

# **The Use of Physical Characteristics to Explain Variation in Ball-Carrying Capability in Elite Rugby Union: A Narrative Review**

**Running Head:** Physical Characteristics and Ball-Carrying Capability in Rugby Union

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## 1 **Abstract**

2 The effectiveness of offensive ball-carrying has been identified as a key determinant in elite rugby union  
3 try-scoring success and subsequent match outcome. Despite this, there is limited research evaluating  
4 the physical qualities believed to underpin ball-carrying capability amongst elite rugby union players.  
5 The aim of this review was to critically appraise the scientific literature that has investigated the use of  
6 physical characteristics to explain ball-carrying capability in elite rugby union. Measures of sprint  
7 performance, specifically acceleration, maximum sprinting speed, and sprint momentum have presented  
8 weak-to-strong correlations with the number of tries scored, line breaks, tackle breaks, defenders  
9 beaten, and dominant collisions recorded amongst international rugby union players. In addition,  
10 unilateral and bilateral vertical countermovement jump height, peak power output, and drop jump  
11 reactive strength index have each demonstrated meaningful associations with the number of tries scored,  
12 line breaks, tackle breaks, and dominant collisions. However, various measures of maximal lower-body  
13 strength have presented only trivial correlations with the game statistics associated with ball-carrying  
14 capability. These trivial correlations are likely a result of the inconsistent and inaccurate methods used  
15 to assess maximal lower-body strength, with methods ranging from a box-squat predicted one-repetition  
16 maximum to a maximal isometric mid-thigh pull. Further investigation is required to assess the  
17 contribution of maximal lower-body strength, agility, repeated sprint ability, and aerobic capacity to  
18 ball-carrying capability in elite rugby union. Such robust, objective data could be used to inform the  
19 specificity of physical preparation and maximise the transfer of these physical qualities to on-field  
20 performance.

21

## 22 **Keywords**

23 Speed; acceleration; momentum; strength; power; agility.

24

## 25 **Introduction**

26 Rugby union is characterised as a high-intensity, intermittent contact sport, requiring athletes to perform  
27 repeated running actions, collisions, and static efforts of differing work-to-rest periods (46). The  
28 profiling of the physical characteristics of elite rugby union players has highlighted a number of  
29 position-specific attributes (19). Typically, the forwards are the strongest, heaviest, and tallest players  
30 in order to be competitive within rucks, mauls, and lineouts (9). This is supported by research  
31 demonstrating the position-specific performance indicators for the forwards incorporated significant  
32 ball-carrying, tackling, and set-piece play (34,35,41,60). In contrast, the key performance indicators for  
33 the backs involved significantly more passing, kicking, evading the opposition, and try-scoring  
34 (10,34,35), therefore, necessitating the physical attributes of acceleration, maximum sprinting speed,  
35 and agility (14). These position-specific performance indicators are further evidenced by backs  
36 recording a greater number of line breaks, tackle breaks, defenders beaten, and tries scored than the  
37 forwards in elite rugby union match-play (53).

38

39 The number of tries scored has been identified as a main determinant of match outcome in elite rugby  
40 union (10), with winning teams recording more tries than losing teams in Rugby World Cup match-  
41 play (33). Recent evidence highlighted effectiveness of the offensive ball-carry, a motion where the  
42 player in possession of the ball challenges the opposition defensive line, as a key determinant of try-  
43 scoring success (51) and subsequent match outcome (7). For instance, Bennett et al., (2020) identified  
44 a number of performance indicators associated with ball-carrying capability as accurate predictors of  
45 match outcome in the group-phase and knockout phase of the 2015 Rugby World Cup (8). Previous  
46 notational analysis has quantified successful offensive ball-carries by the number of tries scored, line  
47 breaks, tackle breaks, offloads, defenders beaten, and metres advanced beyond the gain line per carry  
48 (Table 1) (14,49,53). Research indicates that the number of clean breaks and the average distance  
49 recorded per ball carry differentiated between successful and unsuccessful teams in both domestic (33)  
50 and international competition (43). Moreover, successful teams have been shown to deploy strategies

51 that emphasise the involvement of players who record greater average distances per ball carry, as well  
52 as record a significantly greater number of clean breaks, when compared to their opponents (7).

