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The Anthropometric and Physiological Characteristics of Elite Rugby Athletes

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Abstract

This is the first article to review the anthropometric and physiological characteristics required for elite rugby performance within both Rugby Union (RU) and Rugby League (RL). Anthropometric characteristics such as height and mass, and physiological characteristics such as speed and muscular strength, have previously been advocated as key discriminators of playing level within rugby. This review aimed to identify the key anthropometric and physiological properties required for elite performance in rugby, distinguishing between RU and RL, forwards and backs and competitive levels. There are differences between competitive standards such that, at the elite level, athletes are heaviest (RU forwards ~111 kg, backs ~93 kg; RL forwards ~103 kg, backs ~90 kg) with lowest % body fat (RU forwards ~15%, backs ~12%; RL forwards ~14%, backs ~11%), they have most fat-free mass and are strongest (Back squat: RU forwards ~176 kg, backs ~157 kg; RL forwards ~188 kg, backs ~ 168 kg; Bench press: RU forwards ~131 kg, backs ~118 kg; RL forwards ~122 kg, backs ~113 kg) and fastest (10 m: RU forwards ~1.87 s, backs ~1.77 s; 10 m RL forwards ~1.9 s, backs ~1.83 s). We also have unpublished data that indicate contemporary RU athletes have less body fat and are stronger and faster than the published data suggest. Regardless, well-developed speed, agility, lower-body power and strength characteristics are vital for elite performance, probably reflect both environmental (training, diet, etc.) and genetic factors, distinguish between competitive levels and are therefore important determinants of elite status in rugby.

Key Words:

Elite Athletes; Anthropometric Characteristics; Physiological Characteristics; Genetics.

Introduction

The first documented international rugby match was played in 1871 between England and Scotland, with the origins of the sport believed to have been created in Rugby School, England, in 1823. Rugby split into two codes: Rugby union (RU) and rugby league (RL) in 1895 thought to be due to social, cultural and economic divisions within England (15, 31).

RU is normally played by two teams of 15 athletes (8 forwards and 7 backs) and RL is played by two teams of 13 athletes (6 forwards and 7 backs). In both codes, each athlete has their own specific role and those roles differ somewhat between codes even if the name of the position is the same (e.g. hooker). Both RU and RL matches are 80 minutes duration with a 10-minute half time break. The aim of both games is to advance into the opposition's territory and score as many points as possible. There are many similarities between RU and RL in terms of physical characteristics, movement patterns and rules. However, RL does not have lineouts, rucks, mauls and the number of tackles during one period of ball possession is limited to six, immediately after which the ball must be given to the opposition team to begin their set of six tackles (40, 55).

Positional-Specific Game Demands

Each athlete in RU and RL has a designated position that requires specific physical and technical characteristics (28, 39, 82). In RU, forwards are involved in more scrums, lineouts, rucks and mauls, which demands greater height, mass, and absolute power and strength (i.e. irrespective of body mass) to be effective (27). The backs' main role of advancing into opposition territory in open play requires a combination of speed, acceleration and agility (28), thus power and strength relative to body mass. This is broadly similar to RL where forwards are primarily involved in a high number of tackles and collisions, while backs are predominantly involved in free running (45).

Analysis of elite RL matches found outside backs (winger, fullback, and centre), adjustables (halfback, stand-off and hooker), wide-running forwards and hit up forwards (prop, second row and loose forward) covered mean distances of 6819 m, 6411 m, 5561 m, and 3569 m respectively (42). Thus, backs covered more distance than forwards, while hit up forwards and wide-running forwards were also involved in more moderate and heavy collisions and more repeated high-intensity efforts than the backs (42). This is very similar to elite RU with front row forwards, second row forwards, back row forwards, inside backs and outside backs covering maximum distances during match play of 4757-5139 m, 5027 m, 5244-5422 m, 5902-6389 m and 5489-6272 m respectively, and back row and front row forwards spending more time in high-intensity exercise than the backs (5, 66).

Work to rest ratios have also been analysed during match play in RU and were found to be 1:4, 1:4, 1:5 and 1:6 for front row forwards, back row forwards, inside backs and outside backs respectively (5) within the Super 14 competition. However, in the English Premiership competition work to rest ratios of 1:8 and 1:15 were found for forwards and backs respectively (29). This difference could be partially down to changes in the laws of the game when the studies were conducted, although differing methods of defining work and rest periods could also account for some of the difference. That being said, Deutsch et al. (25) proposes that there are significant demands on all energy systems across all playing positions, although forwards have a greater dependence on anaerobic glycolytic metabolism due to their increased time spent in high intensity activities.

Collisions

Collisions in rugby occur during defensive tackles, offensive hit-ups and from clearing rucks, mauling, mid-air contact and falls (33, 35). Data from rugby-based collision studies can provide an insight into the frequency and magnitude of impacts to which athletes are subjected. However, such data may be dependent upon the coaching strategy implemented by differing teams and codes. These data could aid in the understanding of injury, particularly brain injury, as well as the implementation of recovery protocols and training program (70).

