Applied Physiology and Game Analysis of Rugby Union

Article *in* Sports Medicine · February 2003

DOI: 10.2165/00007256-200333130-00003 · Source: PubMed

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REVIEW ARTICLE

Sports Med 2003; 33 (13): 973-991
0112-1642/03/0013-0973/$30.00/0

Applied Physiology and Game Analysis of Rugby Union

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Contents

Abstract

Increased professionalism in rugby has elicited rapid changes in the fitness profile of elite players. Recent research, focusing on the physiological and anthropometrical characteristics of rugby players, and the demands of competition are reviewed. The paucity of research on contemporary elite rugby players is highlighted, along with the need for standardised testing protocols.

Recent data reinforce the pronounced differences in the anthropometric and physical characteristics of the forwards and backs. Forwards are typically heavier, taller, and have a greater proportion of body fat than backs. These characteristics are changing, with forwards developing greater total mass and higher muscularity.

The forwards demonstrate superior absolute aerobic and anaerobic power, and muscular strength. Results favour the backs when body mass is taken into account. The scaling of results to body mass can be problematic and future investigations should present results using power function ratios. Recommended tests for elite players include body mass and skinfolds, vertical jump, speed, and the multi-stage shuttle run. Repeat sprint testing is a possible avenue for more specific evaluation of players.

During competition, high-intensity efforts are often followed by periods of incomplete recovery. The total work over the duration of a game is lower in the backs compared with the forwards; forwards spend greater time in physical contact with the opposition while the backs spend more time in free running, allowing them to cover greater distances. The intense efforts undertaken by rugby players place considerable stress on anaerobic energy sources, while the aerobic system provides energy during repeated efforts and for recovery.

Training should focus on repeated brief high-intensity efforts with short rest intervals to condition players to the demands of the game. Training for the forwards should emphasise the higher work rates of the game, while extended rest periods can be provided to the backs. Players should not only be prepared for the demands of competition, but also the stress of travel and extreme environmental conditions.

The greater professionalism of rugby union has increased scientific research in the sport; however, there is scope for significant refinement of investigations on the physiological demands of the game, and sports-specific testing procedures.

Since rugby union became professional in 1995, the science examining the sport and its participants has developed rapidly to meet the increased demand for knowledge on the requirements of the game and the characteristics of the players.[1,2] Rugby is played throughout the world, with the International Rugby Board encompassing 92 national unions.[3] The game is played over two 40-minute halves separated by a break no longer than 10 minutes. There are no stoppages, except in the event of an injury. Rugby is a field-based team sport eliciting a variety of physiological responses as a result of repeated high-intensity sprints and a high frequency of contact. The physiological demands of rugby union, like other football codes, are complex when compared with individual sports (e.g. running, cycling, swimming). Detailed assessment of the demands of rugby are lacking despite investigations on the movement patterns during match play, physiological measurements taken during a match or simulated match play, and the assessment of physiological capacities of elite players. More specifically, there is a clear lack of research on the characteristics on contemporary elite rugby players. Previous reviews have summarised the bulk of the earlier literature on rugby.[1,2] This review encompasses more recent research reports on rugby, identifies research paths for the future, and provides guidelines for the testing of elite players. These priorities are primarily the result of the rapid changes occurring in the characteristics of contemporary rugby players.[4]

1. Description of Rugby Union

During an 80-minute game of rugby, the ball is typically in play for an average of 30 minutes;[5] the remaining time is made up of injury time, conversions, penalty shots or when the ball is out of play.[6] Two teams contest play, each with 15 players on the field at one time, with the exception of players being sent off for misconduct. Each player has a designated position and number outlined by the International Rugby Board:[7] (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) left centre; (13) right centre; (14) right wing; and (15) full back.

These positions are grouped, although there is some variation in terminology among researchers, according to the demands placed on the players in each of the individual positions.[8] The two major groups are players numbered 1 to 8, the 'forwards' (ball winners), and 9 to 15, the 'backs' (ball carriers). Within these two groups, players 1 to 3 are referred to as the 'front row', while 1 to 5 are commonly called the 'tight 5'. The 'second row' is formed by the locks (players 4 and 5). The 'loose forwards' are players 6 to 8 and are also referred to as the 'back row'. Within the backs, 'half backs' are players 9 to 10, 'midfield backs' ('centre-three-quarters') are 12 and 13, and 'outside backs' are 11, 14 and 15.

Each of the positional groups' broad physical requirements, skills and tasks have been outlined previously by Quarrie et al.,[9] and Nicholas.[2] The front-row positions demand strength and power as the players are required to gain possession of the ball, are in continual close contact with opposition, and have limited opportunities to run with the ball. The locks are generally tall, with a large body mass and power an additional advantage. The loose forwards require strength and power as a requirement of players in these positions is to gain and retain possession of the ball. It is a prerequisite for the loose forwards to be powerful and mobile in open play, have excellent speed, acceleration and endurance. A good level of endurance is required by the half backs as they control the possession of the ball obtained by the forwards. Good speed is also an important attribute for the half backs, as they need to accelerate away from the approaching defenders. Midfield backs require strength, speed and power as they have a high frequency of contact with the opposition. Outside backs require considerable speed to out-manoeuvre their opponents. They perform a large amount of support running, chasing down kicks and covering in defence.

2. Physical Characteristics of Rugby Union Players

Rugby union players have a diverse range of physical attributes. A distinct physique will naturally orientate a player towards a particular position over others. This makes rugby an atypical sport when compared with a number of other team sports where homogeneity of physique and physical performance attributes are more common.[9]

2.1 Body Mass

There has been a marked change in the body mass of elite rugby players over the last three decades.[4] Consequently, literature older than 10 years can have limited application to current-day rugby players. It is well accepted that body mass is greater for forwards than backs (figure 1).[9-23] For example, within the 1998 New South Wales Super 12 rugby team, front row forwards (112.8 ± 5.7kg) and the remainder of the forwards (108.3 ± 5.3kg) were significantly heavier than the backs (89.0 ± 6.8kg).[24] Positional differences in body mass are also evident in female rugby players,[25] with forwards (68.9 ± 6.6kg) substantially heavier than backs (60.8 ± 5.7kg). The difference between the