53

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55

56 Despite the clear relationship between offensive ball-carrying capability, try scoring likelihood, and  
57 subsequent match outcome, there has been limited research investigating the technical and physical  
58 characteristics common amongst effective ball-carriers. Previously, Sayers and Washington-King  
59 (2005) identified acceleration, maximum sprinting speed, sprint momentum, and the use of contact  
60 skills (e.g., fending strategies) as key determinants of positive phase outcome (51). Specifically, sprint  
61 times over 5-40 m have presented weak-to-strong correlations with the number of tries scored, line  
62 breaks, tackle breaks, defenders beaten, and metres advanced per carry amongst international rugby  
63 union (14,53) and rugby sevens players (49). In addition, Hart et al., (2022) concluded that  
64 improvements in lower-body relative strength, acceleration performance, and position-specific  
65 alterations in body mass are required to maximise the ball-carrying capability of sub-elite rugby union  
66 players due to the large associations observed between these physical measures and game statistics (26).  
67 These studies can provide objective data to inform the development of specific physical characteristics  
68 with the fundamental aim of optimising the transfer of these physical qualities to on-field ball-carrying  
69 performance. However, the majority of these studies have looked at key determinants of ball-carrying  
70 capability in isolation, rather than exploring the contribution of related physical characteristics to ball-  
71 carrying capability. Furthermore, comparison between these studies is difficult due to the inconsistency  
72 in the methods used to assess physical variables, such as maximal strength, peak power output, and  
73 sprint performance. For example, methods used to assess maximal lower-body strength vary from an  
74 isometric mid-thigh pull (IMTP) (14) to a box-squat estimated one-repetition maximum (1RM) (53).  
75 There are also large discrepancies in the accuracy and validity of the methods used to assess these  
76 physical characteristics. For instance, the application of a power clean estimated 1RM to assess peak

77 power output (53) can be limited by the technical capabilities of the participant, rather than their  
78 potential muscular power. Despite these limitations, the identification of the physical characteristics  
79 that underpin offensive ball-carrying capability can have a number of significant implications for  
80 strength and conditioning practitioners, including the tailoring of position-specific physical preparation  
81 programmes to derive adaptations in the physical characteristics most associated with on-field ball-  
82 carrying performance, a key determinant in try-scoring success and subsequent match outcome (7).  
83 Therefore, the aim of this article was to critically analyse and provide a narrative review of the literature  
84 that has investigated the use of physical characteristics to explain ball-carrying capability in elite rugby  
85 union. This critical analysis will permit the main objectives of this review, namely, to identify specific  
86 physical characteristics/assessments that can be used as robust indicators of ball-carrying ability, as well  
87 as those that should not be used for this purpose. Based on the most compelling studies, and our  
88 hypotheses derived from their results, we will also propose new assessments for future research to  
89 investigate.

90

## 91 **Methods**

### 92 **Literature Search Methodology**

93 A structured literature search was conducted for empirical research studies and review articles using  
94 MEDLINE, SPORTDiscus, and PubMed databases from inception to September 2022 with a particular  
95 focus on identifying data by player subgroups of forwards and backs. Key terms were searched for  
96 within the article title, abstract, and keywords using conjunctions “OR” and “AND” with truncation  
97 “\*.”. Combinations of the following Boolean phrases comprised the search terms: physical  
98 characteristics, physical qualities, fitness-test measures, anthropometric, height, body mass, lean body  
99 mass, strength, power, speed, acceleration, maximal velocity, agility, key performance indicators, KPIs,  
100 game statistics, ball carrying and rugby union. Reference lists were also utilised.

101

### 102 **Inclusion and Exclusion Criteria**

103 For the purpose of this article, athletes were classed as “elite” if they competed in the top tier of a  
104 professional competition in a tier one rugby union nation such as the Premiership (England), the Top  
105 14 (France), the Pro 14 (Ireland, Italy, Scotland, South Africa, and Wales), and Super Rugby (Argentina,  
106 Australia, Japan, New Zealand, and South Africa), or if they competed in international competitions for  
107 a tier one nation, for example, 6 Nations (England, France, Ireland, Italy, Scotland, and Wales), the  
108 Rugby Championship (Argentina, Australia, New Zealand, and South Africa), or the Rugby World Cup.  
109 Studies were included in this review on the following criteria: (a) full text available in English and (b)  
110 peer-reviewed journal publications or doctoral dissertations. Studies were excluded if they were  
111 conference papers/posters/presentations.