Impact forces from tackles and hit-ups differ between athlete groups. RL hit-up forwards have the highest rate of collisions (0.8 per min), with a force of >10 *g* every 2 min of match play (22). In contrast, outside backs experience 0.2 collisions per min with an impact force of 1 *g* every 5-9 min (22). Similar collision rates are observed within RU, with forwards experiencing more collisions than backs (0.7-0.9 collisions per min and 0.3-0.4 collisions per min, respectively) (93). RL hit-up forwards also perform the highest number of tackles (0.5 tackles per min), 5-fold more than adjustables and backs (22). Performance analysis findings from elite RL matches support the differing impact levels in RL forwards and backs (49, 109).

Within RU, maximum tackle counts differ amongst playing positions (back row = 29, inside backs = 28, front row = 19, and outside backs = 16) (25), where injury risk is greater for ball carriers than tacklers and when being tackled by two or more opponents is associated with increased risk of injury (88). Reardon et al. (92) reported a mean of 137 collisions for forwards and 94 for backs. In comparison, RL forwards experience approximately 55 collisions (39 tackles, 16 hit-ups) and RL backs experience 29 (16 tackles, 13 hit-ups) per game (56). The differing numbers of collisions between RL and RU indicate the varied styles of play between codes, and thus differing physiological requirements and injury risks.

The Relationship between Physical and Physiological Characteristics and Key Performance Indicators in Elite Rugby

Relationships between anthropometric and physiological parameters and specific match tasks have been identified in both RU and RL (35, 54, 101). Smart et al. (101) compared fitness test data to game behaviours thought to be important for success, finding sprint times over 10 m, 20 m and 30 m had moderate to small negative correlations with line breaks ($r \sim 0.26$), metres advanced ($r \sim 0.22$), tackle breaks ($r \sim 0.16$) and tries scored ($r \sim 0.15$) per game in elite RU. Additionally, the average time of 12 repeat sprints and % body fat in the forwards, and repeated sprint fatigue (% reduction in repeated sprint time) in the backs had moderate to small correlations with a measure of activity rate on and around the ball in competitive matches (r = -0.38, r = -0.17 and r = -0.17, respectively). In RL, Gabbett et al. (35) found that the ability to hit and spin, as well as pass out of the tackle were associated with higher body mass ($\eta = 0.486$ and $\eta = 0.474$, respectively), while athletes with higher skinfold thickness had a reduced ability to beat an opponent (i.e. advance past an opponent using speed and agility) ($\eta = -0.454$), reduced play-the-ball speed ($\eta = -0.435$) and poorer skills when fatigued ($\eta = -0.600$). In addition, the ability to beat an opponent was associated with a higher vertical jump height ($\eta = 0.442$), better agility and faster 20 m and 40 m sprint speeds ($\eta = -0.467$ and $\eta = -0.483$, respectively). Furthermore, the ability to effectively perform a two versus one (defined as: move the defender away from the support player, deliver a timed pass to support player) was associated with faster agility ($\eta = -0.364$), while faster play-the-ball speed was associated with higher estimated VO_{2max} ($\eta = 0.310$) and faster 10 m, 20 m, and 40 m sprint speed ($\eta = -0.327$ to -0.383). Finally, the ability to pass out of the tackle was associated with faster agility ($\eta = -0.485$) and faster 10 m, 20 m, and 40 m sprint speeds ($\eta = -0.406$ to -0.454). These findings demonstrate the importance of anthropometric and physiological characteristics at the elite level of rugby.

The games of RU and RL are physically demanding with elite athletes required to perform frequent bouts of intense activity such as tackling, wrestling, sprinting, running and passing, combined with short periods of low intense activities that include walking, standing and jogging (11, 12, 26, 45, 80, 82). There are many phases of contact, such as tackling, rucks, mauls and scrums that demand differing physical characteristics (12, 26, 82). Rugby Union and RL requires athletes to have well-developed maximal aerobic and anaerobic power, speed, agility and muscular strength and power to allow them to cope with the varied demands of the sport (3, 26, 34). Therefore, the aim of this article is to provide the first review of the literature on the anthropometric and physiological characteristics of elite rugby athletes and, where possible, distinguish between RU and RL, forwards and backs and competitive levels.

For the purpose of this article, athletes are classed as 'elite' in RU if they competed in the top tier of a professional competition in a tier one rugby nation such as Super Rugby (Argentina, Australia, Japan, New Zealand and South Africa), the Premiership (England), the Top 14 (France) or the Pro14 (Ireland, Italy, Scotland, South Africa and Wales) or if they competed in international competitions for a tier one nation. For RL, athletes were classed as elite if they competed in the National Rugby League (NRL) (Australia and New Zealand), Super League or European Super League competitions (England and France), or if they competed in international RL competitions for New Zealand, Australia or England (the top three teams since the ranking system began in 2007 (http://rlif.com)). A structured literature search was performed for empirical research studies and review articles that met the previously mentioned elite classification, with a particular focus on identifying data by player sub-groups of forwards and backs. Additionally, sub-elite literature was searched for comparison in specific instances.