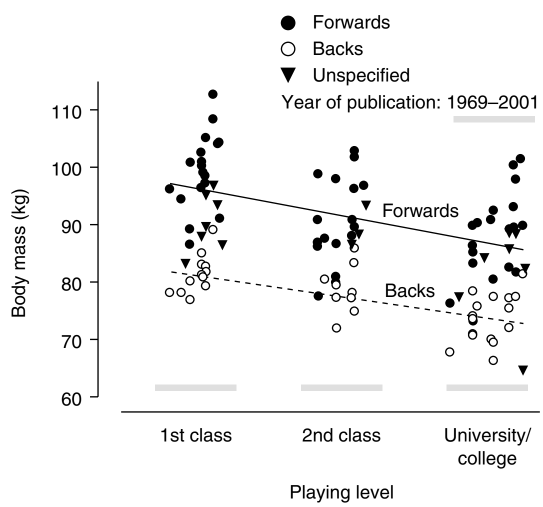

Fig. 1. Body mass (kg) of rugby union players.[9-12,14-16,18-24,26-57] The categories of playing level have been stylised by year for clarity. The solid line represents the between-level trend for forwards and the dashed line represents the between-level trend for backs.

body mass of forwards and backs is less distinct at lower levels of competition,[11,12,26] probably related to greater positional role specificity at elite level (figure 1).

Differences in body mass also occur across different levels of competition. New Zealand senior A forwards (98.5 ± 11.5kg) were significantly heavier than their senior B equivalents (88.1 ± 10.2kg),[11] and as expected, senior players had substantially greater body mass compared with colt-level players.[11,47] However, other researchers have not found these differences among forwards from different playing levels,[14,42] while body mass is similar for backs of different levels.[14,16,58] Increased professionalism in the physical preparation is a likely cause of the increased body mass of rugby players, with this increase greater in the forwards.[4]

Differences in body mass have been observed within the forwards and backs as a discrete group.[9,14,50,58] For example, body mass was markedly lower (89.7 ± 8.1kg) in senior A hookers compared with props of the same level (102.8 ± 8.1kg).[9] Within the backs, inside backs had a substantially lower body mass (75.0 ± 6.9kg) compared with midfield (85.9 ± 6.9kg) and outside backs (83.4 ± 6.9kg).[9] These differences are particularly evident when the large range of player roles within each of the groups are considered.

The body mass of rugby players is generally greater than international players of field hockey (75.0 ± 5.4kg),[59] soccer (77.5 ± 1.3kg)[60] and elite basketball (90.8 ± 11.8kg),[59] but similar to players of rugby league (92.1 ± 10.4kg).[61] In rugby union, a larger body size correlates significantly with scrummaging force [35] and competitive success.[4] Where extra mass consists of fat rather than lean tissue, the power-to-weight ratio is reduced, energy expenditure during movement is increased, and horizontal and vertical acceleration are diminished.[55] In recent years, the greater mobility of the forwards has been associated with lower body fat levels and higher lean body mass.[4,24,54] Apart from physical qualities, elite players must possess excellent technical abilities. An example of this is lowering the centre of gravity and widening the base of support to increase stability.[62,63] Given that mass influences stability,[64] a large lean body mass will assist this technique.

2.2 Height

Differences in stature (standing height) among the various positional groups in rugby are unclear. Recent literature has demonstrated that county and international forwards and backs have similar stature.[23] Conversely, others have shown that both first- and second-class forwards are markedly taller than backs of the same level.[9,11,13,14,18,19,21,22,24,26,65] US national forwards (1.86 ± 0.07m) were markedly taller than backs (1.78 ± 0.05m) of the same level,[19] demonstrating, along with the greater body mass, that the forwards are physically larger than backs.

The higher the level of competition, generally the taller the players (figure 2). For example, senior A forwards (1.86 ± 0.06m) were taller than their senior B counterparts (1.81 ± 0.06m).[11] Within the forward pack, there were significant differences in height between front row, second row and back row players,[9,14,49] with hookers (1.79 ± 0.03m) being significantly shorter than locks (1.92 ± 0.03m).[9] Such variation in stature is also present in the backs

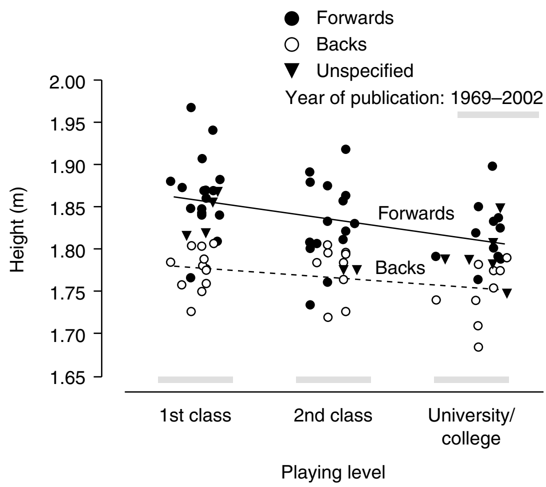

Fig. 2. Height (m) of rugby union players.[9,11,12,14,15,18-24,26-28,30-46,48-53,55,57,65,66] The categories of playing level have been stylised by year for clarity. The solid line represents the between-level trend for forwards and the dashed line represents the between-level trend for backs.

with the inside backs (1.73 ± 0.05m) markedly shorter than the midfield (1.80 ± 0.05m) and outside backs (1.79 ± 0.05m).