112

### 113 **Anthropometric Characteristics**

114 With the establishment of professionalism, factors such as full-time training, enhanced access to sport  
115 science, and technical coaches’ desire for more physical players, has led to improved athletic  
116 development and a substantial increase in player size (18). As an example, the body mass of Northern  
117 Hemisphere international rugby union players has increased by 24.3% (20.6 kg) between 1955 and 2015  
118 (31). The anthropometric differences between forwards and backs have been well documented. Stoop  
119 et al., (2018) concluded that forwards were taller and heavier than backs across all Tier 1 nations (55).  
120 Success in rugby union has also been aligned to body mass with the highest performing teams in Rugby  
121 World Cups between 1987 and 2007 presenting the heaviest forwards and the heaviest average squad  
122 body mass (9). The greater mass of the forwards has been proposed to act as a protective mechanism  
123 from impact injuries as these positions are involved in 68% of all collisions during a match (55) and  
124 60% more high acceleration/deceleration impacts than the backs (12), whilst also presenting a lower  
125 risk of injury (22). However, the composition of the additional body mass is vital to performance.  
126 Excessive body fat has a detrimental impact on performance by increasing metabolic demands, reducing  
127 the body’s ability to dissipate heat, and subsequently reducing an individual’s ability to perform  
128 repeated high-intensity actions (e.g., tackling and ball-carrying) (18,37,53). Moreover, higher levels of  
129 body fat have been associated with a reduced power-to-body mass ratio, reducing an individual’s ability

130 to position themselves in optimal attacking and defensive positions (62). In regard to the effect of  
131 excessive body fat on ball-carrying capability, Smart et al., (2014) demonstrated an inverse relationship  
132 between body fat percentage and activity rate amongst the forwards (53). Smart et al., (2014) defined  
133 activity rate as the count of any action that was performed by an individual player, divided by game  
134 time. Therefore, forwards with a greater body fat percentage demonstrated a reduced game involvement  
135 and recorded fewer repeated high-intensity actions (e.g., line-breaks, tackle-breaks, etc.). In contrast,  
136 the backs presented a weak positive correlation between body fat percentage and activity rate. However,  
137 this may be a result of the confounding position mix within the backs; as the anthropometrical  
138 requirements of the midfield backs (inside and outside centres) are more associated with the contact  
139 elements of rugby union, in comparison to the lighter and leaner half backs and back three (53). A clear  
140 limitation of this study is the lack of individual position analysis that would have provided further  
141 insight into the relationship between body composition and ball-carrying capability amongst the backs  
142 in particular.

143

144 A heavier body mass is considered fundamental for generating increased momentum in physical  
145 collisions (9). The difference in sprint momentum between the ball-carrier and the tackler has previously  
146 been proposed to play a much greater role in the prediction of tackle outcome than ball-carrier  
147 acceleration and velocity (28). Sprint momentum over 10 m has presented very strong correlations with  
148 the number of dominant collisions and offloads amongst international rugby union backs (14) and has  
149 been reported to be a greater indicator of ball-carrying capability than 10 m sprint time amongst  
150 international rugby sevens players (49). Despite this, Cunningham et al., (2018) identified no  
151 relationship between 10 m sprint momentum and ball-carrying capability amongst international rugby  
152 union forwards (14). However, 10 m sprint momentum may not be an applicable measure for the  
153 forward positions (26) as time-motion analysis has demonstrated that forwards typically perform a  
154 greater number of shorter distance sprints during a match in comparison to backs (3), with an average  
155 distance per sprint of <10 m (19). Therefore, 5 m sprint momentum may possess greater associations  
156 with ball-carrying capability amongst the forwards, a hypothesis that future research should investigate.

157 In addition, researchers may wish to utilise player tracking technology to identify the momentum of  
158 each player prior to contact with an opposition defender to isolate the relationship between the  
159 momentum of the ball-carrier and the achievement of positive phase outcomes (28).

160

161 Sprint momentum appears to be more trainable than sprint velocity; with maximum sprinting speed  
162 tending to peak for rugby union players in their mid-20s. In contrast, sprint momentum continues to  
163 improve amongst academy and elite senior rugby players in association with increased body mass  
164 (5,15). A novel aspect of one recent study is the inclusion of simple regression analysis to predict the  
165 level of change in a physical measure necessary to improve an associated game statistic (14). However,  
166 Cunningham et al., (2018) deemed the necessary improvements in 10 m sprint momentum required to  
167 improve the number of dominant collisions and offloads recorded amongst international rugby union  
168 backs to be beyond that which can be achieved from training (>20%) (14). Furthermore, sprint  
169 momentum is an underreported measure within the literature, with some studies failing to present the  
170 relationship between sprint momentum and ball-carrying capability despite reporting measurements of  
171 body mass and sprint times over 10 m, 20 m, and 30 m (53). The window for adaptation in the  
172 development of sprint momentum has been shown to be greater for players in their late teens and early  
173 20s when compared with players in their mid-to-late 20s (5). As sprint momentum has been reported to  
174 be a strong indicator of ball-carrying capability amongst international rugby union players, particularly  
175 the backs (14), developing sprint momentum should be a key focus in the physical preparation of players  
176 within this age category (5,15). To increase sprint momentum, physical training will likely need to  
177 consist of exercises that will promote muscular hypertrophy and maintain maximum sprint velocity  
178 (5,15).