Anthropometric Characteristics of Rugby Union and Rugby League Athletes

Height

Table 1 and 2 display the anthropometric characteristics (i.e. height, body mass and % body fat) of elite RU and RL athletes, which are discussed below. According to the available published data between 1905-1999, RU athlete height increased at a similar rate to that of the general population (85). Sedeaud et al. (95) more recently found that for all RU World Cups between 1987-2007 the backs in the quarter-finalists, semi-finalists, finalists and winners were taller than backs of other teams and a similar pattern was found in the forwards. Similarly, Sedeaud et al. (96) compared the height of elite French RU athletes in the 1988-1989 season to that of 2008-2009. Backs and forwards in 2008-2009 were taller by a mean 5.4 cm and 2.9 cm respectively and a similar pattern was found in the elite under 21 and under 15 years athletes. Comparable changes were seen in RU athletes at English Premiership teams during a shorter time period (2002-2011) with significant increases in height of 1.4 cm·decade^{-1} for backs and 1.3 cm·decade^{-1} for forwards (33). In RL, Till et al. (105) performed a retrospective longitudinal analysis of anthropometric and physical qualities in junior RL athletes that associated with adult career success, finding junior athletes who succeeded in gaining professional careers had greater increases in sitting height from age 13 to 15 years (~6 cm) compared to those who were not successful (~4 cm). From the available data, it appears that elite RU athletes are taller than their RL counterparts and also have a wider range of heights, with differences seen between both forwards and backs: Mean (standard deviation) data are for RU forwards 189 (7) cm vs RL forwards 186 (5) cm; RU backs 182 (6) cm vs RL backs 180 (4) cm (17, 33). The differing physical demands of rugby and its varied playing positions require particular height characteristics with clear differences in height between backs and forwards (28, 45).

Body Mass

The body mass of elite rugby athletes increased dramatically between 1970-2000 (85), and continues to increase (96) well above the general population of young males. There has been a significant increase in mass of RU forwards and backs between World Cups from 1987-2007, with forwards and backs gaining ~1.3 kg and ~1.5 kg, respectively, every 4 years between competitions (95). Further evidence from Sedeaud et al. (96) found elite French RU forwards and backs have become heavier by ~12 kg over the last 20 years, while Fuller et al. (33) reported backs had increased body mass by 2.4 kg·decade^{-1} and forwards 1.9 kg·decade^{-1} between 2002-2011. Thus, due to increases in mass and height of athletes (especially among backs), older research arguably has limited application to present day RU.

Literature at the elite level for RL across World Cups is sparse compared to RU, although previous research has identified body mass as the only physical characteristic to successfully predict selection into a first-grade RL team (37) and whether athletes will be forwards or backs (38). Furthermore, Till et al. (105) found that junior RL athletes who progressed to professional level demonstrated greater gains in body mass between 13 to 15 years of age than those who competed only at an amateur level (15.7 kg and 12 kg, respectively). It is well established that, at the elite level, forwards are significantly heavier than backs in both RU and RL (28, 72, 73, 84). However, elite RU forwards are on average ~4 kg heavier than their RL counterparts: RU forwards 108.3 (8.2) kg vs RL forwards 104 (10.1) kg; RU backs 94 (8.2) kg vs RL backs 95 (9.3) kg (24, 72, 73, 84).

A heavier body mass is considered fundamental for generating increased momentum in tackles and physical collisions (50). As forwards in both RU and RL spend significantly more time in these actions than backs, their larger body mass adds momentum to these contact situations. Success in rugby has also been linked to body mass with evidence showing that the highest performing teams for RU World Cups (1987-2007) have the heaviest forwards (95) and the heaviest average mass of the squad (85). Further, in RU the larger body mass of forwards has been correlated with scrummaging force (90). The greater mass of forwards has also been proposed to act as a protective mechanism from impact injuries (79), as they are involved in 60% more high acceleration/deceleration impacts than backs (23), yet present a lower risk of injury (32, 34).

Percentage Body Fat

Larger body mass has been shown to correlate with higher competitive standard in RU and the ability to predict selection into first-grade RL teams (37, 85, 95). However, the composition of the extra mass is crucial to performance. If the extra body mass comprises fat rather than lean tissue, this will reduce an athlete's power-to-weight ratio and acceleration in the horizontal and vertical planes will be decreased (111).

Calculations of body fat % are problematic due to concerns using doubly indirect methods of measurement - for example, skinfold assessments and the utilisation of predictive equations from studies on cadavers (76). Also, comparisons between RU and RL are limited due to differing measurement techniques and predictive equations applied. These limitations are acknowledged vis-à-vis the following section.

It is generally accepted that % body fat is lower in athletes competing at higher standards of rugby (28, 104). Evidence from RL demonstrates lower % body fat with increased competitive level: amateur forwards 19.9 (3.7)%, backs 17.5 (5)% (36); semi-professional forwards 17.6 (4.4)%, backs 15.2 (4.1)% (41); professional forwards 13.5 (2.9)%, backs 11.1 (2.7)% (73). Elite RU athletes appear to have more body fat than elite RL athletes, with RU forwards reportedly 15.5 (5.5)% and backs 13.5 (4.8)% (72). This could reflect the extra body mass carried by the RU athletes, mentioned previously. However, caution should be taken when interpreting these data as they may not accurately describe the elite athlete population due to the sparse data available. It is likely that elite rugby athlete % body fat is now even lower than previously reported. In both RU and RL, forwards carry more body fat than backs (72, 84) and this might serve as a protective buffer in collisions and physical contact situations (79) experienced more frequently by forwards. The lower % body fat in backs is probably reflective of the higher power-to-body mass ratio and running speed requirements of the backs. Greater lean mass is desirable in rugby athletes to improve strength, power and speed - components critical to performance (28, 85). Competitive success is linked to increased mass of a rugby squad (85), especially mass of forwards (95) and this higher body mass is more functional as lean tissue than fat.