At higher playing levels, there is a clearer distinction in stature between forwards and backs. The positional demands of rugby require certain characteristics and this is particularly evident for the lock position in which the overall jump height achieved during the lineout is crucial to success. Locks have similar relative vertical jump performance to other forwards and are inferior when compared with the backs.[12] Their greater height allows them to achieve a superior absolute jumping height in the lineout. Locks (1.92 ± 0.03m)[9] appear to be the only position that has superior stature to other team field sports such as field hockey (1.77 ± 0.03m)[59] and soccer (1.83 ± 0.01m),[60] while being similar to basketball players (1.91 ± 0.10m).[67]

2.3 Percentage Body Fat

The majority of anthropometric assessments of rugby players have involved quantifying the body fat levels of players. The calculation of percentage body fat is problematic due to limitations in establishing percentage body fat from estimates of body density and skinfold measurements.[68] Comparisons of body fat estimates across studies are also confounded by the measurement error of different methods and prediction equations. Comparisons across the literature should acknowledge this imprecision. Given these concerns, it is now common practice to monitor the body mass and sum of skinfolds in elite athletes in preference to estimating percentage body fat.[69,70]

Figure 3 summarises estimates of percentage body fat in rugby union players, demonstrating that as the level of play increases, the percentage of body fat decreases. This difference, also evident between the forwards and the backs, reduces with increasing playing level. Between positions, first-class and second-class forwards had substantially greater percentage body fat than first-class and second-class backs, respectively.[13,14,19,23] Forwards also have greater absolute fat and fat-free masses than backs.[10]

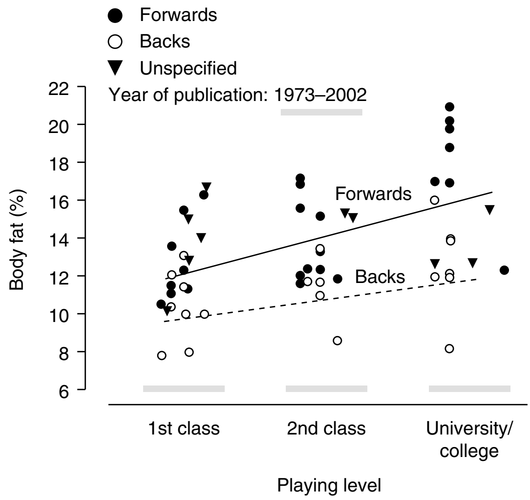

Fig. 3. Percentage body fat (%) of rugby union players.[12,14-16,18-21,23,28,29,31,37,45-47,50,52,54,55,58] The categories of playing level have been stylised by year for clarity. The solid line represents the between-level trend for forwards and the dashed line represents the between-level trend for backs.

Despite some conflicting results, the general consensus is that fat levels decrease with higher levels of play. There were no marked differences in the estimation of percentage body fat between senior (15.1 ± 3.5%) and under 21 (15.6 ± 4.0%) players.[47] Alternatively, earlier data on first-class players demonstrated that forwards (11.1 ± 1.2%) had a lower percentage body fat than their second class equivalents (13.3 ± 1.0%).[15] The differences in percentage body fat may reflect the higher training levels and more favourable dietary practices of elite players.[31,36,54] The lower body fat of the backs (10.0 ± 2.3%)[19] may also reflect the higher speed requirements of these players. Body fat values for backs are similar to other sports such as field hockey (12.4 ± 2.4%),[59] soccer (9.1 ± 1.1%)[71] and track sprinters (9.7 ± 1.7%).[71] While additional body fat may serve as a protective buffer in contact situations,[65] it is a disadvantage in sprinting and running activities. Given the different demands for forwards and backs, it is not surprising that body fat differs between these positions.

2.4 Muscle Fibre Type

It is well established that athletes requiring either high speed or very good endurance have a different proportion of fibre type in the muscle.[72] For rugby players, similar distributions of fast twitch fibres in the vastus lateralis have been found between forwards (53 ± 5%) and backs (56 ± 4%).[52] Another study reported that both forward and back players had 56% fast twitch fibres in the vastus lateralis muscle.[73] In comparison, the vastus medialis and gastrocnemius muscles of ice-hockey players and sprinters were 55–60% fast twitch fibres.[74] Soccer players have percentages of fast twitch fibres ranging from 40–51%.[75] The limited information available on the distribution of muscle fibre types of rugby players suggests similar characteristics to other team sports, with a trend to greater proportion of fast twitch fibres than the running-based sport of soccer.

3. Physical Capacities of Rugby Union Players

The implementation of field and laboratory testing allows for the examination of adaptations to training, assessment of training programmes, evaluation of player qualities, talent identification, prescription of training, and prediction of performance.[76] Such data also complement information gathered from game analysis. The competitiveness of provincial and international competition may limit the distribution of data on the physical capabilities of rugby players. Although attempts have been made to standardise the testing protocols of rugby players,[70,77] there is still little agreement in testing protocols between different research studies.

3.1 Maximal Oxygen Uptake

Maximal oxygen uptake ($\dot{V}O_{2max}$) has been proposed as an indicator of aerobic fitness in rugby players.[78] A high $\dot{V}O_{2max}$ facilitates the repetition of high-intensity efforts,[79] and in soccer is positively related to the distance covered, level of work intensity, number of sprints, and involvements with the ball.[80] The significance of a high $\dot{V}O_{2max}$ for rugby players is unclear, with some investigators concluding that it is highly important,[78] while others, although admitting relevance, suggest it is not a priority.[81] The latter contention is supported by the findings that the $\dot{V}O_{2max}$ of international rugby forwards (51.1 ± 1.4 mL/kg/min)[28] is lower than players from more running-based sports such as soccer (57.8 ± 6.5 mL/kg/min)[45] and field hockey (61.8 ± 1.8 mL/kg/min).[59]

$\dot{V}O_{2max}$ values can be expressed absolutely as litres per minute (L/min) when total power output is important, or relative to body mass per minute (mL/kg/min) for activities where body mass should be considered. An alternative method is to use the logarithms of the power function ratio standard (i.e. mL/kg$^{2/3}$/min).[82] Given the variation in body mass across positions in rugby, it is suggested that researchers present these ratios to allow for accurate comparison. This is particularly the case in rugby given the large range of body mass between forwards and backs.

Table I shows a trend for forwards to have superior absolute $\dot{V}O_{2max}$ values compared with backs.[43,52] When expressed relative to body mass, this trend was reversed with the backs showing higher values.[12,14,18,21,43,52] Changes in physiological capacities appear to follow similar trends to the anthropometrical characteristics of players. Such rapid changes may result in these previous findings having limited application to contemporary rugby players. There is no recent research examining the differences in $\dot{V}O_{2max}$ between forwards and backs when measured directly in a laboratory setting.