179

## 180 **Strength and Power**

181 Muscular strength has previously been defined as the ability to exert force on an external object or  
182 resistance (56). Given that rugby union demands high levels of muscular strength to effectively perform

183 tackling, lifting, pushing, and pulling tasks, and to tolerate the collisions that occur during match-play  
184 (9). Despite the perceived importance of muscular strength, most studies have reported trivial  
185 correlations between various measures of lower-body maximal strength and the game statistics  
186 associated with ball-carrying capability (14,49,53). However, direct comparison between studies is  
187 problematic due to the inconsistency and inaccuracy of the testing protocols used to assess lower-body  
188 maximal strength. For example, Smart et al., (2014) utilised the box-squat exercise to predict a one-  
189 repetition maximum (1RM) from a 2-6RM test score using the formula derived by Lander (1985) (53).  
190 The inter-individual variation in the repetition maximum used to estimate box-squat 1RM compromises  
191 the accuracy and reliability of maximal lower-body strength assessment. Furthermore, the calculation  
192 of an estimated 1RM has been shown to be less accurate than a true 1RM measure (47) and the Lander  
193 (1985) formula has demonstrated a greater average error and lower relative accuracy when compared  
194 to the more commonly used Epley (1985) formula (63). In comparison, Cunningham et al., (2018)  
195 employed a maximum isometric mid-thigh pull (IMTP) assessment to determine absolute and relative  
196 peak force (14). The use of the maximum IMTP assessment has grown in popularity across all sports  
197 and is increasingly being used in rugby union due to its perceived ease of use, time efficiency, and the  
198 reduced requirements for technical instruction when compared to full range of motion compound lifts  
199 such as the barbell back squat or barbell deadlift (38). However, Cunningham et al., (2018) are the only  
200 investigators to employ the maximum IMTP assessment and failed to report the intraclass correlation  
201 coefficient (ICC), coefficient of variation (CV), and 90% confidence intervals (90% CI) leaving the  
202 test-retest reliability of their assessment unknown (38).

203

204 The trivial correlations observed between lower-body maximal strength and the game statistics  
205 associated with ball-carrying capability do not necessarily imply that lower-body muscular strength is  
206 unimportant for success in rugby union. Research investigating the characteristics common amongst  
207 effective ball carriers in Super Rugby (a professional men's rugby union club competition that has  
208 involved teams from Australia, New Zealand, and South Africa) identified 95% of tackle breaks were  
209 achieved with a combination of low body position and strong leg drive (51). Therefore, further research

210 may seek to utilise a qualitative assessment of body position in addition to quantitative assessments of  
211 lower-body strength to identify the determinants of offensive ball-carrying capabilities, particularly  
212 with reference to contact situations. Fundamentally, muscular strength underpins rate of force  
213 development and power production by increasing maximal force potential (39). In theory, the enhanced  
214 force-time characteristics associated with high levels of muscular power should transfer to the ability  
215 to perform general sport skills (e.g., sprinting and jumping) (56). Previous studies have shown that  
216 athletes who are able to produce high levels of muscular power are more effective at the physical  
217 components of rugby union, such as dominating the breakdown or winning collisions (1,25). Therefore,  
218 more powerful athletes are likely to be effective in the areas of the game where physical domination of  
219 opponents increases the likelihood of maintaining possession, retrieving possession, and breaking the  
220 defensive line (2). The most common method for measuring or estimating lower-body muscular power  
221 in rugby union is through vertical jump height (9). Cunningham et al., (2018) reported a number of  
222 strong relationships between various countermovement jump (CMJ) and single-leg countermovement  
223 jump (SL CMJ) variables and the game statistics associated with ball-carrying capability amongst  
224 international rugby union players. For the forwards, CMJ height, absolute peak power output, and  
225 average SL CMJ peak power output presented strong correlations with the number of dominant  
226 collisions. Furthermore, CMJ height, relative peak power output, and average SL CMJ peak power  
227 output each presented a strong relationship with the number of line breaks. For the backs, CMJ peak  
228 power output and average SL CMJ peak power output correlated strongly with the number of dominant  
229 collisions (14). Despite these relationships, Cunningham et al., (2018) deemed the necessary  
230 improvements in muscular power required to enhance the associated game statistics to be beyond those  
231 that can be achieved from training (14). It is unclear why the authors of this study deemed 20% to be  
232 the arbitrary cut-off point for a practically achievable change in a physical quality, especially given the  
233 study reported an 18.4% increase in 20 cm drop jump height to be an achievable adaptation required to  
234 increase the count of being one of the first three players to a defensive ruck by one (14).

