mail | |



**A65. Has external funding for the research been secured?**

*Please tick at least one check box.*

- ☐ Funding secured from one or more funders
- ☐ External funding application to one or more funders in progress
- ☑ No application for external funding will be made

What type of research project is this?

- ◉ Standalone project
- ○ Project that is part of a programme grant
- ○ Project that is part of a Centre grant
- ○ Project that is part of a fellowship/ personal award/ research training award
- ○ Other

Other – please state:

**A67. Has this or a similar application been previously rejected by a Research Ethics Committee in the UK or another country?**

◯ Yes ◉ No

*Please provide a copy of the unfavourable opinion letter(s). You should explain in your answer to question A6-2 how the reasons for the unfavourable opinion have been addressed in this application.*

**A69-1. How long do you expect the study to last in the UK?**

Planned start date: 03/01/2022
Planned end date: 02/01/2025
Total duration:
Years: 3 Months: 0 Days: 0

**A71-2. Where will the research take place?** *(Tick as appropriate)*

☑ England
☐ Scotland
☐ Wales
☐ Northern Ireland
☐ Other countries in European Economic Area

Total UK sites in study 1

**Does this trial involve countries outside the EU?**

◯ Yes ◯ No

**A72. Which organisations in the UK will host the research?** *Please indicate the type of organisation by ticking the box and give approximate numbers if known:*

☐ NHS organisations in England
☐ NHS organisations in Wales
☐ NHS organisations in Scotland
☐ HSC organisations in Northern Ireland
☐ GP practices in England
☐ GP practices in Wales
☐ GP practices in Scotland
☐ GP practices in Northern Ireland
☐ Joint health and social care agencies (eg community mental health teams)
☐ Local authorities
☐ Phase 1 trial units
☐ Prison establishments
☐ Probation areas
☐ Independent (private or voluntary sector) organisations
☑ Educational establishments 1

☐ Independent research units

☐ Other (give details)

Total UK sites in study: 1

**A76. Insurance/ indemnity to meet potential legal liabilities**

***Note:* in this question to NHS indemnity schemes include equivalent schemes provided by Health and Social Care (HSC) in Northern Ireland**

**A76-1. What arrangements will be made for insurance and/or indemnity to meet the potential legal liability of the sponsor(s) for harm to participants arising from the management of the research?** *Please tick box(es) as applicable.*

*Note: Where a NHS organisation has agreed to act as sponsor or co-sponsor, indemnity is provided through NHS schemes. Indicate if this applies (there is no need to provide documentary evidence). For all other sponsors, please describe the arrangements and provide evidence.*

☐ NHS indemnity scheme will apply (NHS sponsors only)

☑ Other insurance or indemnity arrangements will apply (give details below)

Durham University insurance arrangements will apply - see attached insurance document for evidence.

*Please enclose a copy of relevant documents.*

**A76-2. What arrangements will be made for insurance and/ or indemnity to meet the potential legal liability of the sponsor(s) or employer(s) for harm to participants arising from the design of the research?** *Please tick box(es) as applicable.*

*Note: Where researchers with substantive NHS employment contracts have designed the research, indemnity is provided through NHS schemes. Indicate if this applies (there is no need to provide documentary evidence). For other protocol authors (e.g. company employees, university members), please describe the arrangements and provide evidence.*

☐ NHS indemnity scheme will apply (protocol authors with NHS contracts only)

☑ Other insurance or indemnity arrangements will apply (give details below)

Durham University insurance arrangements will apply - see attached insurance document for evidence.

*Please enclose a copy of relevant documents.*

**A76-3. What arrangements will be made for insurance and/ or indemnity to meet the potential legal liability of investigators/collaborators arising from harm to participants in the conduct of the research?**

*Note: Where the participants are NHS patients, indemnity is provided through the NHS schemes or through professional indemnity. Indicate if this applies to the whole study (there is no need to provide documentary evidence). Where non-NHS sites are to be included in the research, including private practices, please describe the arrangements which will be made at these sites and provide evidence.*

☐ NHS indemnity scheme or professional indemnity will apply (participants recruited at NHS sites only)

☑ Research includes non-NHS sites (give details of insurance/ indemnity arrangements for these sites below)

Durham University insurance arrangements will apply - see attached insurance document for evidence.

*Please enclose a copy of relevant documents.*

## PART B: Section 3 – Exposure to ionising radiation

*Complete sub-sections A and/or B as applicable with input from relevant experts. It is advisable to discuss the proposed research at an early stage with (a) a Medical Physics Expert and (b) a Clinical Radiation Expert, who will carry out the required assessments for sub-sections C and D. The lead MPE can also facilitate the completion of sub-sections A and/or B if necessary.*

**1. Does the study involve exposure to radioactive materials?**

○ Yes ◉ No

To update the response above, go to the Project Filter Question 2 'Does the study involve exposure to radioactive materials?' and select an option.