Recent studies on aerobic performance in elite players have used the multi-stage shuttle run as an indication of $\dot{V}O_{2max}$. Using the multi-stage shuttle run test, 94 senior 'A' male rugby players were assessed for predicted $\dot{V}O_{2max}$.[9] Of the forwards, hookers had the highest score (58.7 ± 15.2 mL/kg/min), followed by the locks (55.1 ± 15.2 mL/kg/min), loose forwards (55.1 ± 15.2 mL/kg/min) and props (50.8 ± 15.2 mL/kg/min). For the backs, the inside backs (62.5 ± 16.9 mL/kg/min) achieved the highest level, compared with the midfield backs (59.8 ± 16.9 mL/kg/min) and the outside backs (57.6

Table I. Maximal oxygen uptake ($\dot{V}O_{2max}$) of rugby union players

Study	Level	$\dot{V}O_{2max}$ (L/min)			$\dot{V}O_{2max}$ (mL/kg/min)		
		forwards	backs	unspecified	forwards	backs	unspecified
Cycle ergometer							
Bell[50]	Second						
	prop	4.06			44.0		
	hooker	3.38			43.2		
	lock	4.51			44.9		
	no. 8	4.07			55.8		
	flanker	4.49			50.9		
Maud & Shultz[18]	First	4.26	3.67		45.1	46.7	
Ueno et al.[43]	College	4.37	3.74		54.7	55.2	
Williams et al.[45]	University			3.87			50.3
Treadmill							
Deutsch et al.[38]	First						52.7
Jardine et al.[52]	Second	5.14	4.41		52.0	55.8	
Maud[12]	Second	4.73	4.77		54.1	59.5	
Menchinelli et al.[83]	Second			5.25			62.0
O'Gorman et al.[33]	International						54.1
Reid & Williams[78]	University						51.0
Warrington et al.[28]	International	5.3			51.1		
Predicted (Shuttle Run)							
Holmyard & Hazeldine[21]	First	5.82	4.95		58.0	59.6	
Mayes & Nuttall[47]	First						55.6
	University						55.2
Nicholas & Baker[14]	First	5.04	4.46		51.8	56.3	
	Second	4.85	4.51		53.3	57.7	
Tong & Mayes[48]	First	5.65	4.75		53.8	57.5	

± 16.9 mL/kg/min). These results indicate backs typically possess greater levels of endurance fitness than forwards.[9,11] Some consideration of the testing methodology is warranted because the shuttle run test is only a prediction of $\dot{V}O_{2max}$ rather than a direct measurement. The shuttle run test has previously been documented to be valid and reliable.[84] This relationship may not be as robust when performing the test on elite rugby players. Indeed, one study of international rugby players showed a poor relationship between $\dot{V}O_{2max}$ and shuttle run score.[33] However, the acceleration and deceleration that occurs in the shuttle run test replicates movements in the game of rugby more specifically than the constant speed running in an incremental $\dot{V}O_{2max}$ treadmill test. Subsequently, the fatigue developed during the shuttle run test may have greater applicability to rugby than a treadmill test of endurance. One major limitation of the shuttle run test is the expectation that players will give a maximal effort. If this expectation is not met, then the utility of the test may be questioned.

The absolute values for $\dot{V}O_{2max}$ for forwards are greater than 5.0 L/min.[14,21,48,52] These levels indicate the capability for a very high aerobic power production. This characteristic assists rugby forwards during repeated intense efforts involving scrummaging, rucking and mauling, and explosive running.[52] This is especially the case in rugby where training generally does not include extensive steady-state exercise, rather players are required to perform frequent maximal intermittent efforts that stress the anaerobic energy systems and produce lactate levels in excess of 14 mmol/L (unpublished data, Australian Institute of Sport, with permission). The moderate aerobic capabilities of rugby players

(50–60 mL/kg/min) imply that this component is one of several requirements of the overall fitness profile. On this basis, tests involving the prediction of $\dot{V}O_{2max}$ are sufficient in establishing the endurance capabilities of elite players. Other endurance tests may focus on repeated high-intensity efforts reflecting the work to rest ratios (W : R) that occur during a game.

3.2 Anaerobic Performance

The energy contributions during the work periods in intermittent team game activity are primarily anaerobic in nature. Power in rugby is required in the execution of tackles, explosive acceleration, scrummaging, and forceful play during rucking and mauling.[44] There is also a requirement for high anaerobic capacity during sustained and repeated intense efforts. Apart from literature previously reviewed,[2] there is a paucity of information on the anaerobic characteristics of elite rugby players. Research on the anaerobic characteristics has focused on cycle ergometry or treadmill sprinting of short (<10 seconds) to moderate (30–40 seconds) duration to quantify players abilities.[15,18,20,43,44,85]

Forwards appear to be able to produce higher absolute peak and mean power outputs across a range (7–40 seconds) compared with the backs.[15,18,43,44,85] When the results are expressed relative to bodyweight, the results are similar,[18] or slightly favour the backs compared with the forwards.[20] Players who have the capability to produce high power outputs also tend to have the greatest fatigue during tests of moderate (30 seconds) duration.[44] Similarly to $\dot{V}O_{2max}$, there may be distinct bias in scaling for the body mass for the lighter players. Power function ratios developed for these tests will ensure that comparisons between groups are robust and clear conclusions can be made.

Given the importance of the anaerobic system for supplying energy during rugby competition, it is surprising that there is limited information on these characteristics. This may be a result of the difficulty in performing these tests on large groups of players. A more practical test may involve repeated sprints. Repeat sprint tests can be designed to mimic the movement patterns of a sport and have been shown to be both valid and reliable.[86] The tests may be more time consuming than the multi-stage shuttle run or maximal sprint tests, but specificity to the activity patterns of the game implies that qualities required for rugby will be evaluated.

3.3 Muscle Strength and Power

Strength is the maximal force produced by a muscle or muscles at a given speed.[87] Power is the product of force (strength) and velocity (speed).[87] Rugby performance requires high levels of muscular strength and power for success, particularly for the forwards in scrums, rucks and mauls.[27,47,66] For example, the mean pack force during scrummaging ranges from 6210–9090N (~600–1000kg).[35] Comparisons between different tests cannot be performed as it has previously been shown that various power assessments measure specific qualities in rugby players.[88] This increases the difficulty of comparing strength and power measures across different studies.