235

236 In contrast to the findings observed amongst international rugby union players, Ross et al., (2015)  
237 reported CMJ peak concentric power output presented no relationship with the number of tries scored  
238 and line breaks, and only a trivial correlation with the number of defenders beaten amongst international  
239 rugby sevens players (49). However, a linear position transducer affixed to a 1 kg weighted pole was  
240 used to calculate peak concentric power output from displacement-time data. The use of a linear position  
241 transducer has previously been shown to overestimate a number of kinematic variables used in the  
242 calculation of peak concentric power output, including countermovement jump height (61).  
243 Furthermore, the calculation of peak concentric power output from a linear position transducer has been  
244 shown to be inconsistent and unreliable when compared to measurements of peak force and time to  
245 peak force (24). Ross et al., (2015) also failed to report reproducibility data for the measurement of  
246 CMJ peak concentric power output, so the reliability of this measurement in this population is not  
247 known. . Similarly, Smart et al., (2014) reported only trivial correlations between power clean 1RM and  
248 the game statistics associated with ball-carrying amongst elite rugby union players (53). The power  
249 clean exercise is an Olympic weightlifting derivative that demands a high level of technical competency,  
250 and the use of higher loads has previously been shown to result in changes to kinematic variables  
251 attributable to alterations in technique (11). As such, some argue that Olympic weightlifting derivatives  
252 provide a less valid measure of peak power output when compared to vertical jump tests due to the  
253 greater technical proficiency required. Furthermore, Smart et al., (2014) reported power clean 1RM was  
254 predicted from a two to six repetition maximum lift with the use of the Lander (1985) formula, similar  
255 to the box-squat predicted 1RM (53). This study also failed to report reproducibility data for the power  
256 clean repetition maximum testing. Reproducibility data is essential to provide confidence in the findings  
257 of these studies when comparing physical characteristics and reliable game statistics. This review  
258 recommends further research seeks to use kinematic variables derived from force plate testing in the  
259 measurement of lower-body peak power output when examining the relationship between peak power  
260 output and ball-carrying capability.

261

262 Despite the trivial correlations observed between vertical CMJ peak concentric power output and the  
263 game statistics associated with ball-carrying capability, a moderate correlation was observed between  
264 horizontal jump distance and the number of defenders beaten amongst international rugby sevens  
265 players (49). This finding is attributable to the large associations between horizontal jump performance  
266 and an individual's ability to express large amounts of net horizontal ground reaction force, the key  
267 mechanical determinant of acceleration (40). Barr et al., (2014) previously demonstrated a significant  
268 relationship between horizontal jump distance and 10 m sprint velocity amongst international rugby  
269 union players (4). Despite this finding, Ross et al., (2015) is the only study to investigate the relationship  
270 between horizontal jump performance and the game statistics associated with ball-carrying capability,  
271 and the test-retest reliability of horizontal jump measurements was not reported. In order to be confident  
272 in the associations observed between horizontal jump performance and ball-carrying capability, further  
273 research is required that includes reproducibility data. In addition, Dobbs et al., (2015) highlighted that  
274 unilateral horizontal jump tests assess distinct lower-limb muscular power capabilities amongst highly  
275 trained rugby union players (16). Therefore, further research may seek to incorporate unilateral  
276 horizontal jump testing in their assessment of muscular power capabilities and the relationship with  
277 ball-carrying capability amongst elite rugby union players.

278

279 The countermovement jump assessment employed by Cunningham et al., (2018) provided a good  
280 measure of slower stretch shortening activities, shown to be primarily relied upon by the forward  
281 positions to break through contact and record positive phase outcomes (e.g., tackle breaks and dominant  
282 collisions) (14). However, the countermovement jump does not provide a strong measure of faster  
283 stretch shortening cycle (SSC) movements that are characterised by shorter contraction times and  
284 smaller angular displacement of the hip, knee, and ankle joints (6,21). Hamilton (2009) suggested a  
285 faster SSC measure, such as the drop jump reactive strength index (RSI), may provide a more relevant  
286 neuromuscular examination due to the increased eccentric and SSC demand (23). Cunningham et al.,  
287 (2018) reported that 20 cm, 40 cm and SL 20 cm drop jump RSI presented strong correlations with the  
288 number of tries scored, line breaks, tackle breaks, and dominant collisions amongst international rugby