**2. Does the study involve other diagnostic or therapeutic ionising radiation?**

◉ Yes ○ No

## A. Radioactive materials

### Details of radioactive materials

## B. Other ionising radiation

**B1. Details of other ionising radiation**

*Give details by completing the table below:*

| Procedure | No of procedures | Estimated procedure dose *(use national Diagnostic Reference Levels where available)* |
|---|---|---|
| | 5 | |
| GE Lunar iDXA total body scan | As follows: 2021-22 = 2 (mid and end season) 2022-23 = 3 (pre, mid and end season) | 9.6μSv |
| GE Lunar iDXA lumbar spine bone density scan | 2 (pre and end season) | 13.6μSv |
| GE Lunar iDXA left or right femur bone density scan | 2 (pre and end season) | 13.6μSv |

## C. Dose and risk assessment

**C1. What is the total participant dose from all the exposures in A1 and/or B1, and what component of this is the additional dose over and above standard practice? What are the risks associated with these two doses (total and additional)?**

*The dose and risk assessment should be set out below. This should be prepared by a Medical Physics Expert (MPE) who is a registered clinical scientist registered with the Health Professions Council and has expertise relevant to the planned exposures. Where the study involves different types of exposure (for example, both radioactive materials and other ionising radiation, or more than one imaging method), advice may need to be sought from other MPEs with relevant expertise. The lead MPE should produce a combined assessment for the ethics committee, giving the names of any other MPEs who have contributed to the assessment. Further guidance is available by clicking on the information button.*

This study requires exposures to ionising radiation which are detailed in B1. All the exposures required by the study are additional to routine care. The total procedure dose is 0.037mSv. This is equivalent to around 5 days of natural background radiation in the UK.

Ionising radiation can cause cancer which manifests itself after many years or decades. The risk of developing cancer as a consequence of taking part in this study is around .0002% which is low. For comparison the natural lifetime cancer incidence in the general population is 50%.
This assessment was produced by David Rawlings who is not part of the trial team.

*Special attention must be paid to pregnant/potentially pregnant women or those who are breast feeding, or other potentially vulnerable groups.*

**C2. Declaration by lead Medical Physics Expert**

I am satisfied that the information in sub-sections A and/or B and the assessment in sub-section C provide a reasonable estimate of the ionising radiation exposure planned in this research and the associated risks.

This section was signed electronically by Mr David Rawlings on 05/01/2022 18:12.

| | |
|---|---|
| Job Title/Post: | Clinical Scientist - Bank |
| Organisation: | Newcastle upon Tyne Hospitals NHS Foundation Trust |
| Email: | David.Rawlings1@nhs.net |

**C3. Details of person acting as lead Medical Physics Expert**

| | Title | Forename/Initials | Surname |
|---|---|---|---|
| | Mr | David | Rawlings |
| Post | Clinical Scientist - Bank | | |

*Details of clinical scientist registration with the Health Professions Council:*

| | |
|---|---|
| Registration no | CS01872 |
| Organisation | Newcastle upon Tyne Hospitals NHS Foundation Trust |
| Address | Northern Medical Physics and Clinical Engineering<br>Freeman Hospital |
| Post Code | NE7 7DN |
| Telephone | 07973243309 |
| Fax | |
| Mobile | 07973243309 |
| Email | David.Rawlings1@nhs.net |

**D. Clinical assessment**

*This sub-section should be completed by a Clinical Radiation Expert (CRE) who is a registered doctor or dentist with clinical expertise relevant to the planned exposures. The assessment should cover potential exposure at all research sites, taking account of possible variation in normal clinical practice. Where the study involves different types of exposure (for example, both radiotherapy and other ionising radiation), advice may need to be sought from other CREs with relevant expertise. The lead CRE should produce a combined assessment for the ethics committee, giving the names of any other CREs who have contributed to the assessment. The guidance notes give advice to Chief Investigators on who can act as lead Clinical Radiation Expert (CRE) and advice for the CRE on the assessment of exposures having regard to IRMER.*

*Special attention must be paid to pregnant/potentially pregnant women or those who are breast feeding, or other potentially vulnerable groups.*

**D1. Will the exposure exceed the exposure that might be received as part of normal care at any proposed research site?**

◉ Yes ○ No

**D2. Assessment of additional exposure**

*Explain how the planned exposure compares with normal practice and assess whether it is appropriate, using language comprehensible to a lay person. Consideration should be given to the specific objectives of the exposure, the characteristics of participants, the potential diagnostic or therapeutic benefits to the participant, the potential benefits to society, the risk to the participant and the availability of alternative techniques involving less, or no, ionising radiation.*

*If pregnant or breast-feeding mothers are to be studied give reasons and details of special radiation protection measures to be taken.*

This study involves ionising radiation in the form of DXA scans. The radiation dose that participants in this study will receive has been calculated as equivalent to 5 days of natural background radiation. This is an appropriate method for the study and will ensure important evaluations of both bone and body composition responses to intensive loading through sports training. The information about the small dose of ionising radiation from DXA will be included in the information sheet for participants.