Given that muscle strength is required during the contact situations in rugby,[1,89] forwards should possess greater strength than backs. When evaluated on a range of strength tests, collegiate forwards and backs performed essentially the same,[49] possibly attributable to the young training age of the athletes. The notion that forwards require more strength and backs require speed was supported by Miller et al.,[90] who found that international forwards produced greater force at low isokinetic speeds compared with backs. In contrast, the backs produced greater force at the higher speeds and their results were similar to those of international sprinters.[90]

Within the forward pack, the direct exposure of the front row to high impact forces of the scrum necessitates superior strength than other forwards. This requirement is demonstrated by the force achieved during scrummaging being greater for props (1420 ± 320N) and locks (1450 ± 270N) compared with loose forwards (1270 ± 240N).[35] There is presently limited information on the strength levels of elite rugby union players. The benefits of tracking performance in basic weight-lifting exercises have been demonstrated in elite rugby league players.[91] This reporting of results and implications of training protocols could also assist in the development of scientific knowledge in rugby union.

Leg power can be assessed from vertical jump performance.[92] Figure 4 provides a summary of vertical jump performances of rugby players reported in the literature. The summary indicates that backs generally produce a superior vertical jump performance compared with the forwards,[12,15,19] while, surprisingly, vertical jump performance decreased as playing level increased. Such a comparison over time may be erroneous given the changes in vertical jump assessment over this period (e.g. chalk board method versus Vertec®**1**). More recent results demonstrate that within a forward group, loose forwards (0.55 ± 0.08m) jumped significantly higher than props (0.45 ± 0.03m), while a large difference was also present between the hookers (0.46 ± 0.07m) and loose forwards.[35] These results demonstrate the utility of the vertical jump for monitoring the leg power of rugby players.

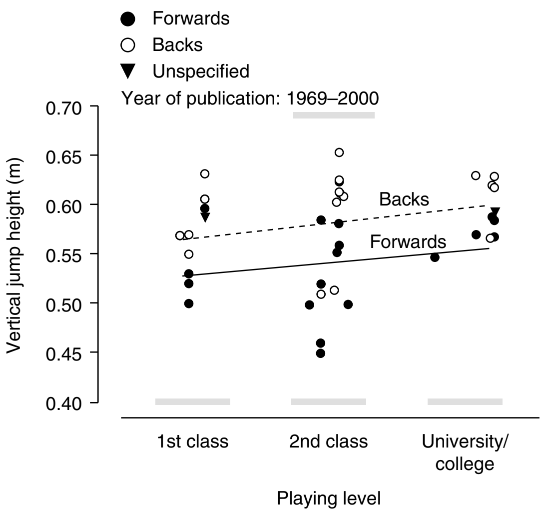

Fig. 4. Vertical jump height (m) of rugby union players.[8,9,11,12,15,18,19,22,34,47,48,93] The categories of playing level have been stylised by year for clarity. The solid line represents the between-level trend for forwards and the dashed line represents the between-level trend for backs.

The force produced during a vertical jump has been shown to be related to scrummaging force.[66] This direct measurement of ground reaction forces allows for the assessment of an athlete's ability to develop force over time. Rate of force development and impulse during a given movement can be derived from these measurements.[92] A more discrete analysis of force-producing capabilities provides feedback on both position-specific qualities and the impact of strength-training interventions. More discrete analysis can be obtained through the use of force plates during specific jumping movements.

There has been a variety of tests implemented to monitor a combination of muscle power and/or endurance (e.g. repeated jumps in place, sit-ups and push-ups).[11,12,15,19,93] Although these tests can be performed within a group of players and descriptive analysis be provided, there are concerns over their standardisation, reliability and validity. This notion is reinforced when the disparity of the results is presented. For example, one study demonstrated that abdominal endurance was superior in forwards (52 ± 8 repetitions per minute) compared with backs (48 ± 6),[12] while another study reported that backs were superior (total repetitions completed, 92) to forwards (71).[15] These tests have narrow application in the testing environment of elite rugby players. Tests that have strong validity and proven reliability (e.g. vertical jump) would be of greater benefit in the assessment of a rugby player's power.

3.4 Speed

Speed and acceleration are essential requirements, as players are often required to accelerate to make a position nearby or sprint over an extended distance. Backs achieve similar sprint times to track sprinters over distances of 15 and 35m.[94] Rugby players typically sprint between 10–20m[41,95] and have been tested over distances of up to 100m.[9,11,15,19] Table II summarises the sprint analyses conducted on rugby players. First-class backs and half-backs were the fastest over 40m, while front row forwards and second row forwards were

1 The use of tradenames is for product identification purposes only and does not imply endorsement.

Table II. Sprint times measured in rugby union players

Study	Level	Protocol	Sprint times (sec)		
			forwards	backs	unspecified
Carlson et al.[19]	National	40 yards (36.6m)	5.12	4.81	
		110 yards (100.6m)	12.92	12.10	
Dowson et al.[94]	Unspecified	15m			2.34
Rigg & Reilly[15]	First class	40m	6.26	5.81	
	Second class		6.45	6.05	
Quarrie et al.[9]	Senior A	30m	4.5	4.3	
	Senior B		4.8	4.5	
	Under 21		4.5	4.4	
	Under 19/18		4.6	4.4	
Quarrie et al.[11]	Club	30m	4.5	4.3	

the slowest.[15] These results are marginally slower than the 5.32 ± 0.26 seconds taken by rugby league players to cover 40m.[96] However, Super 12 backs have a mean ± standard deviation (SD) 40m time of 5.18 ± 0.03 seconds (n = 7) [unpublished data, Australian Institute of Sport, with permission]. First-class players were marginally faster than their second-class counterparts.[15] Backs have also been shown to be faster over 20 and 50m,[93] 30m,[21] and 40 (36.6m) and 100 (91.4m) yards[12] compared with forwards. These results indicate that speed is a discriminating factor between forwards and backs, highlighting the need for specialised sprint training programmes.[97] Future testing of rugby players should include both acceleration and maximal velocity testing over an extended distance (~40m) with intervals at 10m (acceleration) and 30–40m (maximal velocity split).