289 union players (14). Producing a large RSI requires the ability to express large amounts of force in very  
290 short time frames; and drop jump RSI has previously been strongly related to maximum sprinting speed  
291 and agility amongst a mixed group of international rugby union players (13,65). Despite the strong  
292 correlations, Cunningham et al., (2018) reported the improvements in drop jump performance required  
293 to enhance ball-carrying capability were beyond those that could be achieved from training, similar to  
294 the improvements in sprint momentum and vertical jump performance (14). This study is also the first  
295 to analyse the relationship between drop jump performance and ball-carrying capability amongst elite  
296 rugby union players, and further research should incorporate drop jump RSI in the assessment of  
297 muscular power. In addition, future research may consider the assessment of peak power at submaximal  
298 loads (greater than body mass and less than 1RM) in both elite and sub-elite rugby union players, as  
299 currently unpublished peak power data from our group have demonstrated meaningful correlations with  
300 ball-carrying capability in a sub-elite rugby union population. Furthermore, we found the loaded barbell  
301 jump squat to be a reliable and valid measure of a rugby player's capacity to produce power at  
302 submaximal loads.

303

#### 304 **Speed**

305 Sprint velocity is an essential characteristic for rugby union players, as it enables them to rapidly  
306 position themselves in attack and defence (9). Tierney et al., (2017) demonstrated high-speed running  
307 intensity (>5 m.s) and very high-speed running intensity (>7 m.s) were key determinants in successful  
308 attacking 22 m zone entries, as high-speed running intensity related to the forwards efforts in positioning  
309 themselves quickly and being available for the next phase of play (58). Research investigating the  
310 physical characteristics common amongst effective ball carriers has shown that acceleration, maximum  
311 sprinting speed, and sprint momentum are the main determinants of positive phase outcome (51).  
312 Specifically, average sprint velocity over 5 m, 10 m, 20 m, 30 m, and 40 m have presented strong  
313 correlations with the number of tries scored, line breaks, tackle breaks, defenders beaten, and dominant  
314 collisions amongst international rugby union (14,53) and rugby sevens players (49). These findings are  
315 attributable to the counterbalance reaction that is initiated when a ball-carrier enters the pre-contact

316 phase at a velocity considerably greater than that of the tackler. If the tackler is unable to adjust their  
317 velocity to match that of the ball-carrier, the outcome of the tackle is likely to be unsuccessful resulting  
318 in a tackle break, dominant collision or a missed tackle (29). Furthermore, ball-carrier velocity has  
319 previously been described as the key technical determinant for successful line breaks (32) and  
320 individuals who received the ball at higher running velocities have been shown to record the greatest  
321 number of positive phase outcomes (51). Despite this, researchers propose the difference in momentum  
322 between the ball-carrier and the tackler plays a much greater role in the prediction of tackle outcome  
323 than the ball-carrier's velocity (28). The basic physical principles of collisions suggest the individual  
324 with the greater momentum is more likely to dominate the tackle contest. Hendricks et al., (2014)  
325 highlighted that forwards were generally heavier than backs and subsequently possessed a greater  
326 momentum and a tactical predetermination to carry the ball into contact (28). In comparison, the backs,  
327 particularly the back three positions, are more reliant on the application of maximum sprint velocity to  
328 evade defenders and achieve positive phase outcomes. Therefore, strength and conditioning  
329 practitioners should seek to enhance maximum sprint velocity amongst this position group, particularly  
330 as the backs frequently receive the ball in motion at high running velocities (54), reducing their reliance  
331 on rapid acceleration from a primary static position.

332

### 333 **Agility**

334 The ability to quickly accelerate, decelerate, and change direction is believed to be vital in rugby union  
335 (9). However, to the author's knowledge, there is no published data for tests of agility in elite rugby  
336 union athletes. This may be a result of the difficulty in the direct assessment of agility as common  
337 methods do not account for the perceptual and decision-making elements (66). Agility has recently been  
338 defined as "a rapid whole-body movement with a change of velocity or direction in response to a  
339 stimulus" (45). In comparison, a change of direction task is pre-planned (66) and assessed by protocols  
340 such as the Illinois agility test, L-Run, 505, and various other courses reported in the literature (9). In  
341 order to directly assess an athlete's agility, researchers must stimulate an individual's perception-action  
342 cycle. The perception-action cycle is the circular flow of information that takes place between the

343 organism and its environment in the course of a sensory-guided sequence of behaviour towards a goal  
344 (36). Whether attacking or defending, agility is an open skill that requires the ability to perceive relevant  
345 information about an opponent's movements and react quickly and accurately. Therefore, in order to  
346 accurately assess an individual's agility, researchers must provide a stimulus for the athlete to respond  
347 to. Open-skill agility tests are typically more difficult to standardise as the testing environment is  
348 obviously unpredictable. Standardisation of protocol, such as how many direction changes there will be  
349 per test and fixing the distance to be moved when a directional change is indicated, will increase the  
350 test reliability (20,42,64,66). Further research should seek to standardise a rugby-specific agility test in  
351 order to investigate the relationship between agility and ball-carrying capability. Furthermore, to the  
352 authors' knowledge, there is no study that has investigated the relationship between a reliable and valid  
353 measure of change of direction speed and ball-carrying capability.