**D3. Declaration by lead Clinical Radiation Expert**

I am satisfied that the exposure to ionising radiation planned in this research study (as defined in A1 and/or B1) is reasonable and that the risks are adequately described in the participant information sheet for the study.

This section was signed electronically by Dr Nicola Keay on 18/01/2022 10:25.

Job Title/Post:

Organisation:

Email:

**D4. Details of lead Clinical Radiation Expert**

| | Title Forename/Initials Surname |
|---|---|
| | Dr Nicola Keay |
| Post | Medical Doctor and Honorary Clinical Lecturer |
| Details of professional registration | ◉ General Medical Council ○ General Dental Council |
| Registration no | 3466230 |
| Organisation | University College London |
| Address | Division of Medicine |
| | UCL |
| | London |
| Post Code | |
| Telephone | |
| Fax | |
| Mobile | |
| Email | nickykeayfrancis@googlemail.com |

*Employers responsible for radiation facilities at research sites must have written procedures to meet the requirements of the Ionising Radiation (Medical Exposure) Regulations 2000 (IRMER). R & D offices for NHS sites will seek confirmation from local radiation experts that local IRMER authorisation procedures have been followed. Where the local Medical Physics Expert or IRMER Practitioner disagrees with the assessments made in this Section and/or the care organisation is unable to adhere to the protocol, this should be discussed with the Chief Investigator and the lead experts for the study. Any necessary variation in the protocol or participant information sheet at particular sites should be notified to the main REC as a substantial amendment and an ethical opinion sought.*

## PART C: Overview of research sites

**Please enter details of the host organisations (Local Authority, NHS or other) in the UK that will be responsible for the research sites.** *For further information please refer to guidance.*

| Research site | | Investigator/ Collaborator/ Contact | |
|---|---|---|---|
| Institution name | Durham University | Title | |
| Department name | Sport and Exercise Sciences | First name/ Initials | Karen |
| Street address | Sports and Wellbeing Park, Maiden Castle | Surname | Hind |
| Town/city | Durham | | |
| Post Code | DH1 3SE | | |

## PART D: Declarations

**D1. Declaration by Chief Investigator**

1. The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it.
2. I undertake to fulfil the responsibilities of the chief investigator for this study as set out in the UK Policy Framework for Health and Social Care Research.
3. I undertake to abide by the ethical principles underlying the Declaration of Helsinki and good practice guidelines on the proper conduct of research.
4. If the research is approved I undertake to adhere to the study protocol, the terms of the full application as approved and any conditions set out by review bodies in giving approval.
5. I undertake to notify review bodies of substantial amendments to the protocol or the terms of the approved application, and to seek a favourable opinion from the main REC before implementing the amendment.
6. I undertake to submit annual progress reports setting out the progress of the research, as required by review bodies.
7. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of patient or other personal data, including the need to register when necessary with the appropriate Data Protection Officer. I understand that I am not permitted to disclose identifiable data to third parties unless the disclosure has the consent of the data subject or, in the case of patient data in England and Wales, the disclosure is covered by the terms of an approval under Section 251 of the NHS Act 2006.
8. I understand that research records/data may be subject to inspection by review bodies for audit purposes if required.
9. I understand that any personal data in this application will be held by review bodies and their operational managers and that this will be managed according to the principles established in the Data Protection Act 2018.
10. I understand that the information contained in this application, any supporting documentation and all correspondence with review bodies or their operational managers relating to the application:
    - Will be held by the REC (where applicable) until at least 3 years after the end of the study; and by NHS R&D offices (where the research requires NHS management permission) in accordance with the NHS Code of Practice on Records Management.
    - May be disclosed to the operational managers of review bodies, or the appointing authority for the REC (where applicable), in order to check that the application has been processed correctly or to investigate any complaint.
    - May be seen by auditors appointed to undertake accreditation of RECs (where applicable).
    - Will be subject to the provisions of the Freedom of Information Acts and may be disclosed in response to requests made under the Acts except where statutory exemptions apply.
    - May be sent by email to REC members.
11. I understand that information relating to this research, including the contact details on this application, may be held on national research information systems, and that this will be managed according to the principles established in the Data Protection Act 2018.
12. Where the research is reviewed by a REC within the UK Health Departments Research Ethics Service, I understand that the summary of this study will be published on the website of the Health Research Authority (HRA) together with the contact point for enquiries named below. Publication will take place no earlier than 3 months after the issue of the ethics committee's final opinion or the withdrawal of the application.