3.5 Seasonal Variations in Physiological and Anthropometric Characteristics

Changes in physiological and anthropometrical characteristics over the duration of a season have been detailed.[21,48,98] Within a season, different dietary, conditioning and resistance-training strategies elicit variations in the physical status of players. National-level rugby players may exhibit a marked reduction in body fat, and an increase in aerobic power during the pre-season when training volumes are high.[21,48] Within a competitive season, the changes are less notable, with slight improvements in speed[21] and reduction in anaerobic threshold.[98] The players also have high competition, training and travel demands that can affect physical well-being. Australian and New Zealand Super 12 players are regularly required to travel to South Africa and perform at moderate altitude. At this altitude, cognitive performance is maintained,[99] yet physical performance is impaired for 48 hours, as measured by the multi-stage shuttle run.[40] This test has been shown to accurately evaluate the influence of hypoxia on performance.[100] In such cases, the teams living and training at altitude have been shown to have an advantage over their lowland opponents.[101,102] Players are also required to perform in extreme climatic conditions. For example, late summer trial matches in South Africa resulted in players' body temperatures rising above 40ºC,[56,57,103,104] increasing the risk of heat illness. These initial findings demonstrate the utility of monitoring player's physiological status over the duration of a season and preparing them for specific climatic conditions.

4. The Demands of Rugby Competition

Researchers have used movement analysis,[5,41,95,105-109] measurement of physiological parameters such as heart rate[41,109] and the concentration of blood lactate,[5,41,95,108] blood glucose,[52] muscle glycogen[52] and plasma free fatty acids[57] to establish the physiological responses to rugby. In time-motion analysis, movement patterns, distance covered, average velocities, levels of exertion and W : R ratios can be established by quantifying the time spent in different activities. Rugby is typical of many team sports, with a range of work intensities, durations and recovery periods.[5,6,110] Rugby requires qualities such as endurance, speed, agility, power, flexibility and sport-specific skill. Quantifying the metabolic demands of the sport has been problematic given the inherent variability in movement patterns within and between games. This variability is attributable to the many factors that influence the patterns of activity during play including environmental conditions, fitness, competition level, officiating styles, team interaction and tactics. Further collection of time-motion data on elite rugby players during competition will assist in accounting for variation in movement patterns.

There are clear differences in the physiological demands of the different positions in rugby. While the forwards are engaged in intense activity, the backs are typically walking, standing, running in support play or covering in defence.[95] Forwards spend more time pushing and competing for the ball, while backs spend more time in intense running.[95] Several studies have demonstrated that the total work performed (quantified by heart rate and movement patterns) is lower for the backs than the forwards.[5,41,95,107,111] The information obtained from these analyses allows coaches to structure training programmes specific to the requirements of the game, and facilitates more effective training and improved performance.[41]

4.1 Time-Motion Analysis

Time-motion analysis is an efficient tool for gathering information regarding the movement patterns and energy demands of players in football competition. Time-motion analysis has been used to quantify the movements of a range of sports including soccer,[60] rugby,[5,6,41,95,107-109,111] Australian football[112] and hockey.[59] Although time-motion analysis directly quantifies the movements of players during competition, its validity is questionable because time-motion analysis simplifies movement patterns into categories, when actual play involves a dynamic combination of tasks, skills and tactics. Time-motion analysis is able to extract important information regarding the demands of competition and in the past has been the preferred method in quantifying player movements.

In rugby, changes in the rules have made the play 'more open', faster and more attractive to spectators.[113,114] For example, there is greater policing of the breakdown by referees in an attempt to ensure that the ball is quickly recycled and play continued. The structure of play has also improved with teams having a set plan and definitive roles for each player. Few studies have detailed the movements of players during rugby either under the new or traditional rules and there is a need for further analysis on the current game at the elite level. Existing studies have generally established the match demands by calculating the distances travelled, the time spent in different activities and frequency of occurrence for each activity for players in a variety of positions. Apart from research on elite under-19 players,[41] there is presently limited information on the movement patterns of elite rugby union players. Greater data collection will assist in accurately establishing the demands of rugby competition. Data collected prior to rugby becoming professional in 1995 are reviewed; however, these data may not accurately reflect the demands of the current game.

4.1.1 Reliability of Time-Motion Analysis

Time-motion analysis is a time-consuming process inherently prone to measurement error. This is because observations are influenced by an observer's knowledge, perceived seriousness of competition, focus of attention, state of arousal and priming for anticipated events.[62] Researchers using time-motion analysis have typically reported the reliability of their methods,[41,60,67,115] although none have reported the Typical Error of Measurement (TEM) that is a mandatory requirement in other physiological tests.[116,117] Reliability is an assessment of the consistency of a measure and is usually determined by testing and then retesting individuals under the same conditions.

In one time-motion analysis report, inter-tester reliability was established by analysing 5 minutes of footage twice ($r = 0.98$–0.99).[95] Rugby analysts have used the repeated measurement method for a single individual to identify within-observer reliability, reporting a standard deviation of 1.3m for distance travelled during the game, and 0.09 seconds for the duration of activity.[5] Increasing the data on elite rugby players movement patterns is essential for improved knowledge of the demands of the game.

4.1.2 Movement Patterns

During rugby competition, 85% of the game time is typically spent in low-intensity activities, and 15% in high-intensity activities.[6,41,111] This distribution of high- and low-intensity activity appears unchanged in studies conducted between 1978 and 1998 despite casual observation that the overall intensity of rugby has increased. At present, there are no quantitative data to verify this contention. The stoppages in play for injuries and kicks are responsible for the prolonged rest periods.[5] The high-intensity activity is made up of 6% running, and 9% tackling, pushing and competing for the ball.[95] These periods of high-intensity activity place considerable demands on anaerobic metabolism, with two-thirds of rest periods greater in duration than the preceding high-intensity effort.[41] During game stoppages, players switch to low-intensity activity. For players close to the ball, high-intensity exercise recommences upon the continuation of play.[5] Morton[6] reported a back will have the ball in hand for no more than 60 seconds, and suggested that much of their contribution involves covering in defence, acting as a support player, or running decoy lines to distract the opposition.

Early research by Morton[6] reported 135 activity periods during international and regional matches, with 56% of activities lasting less than 10 seconds, 85% lasting less than 15 seconds, and only 5% lasting longer than 30 seconds. Similarly, in an analysis of 1986 Five Nations games there were 180 separate actions with 96 stoppages.[108] 70% of actions were 4–10 seconds in duration with single actions for forwards and centre three-quarters lasting 7 seconds. The mean duration of recovery periods has been reported to be 33 seconds during international matches[108] with the majority of rest periods less than 40 seconds.[6,108,118] Treadwell[107] established that half backs in first-class matches had the greatest number of discrete movement patterns (n = 432) compared with centres (n = 270), wings/full back (n = 296), front five (n = 332), and back row (n = 320). There were no differences between the number of changes in movement patterns between the backs (n = 333) and the forwards (n = 326). This breakdown of movements suggests a large anaerobic demand in the game of rugby given the high number of short- to medium-duration activities (up to 30 seconds), and the large number of changes in activity.