354

### 355 **Aerobic and Anaerobic Characteristics**

356 Rugby union has been characterised as a high intensity intermittent sport, requiring athletes to perform  
357 repeated bouts of high-speed running (>5 m.s) in short periods of time, as well as sustained and repeated  
358 high intensity actions, such as sprinting, tackling, and scrummaging (9). Typically, these repeated high-  
359 intensity actions are interspersed with periods of low intensity or static efforts (46). It has been  
360 established within literature that a well-developed aerobic capacity improves the repeatability and  
361 sustainability of repeated high-intensity actions (59). The aerobic system is essential for the  
362 replenishment of adenosine triphosphate (ATP) and the buffering of metabolites, such as lactic acid,  
363 following sustained periods of high intensity effort (44,50). Swaby et al., (2016) observed a strong  
364 relationship between maximal aerobic speed and the distance covered during a game amongst elite  
365 rugby union players (57). Maximal aerobic speed can be defined as the lowest running velocity at which  
366 maximal oxygen uptake occurs ( $\dot{V}O_{2max}$ ) and has been shown to be a valid measure of aerobic fitness  
367 amongst rugby union players (57). This finding suggests that superior physical performance has a strong  
368 relationship with aerobic capacity. However, aerobic capacity has not been shown to demonstrate a  
369 significant relationship with the limited measures of technical performance (i.e. total carries or total

370 passes) examined amongst international rugby sevens players (27). Similarly, Cunningham et al., (2018)  
371 observed no significant correlations between Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IRT1)  
372 distance run and the game statistics associated with ball-carrying capability amongst international rugby  
373 union backs. In comparison, Yo-Yo IRT1 distance run only presented a strong correlation with the  
374 percentage of carries made that were over the gain-line amongst forwards (14). However, the game  
375 statistics associated with ball-carrying capability are predominantly characterised as performance-based  
376 match activities, and much stronger correlations were observed between Yo-Yo IRT1 distance run and  
377 effort-based match activities, such as the number of total carries, tackles, passes, or the count of times  
378 the player was in the first three support players to the ruck in attack and defence (14). Thus, although  
379 aerobic capacity is related to the ability to repeat high-intensity actions (through faster recovery between  
380 bouts) over a prolonged period (17), it may be more appropriate for future research to investigate a  
381 potential relationship between aerobic fitness (e.g., maximum aerobic speed) and the ‘rate of fatigue’  
382 in ball-carrying capability across the course of a rugby union match. Whilst the latter variable has not  
383 yet been reported in the literature, it may be more informative to investigate such a relationship in terms  
384 of understanding how to maintain optimal ball-carrying capability throughout a match.

385

386 Due to the repeated sprinting nature of rugby union, anaerobic capacity has also been proposed as a key  
387 indicator of an individual’s physical capacity for competition. Despite this, there are very few studies  
388 that have used repeated sprint tests to measure anaerobic performance amongst rugby union athletes.  
389 This lack of research may be due to the time consuming and resource dependent nature of repeated  
390 sprint testing, which is unfavourable amongst larger sample sizes (17). Smart et al., (2014) reported  
391 only a weak inverse correlation between repeated sprint fatigue and the number of tries scored amongst  
392 international rugby union backs (53). This finding is in accordance with Ross et al., (2015), who  
393 reported a moderate correlation between repeated sprint ability and the number of tries scored and line  
394 breaks amongst international rugby sevens players (49). Both studies also observed a weak-to-moderate  
395 correlation between repeated sprint ability and activity rate (49,53), defined by Smart et al., (2014) as  
396 the count of any action that was performed by the player divided by game time (53). The stronger

397 correlations observed amongst international rugby sevens players may be a result of their greater  
398 reliance on repeated sprint ability when compared to rugby union backs (52). In addition, rugby sevens  
399 match-play is characterised by shorter periods of low intensity effort between longer sustained bouts of  
400 high-intensity activity (30,48). Despite this, these findings suggest repeated sprint ability may be an  
401 important contributing factor to an individual's ability to maintain ball-carrying capability during  
402 periods of repeated high-intensity activity, as well as over the course of a full rugby union match.