Success in rugby is related to anthropometric characteristics with the highest performing teams in RU world cups (1987-2007) having the heaviest forwards and tallest backs (95) and the heaviest average mass of the squad (83). The anthropometric characteristics of rugby athletes (summarised in Table 1 and 2) also appear to be fundamental to their positional demands, with forwards typically being taller, heavier and with higher body fat than backs (33, 45). There can also be large differences according to playing position which is lacking in the literature as most data is presented as squad or split between forwards and backs, rather than on specific positions. In RU, for example, elite scrum half athletes are approximately 85 kg and 177 cm, whilst second row athletes are approximately 113 kg and 198 cm - a difference of 28 kg and 21 cm (33). These differences in anthropometric characteristics according to playing position, as well as the trend that athletes are becoming taller and heavier, could have a significant impact on how the game is played. Increases in mass will potentially increase impact forces in the tackle (108) and scrum (83), which could have implications on the severity and incidence of injury. This increased incidence and severity of injury could reduce athlete availability for selection across a season and increase demand for larger squads of athletes (33).

********************************Table 1 somewhere near here**********************************

********************************Table 2 somewhere near here**********************************

Physiological Capacity of Rugby Union and Rugby League Athletes

Maximal Aerobic Power

Tables 3 and 4 display the physiological characteristics (10 m and 30 m sprint times, 1RM bench press and back squat) of elite RU and RL athletes, which are discussed below. Due to the length of RU and RL matches, the considerable distance covered at low speeds (49) and the requirement of fast recovery after high-intensity activity, it might be assumed that a high maximal rate of oxygen uptake (VO_{2max}) would be important for performance (64). However, both elite RU and RL athletes have lower VO_{2max} levels than elite performers in other invasion sports such as football (60.1 (2.3) $mL\cdot kg^{-1}\cdot min^{-1}$ (102) and field hockey (55.8 (4.0) $mL\cdot kg^{-1}\cdot min^{-1}$) (62). However, it is likely that elite rugby athletes have higher absolute VO_{2max} levels compared to their other invasion sport counterparts but due to their extra body mass their relative values are lower. RL athletes appear to have somewhat higher VO_{2max} levels than their RU counterparts (RL squad: 54.9-55.9 $mL\cdot kg^{-1}\cdot min^{-1}$ v RU backs: 48.3 (2.1) $mL\cdot kg^{-1}\cdot min^{-1}$; forwards: 41.2 (2.7) $mL\cdot kg^{-1}\cdot min^{-1}$) (47, 48, 94), however, this is based on RL whole squad data rather than player sub-group, as no data could be found for this in RL. Caution should be taken when interpreting these rugby data due to different methods of data collection, i.e. the RU data derive from a direct measure of VO_{2max} in a laboratory setting, while the RL data were estimated from a multi-stage shuttle run using regression equations to predict VO_{2max}. Additional error is introduced when extrapolating from running performance alone to VO_{2max} due to inter-individual differences in running economy, lactate metabolism and state of training (77, 91). Furthermore, the published RU data are over a decade old and are not likely to be applicable to present day RU.

To the authors' knowledge there is no data distinguishing between VO_{2max} levels of elite RL forwards and backs, although in RU backs have higher relative (accounting for body mass) VO_{2max} but lower absolute values than forwards (12). Although certainly not the highest of field sport athletes, elite RL and RU athletes still have aerobic power somewhat above non-athletic populations, which enables them to perform and recover during repeated efforts of tackling, rucking, scrummaging and explosive running (45). However, it is worth noting that VO_{2max} is poorly associated with match performance (47, 54), which would question its utility in an applied setting. Furthermore, VO_{2max} differs between playing standards (48, 104) and is perhaps most important at junior level where it is the strongest discriminator between playing standards in RL (104).

Anaerobic Performance

Rugby Union and RL have large periods of competition where athletes perform repeated bouts of high-speed running (>5 $m\cdot s^{-1}$) in short periods of time (52, 68), as well as periods of sustained and repeated intense efforts such as tackling, collisions and scrummaging (25). These phases of play require athletes to have a high anaerobic capacity to compete at the highest level. However, presenting anaerobic capacity data here is particularly challenging, because methods used to assess this parameter are highly variable. For example, some studies have utilised the Yo-Yo Intermittent Recovery Test (4, 53, 65), while others have utilised prolonged high-intensity running ability tests (47, 48, 54), which comprise of 8 repetitions of 12 s sprints (20 m forward, turn 180°, sprint

10 m, turn 180° and sprint 20 m etc) or repeated sprint ability tests (Rugby-Specific Repeated-Speed (RS^2)) test which consists of 3 sets of 3 or 4 individual sprints performed maximally at set times. Between sprint sets, periods of standardized work are set where players jog with weighted bags over their shoulders and perform down and ups (move from standing to prone position and back to standing). The protocols differ slightly between forwards and backs (100). Due to these inconsistent approaches, an interesting attempt has recently been made to validate specific repeat high-intensity effort tests (6). Austin et al. (6) designed three repeated high-intensity exercise tests (RHIE backs test, RHIE RL forward test and RHIE RU forward test), each test including a variety of sprints (ranging 10-20 m), decelerations, tackles and for RU forwards the inclusion of scrummaging. A superior high-intensity running ability is associated with greater playing minutes (48), greater total and high-speed distance covered during matches (55) and quicker recovery after matches (65). Conversely, an inverse association has been reported between high-intensity running during testing and the number of collisions and high-intensity efforts performed in matches (54). This is likely due to forwards performing worse than backs in the high-intensity running test in conjunction with forwards completing a greater amount of collisions than backs during matches. The findings also infer that rugby athletes with greater high-intensity running ability may be better able to avoid contact. Forwards spend longer periods in high-intensity work than backs, due to their increased contributions in scrums, rucks and mauls, while backs spend nearly two to three times longer performing high-intensity running than forwards (25). The ability of both forwards and backs to maintain high work rates is potentially linked to success in RL, with elite and semi-elite competitions demonstrating that winning sides cover greater match distances (10, 43).