**Contact point for publication** *(Not applicable for R&D Forms)*

*HRA would like to include a contact point with the published summary of the study for those wishing to seek further*

*information. We would be grateful if you would indicate one of the contact points below.*

- ○ Chief Investigator
- ○ Sponsor
- ○ Study co-ordinator
- ○ Student
- ◉ Other – please give details
- ○ None

Title:
Dr
Forename / Initials:
Karen
Surname:
Hind
Post:
Associate Professor
Work address:
42 Old Elvet, Durham University
Work email:
karen.hind@durham.ac.uk
Work telephone:

**Access to application for training purposes** *(Not applicable for R&D Forms)*

*Optional – please tick as appropriate:*

☐ I would be content for members of other RECs to have access to the information in the application in confidence for training purposes. All personal identifiers and references to sponsors, funders and research units would be removed.

Signature: .....

Print Name: Lewis Williams

Date: 18/01/2022 *(dd/mm/yyyy)*

**D2. Declaration by the sponsor's representative**

*If there is more than one sponsor, this declaration should be signed on behalf of the co-sponsors by a representative of the lead sponsor named at A64-1.*

I confirm that:

1. This research proposal has been discussed with the Chief Investigator and agreement in principle to sponsor the research is in place.
2. An appropriate process of scientific critique has demonstrated that this research proposal is worthwhile and of high scientific quality.
3. Any necessary indemnity or insurance arrangements, as described in question A76, will be in place before this research starts. Insurance or indemnity policies will be renewed for the duration of the study where necessary.
4. Arrangements will be in place before the study starts for the research team to access resources and support to deliver the research as proposed.
5. Arrangements to allocate responsibilities for the management, monitoring and reporting of the research will be in place before the research starts.

   Please note: *The declarations below do not form part of the application for approval above. They will not be considered by the Research Ethics Committee.*
6. Where the research is reviewed by a REC within the UK Health Departments Research Ethics Service, I understand that the summary of this study will be published on the website of the National Research Ethics Service (NRES), together with the contact point for enquiries named in this application. Publication will take place no earlier than 3 months after issue of the ethics committee's final opinion or the withdrawal of the application.
7. Specifically, for submissions to the Research Ethics Committees (RECs) I declare that any and all clinical trials approved by the HRA since 30th September 2013 (as defined on IRAS categories as clinical trials of medicines, devices, combination of medicines and devices or other clinical trials) have been registered on a publically accessible register in compliance with the HRA registration requirements for the UK, or that any deferral granted by the HRA still applies.

Signature: .....

Print Name:

Post:

Post:

Organisation:

Date: *(dd/mm/yyyy)*

**D3. Declaration for student projects by academic supervisor(s)**

1. I have read and approved both the research proposal and this application. I am satisfied that the scientific content of the research is satisfactory for an educational qualification at this level.

2. I undertake to fulfil the responsibilities of the supervisor for this study as set out in the UK Policy Framework for Health and Social Care Research.

3. I take responsibility for ensuring that this study is conducted in accordance with the ethical principles underlying the Declaration of Helsinki and good practice guidelines on the proper conduct of research, in conjunction with clinical supervisors as appropriate.

4. I take responsibility for ensuring that the applicant is up to date and complies with the requirements of the law and relevant guidelines relating to security and confidentiality of patient and other personal data, in conjunction with clinical supervisors as appropriate.

**Academic supervisor 1**

This section was signed electronically by Dr Katie Di Sebastiano on 31/01/2022 22:20.

| | |
|---|---|
| Job Title/Post: | Assistant Professor |
| Organisation: | Durham University |
| Email: | kathleen.di-sebastiano@durham.ac.uk |

**Academic supervisor 2**

This section was signed electronically by Dr Shaun McLaren on 31/01/2022 21:26.

| | |
|---|---|
| Job Title/Post: | Teaching Fellow |
| Organisation: | Durham University |
| Email: | shaun.mclaren@durham.ac.uk |

**Academic supervisor 3**

This section was signed electronically by Dr Karen Hind on 31/01/2022 19:55.

| | |
|---|---|
| Job Title/Post: | Associate Professor |
| Organisation: | Durham University |
| Email: | karen.hind@durham.ac.uk |

**I) Durham University department ethical approval application: Reference approval number - SPORT-2022-06-24T16_05_50-cvmc73**

**Ethical Approval:** [redacted]

Ethics <[redacted]>
Mon 11/07/2022 13:51
To: [redacted]
Cc: SES-RESEARCHADMIN, S S. [redacted]

Please do not reply to this email.

Dear [redacted]

The following project has received ethical approval:

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

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

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

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

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