The activities of scrummaging, rucking and mauling, lineouts and tackles are critical components in the game of rugby. On average, first-class forwards spend 8 minutes in intense static activity scrummaging during the game, and 5 minutes in rucks and mauls; representing 15% of the total time.[107,109] Forward players carry the ball into contact on more occasions than backs[63] and spend considerably more time in rucks and mauls than backs. Although centres spend more time in intense running,[95] the time spent in static exertion by the forwards contributes to a greater time spent in high-intensity activity (forwards; 11 minutes) compared with the backs (4 minutes).[41,95] Each scrum lasts approximately 5–20 seconds, with each lineout approximately 15 seconds in duration.[6] A back row forward performed 19 tackles during a first-grade rugby game,[109] which is less than the 20–40 tackles made by national rugby league players per game.[61]

4.1.3 Work to Rest Ratios

W : R ratios provide an objective means of quantifying the physiological requirements of an activity. The W : R ratios of International Five Nations rugby players were normally distributed, except for a high occurrence of W : R ratios in the 1 : >4 range due to stoppages for injuries or kicks at goal.[5] The mean duration of work was 19 seconds with the W : R ratios of 1 : 1–1.9 and 1–1.9 : 1 occurring most frequently. Sixty-three percent of the W : R ratios had work periods less than the rest period.[5] Similarly, the mean W : R ratio for under-19 colts (forwards and backs) was 1 : 1.4 and 1 : 2.7, respectively,[41] with one-third of the work periods followed by rest periods equal to, or shorter than, the work duration.

Short incomplete recoveries (less than 20 seconds) may not allow full replenishment of creatine phosphate stores, increasing the reliance on anaerobic glycolysis in the following work periods.[41] Fatigue and reduction in performance may ensue evidenced by the fact that, for rugby players, 30 seconds rest between maximal sprints elicits a marked reduction in sprint performance compared with 60 seconds rest.[30]

4.1.4 Distances and Velocities

Early estimations on the distance covered during a rugby match indicated that a centre covered 5800m, of which 2200m was walking, 1600m jogging and 2000m sprinting.[6] Deutsch et al.,[41] monitored six players during four under-19 matches between different teams. Although backs had a lower overall exertion based on heart rate, they covered the greatest distance, with props and locks covering 4400 ± 398m, back row 4080 ± 363m, inside backs 5530 ± 337m, and outside backs 5750 ± 405m, respectively. In comparison to a more running-based sport, Danish soccer players covered 10 800m (range: 9490–12 930m) over a 90-minute game.[60]

Within elite under-19 colts rugby, forwards spent a larger percentage of time standing still (46%) compared with the backs (39%), and covered a shorter distance in all gait movements except jogging.[41] The majority of recovery was passive (stationary) for the forwards and active (walking or jogging) for the backs. While the forwards are primarily engaged in non-running intense activity, the backs are typically walking, standing or waiting for the ball to be delivered from the contest.[95] The backs (253 ± 45m) cover greater distance at sprinting speed compared with the forwards (94 ± 27m), and complete more backwards and sideways (utility) movements (backs 72 ± 7, forwards 22 ± 4).[41] The mean distance of individual sprints was similar for both the forwards and backs (17m and 21m, respectively).[41] Props and locks covered the greatest distance at a low-intensity pace, indicating more continuous activity and generally greater involvement for these players given their proximity to the contest.[41,107]

McLean[5] conducted a time-motion analysis on telecast international matches (Five Nations Championship, 1989–90). Plots of players' paths were made on a scaled diagram of a rugby pitch to measure the distance covered. The average velocity was 5–8 m/sec for players who were in close proximity to the ball.[5] An alternative method was employed by Deutsch et al.,[41] who, using a game simulation, measured players' velocities during isolated activities. The mean speed when sprinting was 6.8 m/sec, striding (cruise) 4.9 m/sec, jogging 3.2 m/sec, walking 1.5 m/sec, and utility 1.4 m/sec.[41] The acceleration phase of the sprints was not considered in these analyses, nor were any changes of direction, which commonly occur during the game.

Speed and acceleration are two important qualities in team sport performance,[96] with running speed over short distances fundamental to success in both field and court sports.[96,119] The typical sprint distance of 20m in the game of rugby[41] implies that acceleration capabilities are of primary importance to rugby players, who appear to complete their acceleration phases earlier than the 30–50m taken by elite sprinters.[96] Research is required to discriminate between the qualities of acceleration and maximal speed and the influence of starting speed, proximity of other players, ball carrying and the number and nature of any changes of direction.

4.1.5 Differences Between Levels of Competition

Two studies have investigated the movement pattern differences among various levels of competition.[95,111] During Super 12 games, the premier Southern Hemisphere rugby competition, the total work (time spent cruising, sprinting, tackling, jumping, rucking/mauling, and scrummaging) for forwards (10 minutes) and backs (4 minutes) was similar to forwards and backs of club level (10 and 4 minutes, respectively).[111] The number of work efforts per game for Super 12 forwards (122 ± 18) and backs (47 ± 9) was similar to first-division players (forwards 118 ± 23, backs 55 ± 11). The mean work period for Super 12 forwards and backs was 5.1 and 4.7 seconds, respectively. The average rest period (inactive, walking, jogging, shuffling sideways or backwards) ranged from 34 seconds for first-division forwards to 100 seconds for Super 12 backs. During club and international-level games, differences were found in the time spent in running activities with centres of international standard spending more time per game in non-running intense activity (5.4%) than club centres (1.8%).[95] Super 12 backs spent more time in utility movements (backwards and sideways walking, and jogging) when compared with the club backs (3.7 ± 2.0% and 2.3 ± 1.0%, respectively).[111] Overall, there appears to be only minor differences in movement patterns of players between international- and club-level rugby. It is possible that the game speed between these levels of competition is not apparent from the time-motion analysis data collected.