Speed

Sprinting speed is an essential characteristic for RL athletes as it will enable them to quickly position themselves in attack and defence (81). Acceleration appears to be more important than maximum velocity sprinting as almost 40% of all sprints performed are between 6-10 m and 85% of all sprints are under 30 m (64). In both RU and RL, backs are faster than forwards (Tables 3 and 4), particularly over longer distances such as 30 m or 40 m (36, 81, 100). Baker and Newton (9) report 10 m and 40 m RL squad sprint times of 1.61 (0.06) s and 5.15 (0.24) s, respectively, while De Lacey et al. (24) report 10 m and 40 m sprint times for RL forwards of 1.72 (0.07) s and 5.40 (0.27) s and for RL backs 1.66 (0.03) s and 5.11 (0.09) s, respectively. Hansen et al. (57) report RU squad sprint data for 10 m and 30 m of 1.91 (0.10) s and 4.40 (0.25) s, respectively, while Crewther et al. (18) report 10 m and 20 m sprint times for RU forwards of 1.85 (0.06) s and 3.16 (0.10) s and for RU backs 1.73 (0.06) s and

2.96 (0.09) s, respectively. Cross et al. (21) directly compared the sprinting ability of RU and RL athletes, reporting 10 m sprint times of 2.04 (0.12) s and 2.08 (0.08) s for RU forwards and RL forwards respectively and 1.95 (0.04) s and 2.01 (0.10) s for RU backs and RL backs respectively. For 30 m sprint times, RU backs achieved 4.32 (0.09) s and RL backs 4.39 (0.11) s, but no data were reported for forwards at this distance. Cross et al. (21) utilised a radar device to measure speed, while all the other mentioned studies utilised timing gates - this could account for the slightly slower times seen in Cross et al's. (21) study. We are not aware of directly comparable sprint data for 30 m or 40 m for elite forward RU and RL athletes. However, outside backs for both RU and RL are the fastest over 10-40 m, while front row and second row forwards are the slowest (14, 100). This indicates that speed is a discriminating factor between backs and forwards, while speed is also a discriminating factor between competitive standards with elite athletes the fastest (48, 104, 105). In addition to this, data appear to suggest that the distance covered at faster speeds (above 5 $m{\cdot}s^{-1}$) is higher during tier one RU international matches compared to professional club matches (89). This potentially has implications for injury incidence and severity, due to higher momentum during collisions between athletes.

Agility

The ability to quickly accelerate, decelerate and change direction is thought to be vital in RL (42, 45, 80). However, little difference has been found between change of direction speed performance across RL senior competitive levels (37, 46, 51, 98) or positions (41). Gabbett et al. (46) reported 505 test scores for professional and semi-professional RL athletes of 2.24 (0.05) s and 2.27 (0.07) s, respectively, and had previously reported similar findings between first and second grade RL athletes in the 505 test (2.34 (0.20) s and 2.39 (0.15) s, respectively). Conversely, when a sport-specific stimulus is added to test reactive agility there are clear differences between competitive levels and positions (44, 51, 98), with Gabbett and Benton (44) reporting times for a reactive agility test for elite and sub elite RL athletes of 2.35 s and 2.56 s, respectively. Thus, characteristics such as anticipation, visual scanning and game reading are essential to reactive agility and are separate qualities to change of direction speed (64). Evidence therefore suggests that what separates elite RL athletes from those at lower competitive standards in regards to agility is primarily their ability to read game situations, make decisions and change direction quickly in response. To the authors' knowledge, there are no published data for tests of agility in elite RU athletes, although it is likely that RU athletes have similar characteristics to elite RL athletes.

Muscular Strength and Power

Strength

Having high levels of muscular strength and power is crucial in rugby, as being able to generate high levels of muscular force rapidly will enable athletes to perform more effectively during tackling, wrestling, rucking, jumping, sprinting and changes of direction (81). Distinct differences in strength in regards to the bench press and back squat have been found between forwards and backs in both RU and RL (78, 81, 100, 101) (Table 3 and 4). RL forwards and backs appear to have greater maximal back squat than RU athletes (Forwards: RU 165-186 kg vs. RL 188 kg; Backs: RU 145-168 kg vs. RL 168 kg) (78, 100, 101), although maximal bench press appears higher for RU athletes (Forwards: RU 125-136 kg vs. RL 119-124 kg; Backs: RU 111-125 kg vs. RL 113-112 kg) (78, 81, 100, 101). However, the data for RL athletes are dated and the strength of present day athletes could differ. In RU, the props are the strongest athletes (Back Squat: 184 (19) kg; Bench Press: 133 (18) (100)) and the inside and outside backs the weakest (Back Squat: 141 (20) kg; Bench Press: 111 (16) (100)), Back Squat: 145 (24) kg; Bench Press: 109 (16) (100), respectively). In RL, although forwards are stronger in terms of total mass lifted, when expressed relative to body mass there were no differences between forwards and backs (17). Although there are sparse data available for elite RU and RL athletes, lower-body strength would appear particularly important and data from RL semi-professional level show positive associations between 3 RM squat and distances covered at both high and low intensity and also with number of high intensity bouts during matches (53, 65). It is reasonable to assume that these findings would be similar at the elite level of both RL and RU. Regarding athlete competitive standard, muscular strength has been shown to be a potent discriminator in RL, with differences found between elite professionals, college and high school athletes (8). Furthermore, differences in lower body strength have been reported between elite professional and semi-professional RL athletes (1 RM back squat: 175 (27) kg and 149 (14) kg, respectively) (9).

Table 3 somewhere near here**********************

Table 4 somewhere near here**********************

Power

The most common methods of measuring or estimating lower body muscular power in rugby are via vertical jump height (36, 37, 41, 46), peak power from jump squats (8, 9) and for the upper body via the use of bench throws (8, 17). Jump height is not a direct power measurement, but due to its simplicity is quite widely used to estimate peak power. In both RU and RL, backs produce greater vertical jump performances compared to forwards (28, 37), which is likely due to lower body mass levels rather than higher peak power production. However, direct comparisons between RU and RL data are problematic, due to differing testing protocols utilised and limited current data available, particularly for RU athletes. In RL, greater lower-body relative power is associated with lower sprint times over 5 m, 10 m, and 30 m (20) and dominant tackles during matches (47). Further, the results of jump squats can discriminate between competitive levels in RL with elite athletes achieving significantly higher results: elite RL professional jump squat = 1,897 (306) W; semi-professional RL = 1,701 (187) W (9). This corresponds with previous research demonstrating increases in muscle power as competitive level increased (37, 38). Similar findings have been observed in RU with elite athletes producing greater absolute and relative power outputs during the bench throw and jump squat than semi-professional and academy level athletes. For example, bench throw: professional 1,140 (220) W, semi-professional 880 (90) W, academy 800 (110) W; jump squat: professional 5,240 (670) W, semi-professional 4,880 (660) W, academy 4,430 (950) W (2).

Rate of Force Development

Tests of vertical jump height and mean and peak power output from jump squats and bench throws can provide some useful data on the power capabilities of elite rugby athletes. However, more direct measures of the underlying properties essential for the explosive force requirements within rugby arguably have greater external validity and may provide more useful data, such as rate of force development (RFD). The more commonly used measures of power including peak and mean power output have been questioned regarding their external validity within the literature (19, 71), with a major limitation being that they do not take account of the temporal characteristics of force measurement such as RFD. Significant associations have been observed between RFD utilising the isometric mid-thigh pull (IMTP) exercise and strength, agility and sprint performance within collegiate RU athletes (110). Furthermore, RFD measured during isometric squats correlated with 5 m and 20 m sprint performance (r = -0.63 and r = -0.54, respectively), as well as counter-movement jump height (r = 0.61) in rugby union athletes competing in English National League 2 or higher (107). Specifically, sprint performance was associated with early phase (≤ 100 ms) RFD, while jump height was related to later phase (> 100 ms) explosive force (107). These findings suggest that the relationship between RFD and athletic performance is dependent on the force-time characteristics of the athletic activity. It is important to note that the measurement of RFD is complex, due to the large variability in rapid muscle activation capacity at the initial onset of contraction (75). This is particularly notable during less rigidly controlled movements such as multi-joint isometric squats and IMTP, where more compliance likely occurs within some dynamometer systems compared to isolated single-joint tasks. Therefore, associations between RFD and performance should be scrutinised carefully.

RFD is normally measured during single-joint dynamic movements (1) because this allows for more experimental control than during multi-joint movements. Single and multi-joint isometric actions are also used, but because muscle contraction velocity and length affect force, measurement of RFD is usually more challenging (106). Thus, tests such as the IMTP (110), isometric squat (107) and isometric knee extension (13) have been used to assess RFD within rugby. However, it is debatable how relevant these forms of testing are, as they do not replicate the dynamic multi-joint contractions that dominate rugby performance. This is potentially one of the reasons, alongside the questionable reliability of RFD measurement, as to why jump testing is a more commonly used method. Jumping, however, is possibly not the optimal exercise for developing RFD, as Kawamori et al. (67) found that time to peak RFD during midthigh clean pulls (a derivative of a clean squat; the bar starts at the midthigh area and is pulled maximally upwards but is not 'caught' like a clean squat) at a variety of loads was faster (30% 1RM, 100 (14) ms) than time to peak RFD in both countermovement (263 (64) ms) and vertical (195 (27) ms) jumps, suggesting that Olympic-style weightlifting exercises might be more appropriate than vertical jumping for training to develop RFD.