4.2 Heart Rate Responses

Although there are limitations in using heart rate to assess intense intermittent activity,[109] heart rate analysis can be used to estimate the average work intensity during a game as a function of the linear relationship with oxygen uptake at sub-maximal workloads.[41] There are limited heart rate data on rugby players during match play due to logistical problems in taking measurements during highly vigorous contact sport. Morton[6] reported that a back's heart rate ranged between 135–180 beats/min throughout the game with a mean of 161 beats/min. This is similar to the mean heart rates of Australian football (164 beats/min, SD not reported),[112] field hockey (159 ± 8 beats/min)[59] and basketball players (165 ± 9 beats/min)[67] during match play. Using heart rate data collected during competition, Deutsch et al.,[41] found a higher mean level of exertion in the forwards than the backs. There was no difference between forwards and backs for the time spent at maximal heart rate. The forwards spent approximately 72% of the match at a heart rate greater than 85% of their maximal competition heart rate. The backs spent the majority of time in moderate- (37% of total time) and low-intensity (18% of total time) activities eliciting heart rates less that 85% of maximal competition heart rate.[41] The available data underline the relatively intense nature of competitive rugby, with the forwards having a higher total work rate than the backs.

4.3 Lactate Accumulation

The concentration of blood lactate is a measure of exercise intensity for the preceding few minutes.[41] There are logistical difficulties in collecting blood samples during competitive rugby because sampling is dictated by stoppages in play and may not relate directly to specific passages of intense activity. Periods of low intensity allow blood lactate to be metabolised, therefore the blood lactate figures presented in table III characterise the most recent activity undertaken by the players, rather than a representation of the overall demands of the game.[5] For example, Docherty et al.,[95] found mean lactate

Table III. Within-competition blood lactate levels of rugby union players

Study	Level	Methods	Position	Blood lactate (mmol/L)	
				mean ± SD	maximum
Deutsch et al.[41]	Under 19	During penalty kicks and injury stoppages (n = 24)	Forwards	6.6 ± NR	8.5
			Backs	5.1 ± NR	6.5
		Accusport analyser			
Docherty et al.[95]	International	Post game (5–10 min) [n = 11]	All	2.8 ± 1.6	
McLean[5]	1st Division	During penalty kicks and injury stoppages (n = 6)	Props	5.4 ± 0.6	5.9
			No. 8	6.7 ± 1.6	9.8
			Fly half	5.9 ± 1.1	7.5
		Analox LM3 analyser			
Van Rensburg et al.[57]	Under 20	Post-match	All	3.8 ± NR	
Menchinelli et al.[108]	International			Range = 6–12	

NR = SD not reported; **SD** = standard deviation.

values of 2.8 ± 1.6 mmol/L following a game and suggested that the aerobic system be developed to facilitate low-intensity running activities and recovery of the phosphagen stores.[95]

During Scottish first-division games, centres and props achieved 56% and 85% of their peak blood lactate values, respectively, during a maximal treadmill test to exhaustion.[5] Forwards sustained higher mean and peak blood lactate concentrations than the backs. Deutsch et al.,[41] found the game mean blood lactate values were higher in the forwards (6.6 mmol/L) compared with the backs (5.1 mmol/L). Deutsch et al.,[38] established a positive relationship between $\dot{V}O_{2max}$ and the rate of lactate clearance from the blood in elite rugby players. It was suggested that enhanced aerobic capacity improves the recovery from high-intensity exercise through faster removal of blood lactate.[38]

4.4 Tactical Considerations

Notational analysis has been used to examine the tactics of successful teams.[62,63,105,120] McKenzie et al.,[62] analysed contact situations during the 1987 World Rugby Cup and factors contributing to greater ball retention. The most successful team of the competition had the highest number of contact situations and the greatest ball retention. Crossing the advantage line resulted in greater ball retention (67%) than remaining behind, or at, the advantage line (56%). The ball was retained more often when the contact situations were close (5m) to the start of play compared with over 20m away. In contrast, Smyth et al.,[63] found no difference in the distance from initial play for successful ball retention. McKenzie et al.,[62] concluded that a low body position facilitates greater retention than medium to high body positions. When players turned towards support there was greater ball retention (68%) compared with turning away from support (62%) or not turning at all (42%).[62] This supportive play assisted in ball retention when decisive contact with either the ball carrier or the defending players was made by 'driving', 'ripping' or 'wedging'.[62] These results highlight the importance of developing and improving fundamental positional skills in international rugby.

5. Conclusions

There are clear differences in the physiological and anthropometric characteristics of forwards and backs in rugby. Backs tend to be leaner, shorter, faster, more aerobically fit relative to body mass and more explosive (vertical jump) than their forward counterparts. Forwards produce better absolute results when measured for strength and aerobic endurance, but when expressed relative to body mass (kg) the results favour the backs. Greater body mass predisposes the forwards to select this positional group as it assists in the contest situations of the game. Movement analysis has clearly demonstrated that forwards are involved in more contact situations than the backs. The backs cover a greater distance during a game, but the high degree of physical contact undertaken by the forwards results in greater total work (quantified by time-motion analysis), higher heart rates and blood lactate levels. Ninety-five percent of activities last less than 30 seconds, and rest periods are generally greater than the preceding work effort. Rugby is primarily anaerobic, although the aerobic system is utilised during rest periods to replenish energy stores. Further analysis of the demands of rugby is required, with researchers focusing on specific components of the game (e.g. high-intensity running) in order to refine training programmes designed to meet the demands of competition.

Greater professionalism in rugby has increased the interest in sports science aspects of training and competition. Studies have investigated the seasonal variation in performance, effects of specific tactics, influence of climate and the consequences of acute altitude exposure. Further research in these areas, coupled with more comprehensive studies of the physical characteristics of players, fitness requirements and movement patterns of contemporary rugby, will contribute to the development of more effective conditioning programmes.

Acknowledgements

The authors would like to acknowledge the contributions of the Australian Rugby Union, Australian Institute of Sport, and the University of Queensland. We would also like to thank Prof. Allan Hahn, Dr David Jenkins, Mr Steuart Livingstone, Mr Damian Marsh and Mr Jason Weber for their valuable input into the development of this manuscript. No sources of funding were used to assist in the preparation of this manuscript. The authors have no conflicts of interest that are directly relevant to the content of this manuscript.

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