Data are sparse regarding RFD utilising Olympic-style weightlifting in rugby, likely due to the mentioned reliability issues. Two papers were identified, one for RU (69) and one for RL (16). Kilduff et al. (69) tested 12 professional RU athletes for maximum efforts of the hang power clean (a derivative of the clean squat; the bar starts just below the knee and is rapidly pulled vertically where it is 'caught' in a partial front squat position). Peak RFD was observed at the heaviest load of 90% (1 RM), with athletes producing 29,858 (17,663) $N{\cdot}s^{-1}$. Comfort et al. (16) examined 11 elite professional RL athletes during variations of the power clean. All attempts utilised a load of 60% of a predetermined 1 RM power clean and a peak RFD of 9,769 (4,012) $N{\cdot}s^{-1}$ was observed during the hang power clean. Further research is needed in this area with consistent methods employed to enable comparison between RU and RL athletes as well as competitive level. However, it is hypothesised that RFD could be a potent descriptor of competitive level within rugby, with the highest forces produced in the shortest time by elite athletes, though there is no evidence readily available to confirm this.

Genetic Factors

Many of the anthropometric and physiological characteristics of elite rugby athletes mentioned within this article can potentially be explained in part by genetic influences. For example, a considerable proportion of the inter-individual variability in multiple traits relevant to rugby performance, such as VO_{2max}, muscle strength, short-term muscle power and injury susceptibility is inherited (58). Emerging evidence from the RugbyGene project has identified a number of key findings to date. Heffernan et al. (59) found that elite RU backs (especially the back three playing positions) appeared to have at least one genetic component previously associated with better sprint ability. The *ACTN3* R577 allele, repeatedly associated with speed and power ability (30, 74), was more common in the back three position athletes (68.8%) than non-athletes (58.0%; $P = 0.04$; odds ratio (OR) = 1.60) and forwards (47.5%; OR = 2.00). The reduced frequency of the R allele in forwards and their corresponding higher XX genotype frequency could indicate inherited fatigue resistance in those athletes, advantageous for maintaining performance despite relatively short rest periods within matches. Indeed, *ACTN3* 577XX human muscle displays elevated calcineurin activity (99), which is associated with enhanced adaptation to endurance training including an increased switch from fast-twitch glycolytic fibres towards fast-twitch oxidative in an experimental mouse model (99). Later, Heffernan et al. (61) reported genotype and allele frequency differences in the fat mass and obesity associated (*FTO*) polymorphism rs9939609 (previously associated with parameters of obesity such as body mass index (63)). The rs9939609 T allele was more common (94%) in elite RU back three and centre athletes (reliant on lean mass relative to body mass for success rather than total body mass) than other elite RU athletes (82%; $P = 0.01$, OR = 3.34) and non-athletes (84%; $P = 0.03$, OR = 2.88). Heffernan et al. (61) also observed directly that the back three and centre athletes had greater peak power relative to body mass than other RU athletes (14%; $P = 2 \times 10^{-6}$). The most recent data from the RugbyGene project show differences in allele and genotype frequencies of the *COL5A1* rs12722 and rs3196378 polymorphisms (previously associated with soft tissue injury risk (86, 97)) between elite rugby athletes (RU and RL) (rs12722: CC genotype = 21%, C allele = 47%; rs3196378: CC genotype = 23%, C allele = 48%) and non-athletes (rs12722: CC genotype: 16%, C allele = 41%, $p \leq 0.01$; rs3196378: CC genotype = 16%, C allele = 41%, $p \leq 0.02$) (65). In particular, the CC genotype was most overrepresented in athletes who competed in the back three and centre positions (24%) compared with non-athletes, with the athletes having more than twice the odds (OR = 2.25, $P = 0.006$) of possessing the CC genotype associated with lower injury risk. Therefore, the higher CC genotype and C allele frequencies in the rugby athletes suggest they may have an inherited resistance against soft tissue injury, which has enabled them to achieve elite status despite exposure to the high-risk environment of elite rugby training and competition. The above-mentioned studies by the RugbyGene project are all candidate-gene approaches which concentrate on specific gene/s that have been chosen due to *a priori* hypothesis about their function on a phenotype. This approach has been criticised due to its inability to include all causative genetic variants and 'anonymous' approaches such as genome-wide association studies (GWAS) are more sophisticated (103). That said, GWAS typically test hundreds of thousands of hypotheses simultaneously and consequently need extremely large sample sizes. When investigating an elite population these 'large' sample sizes are almost unattainable when using a satisfactory (narrow) definition of 'elite'. Thus, when examining an elite population such as rugby athletes, the candidate-gene approach is suitable to investigate candidate genetic variants that have previously been associated with a relevant phenotype, but less useful to investigate genetic variants without such prior evidence.

Anthropometric and Physiological Data at an Elite Level

This article has attempted to extrapolate data from the literature based on elite rugby athletes with particular focus on player sub-group (forwards/backs). This was particularly challenging as most articles reported squad data rather than using player sub-groups. Furthermore, a variety of differing methods and sample sizes have been utilized throughout the literature, which lead to complexities in suggesting these data are truly representative of the elite level. We have data collected in more recent years from elite RU athletes (PRO14, English Premiership and International), utilising laboratory gas analysis for VO_{2max}, DEXA and skinfold measures for % body fat, timing gate measures of 10, 20, 30 and 40 m sprints and 1 RM of bench press and back squat for all player sub-groups. Although it is very important that these methods and data should be exposed to the full rigor of peer-review, for the purpose of this article it is worth noting that our most recent (as yet unpublished) data suggest that elite RU athletes have lower % body fat, higher maximal aerobic power and are stronger, faster and more powerful than reported in the literature. Future research in this area should aim to establish multi-club, multi-position characteristics utilizing reliable and valid testing procedures which would provide robust data for sports scientists working in elite rugby.

Practical Applications

The cumulative body of evidence suggests that elite rugby athletes require relatively high levels of functional body mass with low % body fat, they should have high levels of relative and absolute strength and power as well as aerobic and anaerobic power. Additionally they are required to be fast and agile. Therefore, strength and conditioning coaches and sports scientists need to consider all these parameters when programming at the elite level, to enable the enhancement of each variable with minimal detriment to another. Doing so in parallel with long competitive seasons is also a challenge and probably requires a periodized approach to balance short-term performance with long-term development of important anthropometric and physiological characteristics.

Conclusion

The literature on rugby suggests that as competitive standard rises, athletes are heavier with lower skinfold thicknesses and % body fat, they have more fat-free mass and are stronger, faster and more powerful (100). We recommend a cautious interpretation of some data reviewed in this article, due to limited data regarding certain parameters, some inconsistencies in methods between studies and slightly dated research in a sport that practitioners anecdotally describe as ever-changing. Indeed, it is likely that present day elite rugby athletes have lower % body fat, higher maximal aerobic power and are faster, stronger and more powerful than presented within this article. Nevertheless, well-developed speed, agility, lower-body power and strength characteristics appear vital for performance at the elite level of rugby competition (64). This confirms the importance of specific anthropometric and physiological characteristics in distinguishing between competitive playing standards in both RU and RL (7, 87). There is also emerging evidence to suggest that elite rugby athletes have differing genetic characteristics compared to non-athletes, which enables them to achieve career success and specialise in particular playing positions. Understanding the underlying biological characteristics of elite rugby athletes will allow strength and conditioning programmes to be further developed to meet the requirements of specific positions and codes within elite rugby.

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Tables:

Table 1: Anthropometric characteristics of elite rugby union athletes.

Forwards or Backs (n)	Height (cm)	Body mass (kg)	% Body fat	Reference
Forwards (18)	188 (6)	111 (6)	14.4 (3.0)	(20)
Backs (16)	181 (6)	93 (7)	10.3 (1.9)	(20)
Forwards (8)	190 (10)	115 (6)	-	(23)
Backs (7)	182 (10)	93 (5)	-	(23)
Forwards (320)	189 (7)	111 (8)	-	(38)
Backs (234)	182 (6)	91 (8)	-	(38)
Forwards (17)	188 (7)	108 (8)	15.5 (5.5)	(79)
Backs (13)	183 (5)	94 (8)	13.5 (4.8)	(79)

Data are presented as mean (SD).

Table 2: Anthropometric characteristics of elite rugby league athletes.

Forwards or Backs (n)	Height (cm)	Body mass (kg)	% Body fat	Reference
Forwards (12)	186 (5)	102 (8)	-	(18)
Backs (6)	180 (4)	86 (9)	-	(18)
Forwards (6)	187 (10)	107 (7)	-	(23)
Backs (9)	180 (10)	95 (12)	-	(23)
Forwards (22)	185 (6)	104 (10)	-	(26)
Backs (17)	181 (6)	95 (9)	-	(26)
Forwards (45)	183 (7)	98 (8)	13.5 (2.9)	(81)
Backs (31)	178 (6)	86 (7)	11.1 (2.7)	(81)

Data are presented as mean (SD).

Table 3: Physiological characteristics of elite rugby union athletes

Forwards or Backs (n)	10 m Sprint Time (s)	30 m Sprint Time (s)	1RM Bench Press (kg)	1RM Back Squat (kg)	Reference
Forwards (18)	1.85 (0.06)	-	-	-	(20)
Backs (16)	1.73 (0.07)	-	-	-	(20)
Forwards (8)	2.04 (0.12)		-	-	(23)
Backs (7)	1.95 (0.04)	4.32 (0.09)	-	-	(23)
Forwards (556)	1.80*	-	125*	165*	(110)
Backs (442)	1.70*	-	111*	145*	(110)
Forwards (279)	1.78 (0.09)	-	136 (19)	186 (35)	(111)
Backs (231)	1.69 (0.07)	4.04 (0.14)	125 (17)	168 (32)	(111)

Data are presented as mean (SD). *= Only Individual position data reported in this article – therefore, this is the calculated mean of all individual player positions within the sub-group (forwards/backs).

Table 4: Physiological characteristics of elite rugby league athletes

Forwards or Backs	10 m Sprint Time (s)	30 m Sprint Time (s)	1RM Bench Press (kg)	1RM Back Squat (kg)	Reference
Forwards (6)	2.08 (0.08)	-	-	-	(23)
Backs (9)	2.01 (0.10)	4.39 (0.11)	-	-	(23)
Forwards (22)	1.72 (0.07)	-	-	-	(26)
Backs (17)	1.66 (0.03)	-	-	-	(26)
Forwards (24)	-	-	119 (13)	188 (18)	(87)
Backs (27)	-	-	113 (15)	168 (15)	(87)
Forwards (63)	-	-	124*	-	(90)
Backs (55)	-	-	112*	-	(90)

Data are presented as mean (SD). *= Only Individual position data reported in this article – therefore, this is the calculated mean of all individual player positions within the sub-group (forwards/backs).