403

404 INSERT FIGURE 1 NEAR HERE.

405 INSERT TABLE 2 NEAR HERE.

406

#### 407 **Practical Applications**

408 The aim of this narrative review was to critically appraise the scientific literature that has investigated  
409 the use of physical characteristics to explain ball-carrying capability in elite rugby union. Match  
410 analysis has established that the effectiveness of offensive ball-carrying, quantified by the number of  
411 tries scored, line breaks, tackle breaks, dominant collisions, offloads, defenders beaten, and metres  
412 advanced over the gain line (Table 1), is a main determinant of try scoring success and subsequent  
413 match outcome. The scientific literature investigating the relationship between physical characteristics  
414 and the game statistics associated with ball-carrying capability have identified acceleration, maximum  
415 sprinting speed, sprint momentum, repeat sprint ability, and muscular power output as key determinants  
416 of positive phase outcome. For the backs, measures of acceleration and maximum sprinting speed  
417 presented the most meaningful correlations with the game statistics associated with ball-carrying  
418 capability (Table 3) as a result of the counterbalance reaction that is initiated when a ball carrier enters  
419 the pre-contact phase at a velocity considerably greater than that of the tackler. For the forwards, slower  
420 stretch shortening activities, such as countermovement jump peak power output, and acceleration  
421 performance presented the most meaningful relationships with ball-carrying capability (Table 2).  
422 However, we recommend a cautious interpretation of some data reviewed in this article due to the

423 limited information regarding certain parameters (e.g., agility) and the inconsistencies in the methods  
424 used to assess strength and power capabilities. Further investigation is required to assess the relationship  
425 between physical qualities and the game statistics related to ball-carrying capability and future research  
426 should seek to use simple regression analysis to predict the level of change in physical measures  
427 required to improve ball-carrying capability. In addition, future research may also seek to incorporate  
428 qualitative assessment of the body positions and fending strategies employed by the ball-carrier to  
429 identify the associations between these qualities and ball-carrying capability. These objective data could  
430 be used to inform the specificity of physical preparation and maximise the transfer of these physical  
431 qualities to on-field ball-carrying performance. Having provided a critical analysis of the literature  
432 pertaining to physical characteristics/assessments associated with ball-carrying capability in rugby  
433 union, the main objective of this review was to provide guidance on which characteristics could be used  
434 by practitioners as strong/weak indicators of ball-carrying capability, which we have summarised in  
435 Fig. 1. A second objective was to identify specific characteristics that require further investigation (also  
436 summarised in Fig. 1), thus providing direction for future studies in applied rugby union research.

437

### **Conflicts of Interest**

The authors have no conflicts of interest to disclose.

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**Table 1** – Operational definitions of game statistics reported in studies.

<b>Game Statistic</b>	<b>Definition</b>	<b>Reference</b>
Tries Scored	Number of tries scored by an individual.	(14,48,53)
Line Breaks	Number of times an individual in possession of the ball breaks the defensive line.	(14,48,53)
Tackle Breaks	Number of times an individual in possession of the ball breaks an unsuccessful tackle.	(14,53)
Defenders Beaten	Number of tackles evaded by an individual in possession of the ball.	(48,53)
Dominant Collisions	Number of collisions in attack where an individual makes ground following the collision.	(14)
Offloads	Number of times an individual completed a successful pass in the process of being tackled.	(14)
Carries Over Gain Line (%)	Percentage of carries made that were over the gain line.	(14,53)
Metres Advanced (m)	The total displacement travelled by an individual in possession of the ball. Half backs were excluded due to the large amount of backwards travelling when in possession of the ball.	(53)
Activity Rate (m.min <sup>-1</sup> )	Count of any action performance by an individual and coded, divided by game time.	(53)

**Table 2** – Physical characteristics, testing protocols, output measures and associated game statistics (*r*) amongst elite rugby union forwards reported in studies.

Characteristic	Test	Output Measure	Associated Game Statistic	Reference	
<b>Anthropometric Characteristics</b>	Body Mass	Body Mass (kg)		(14,53)	
	Sum of 8 Skinfolds	Body Fat Percentage (%)	Activity Rate ( <i>r</i> = 0.17)	(53)	
		Fat Free Mass (kg)		(53)	
<b>Strength</b>	Box-Squat 2-6 RM	Estimated 1RM (kg)	Tackle Breaks ( <i>r</i> = 0.09)	(53)	
			Defenders Beaten ( <i>r</i> = 0.05)	(53)	
			Carries Over Gain Line ( <i>r</i> = 0.05)	(53)	
	Bench Press 2-6 RM	Estimated 1RM (kg)		(53)	
	Chin-Ups 2-6 RM	Estimated 1RM (kg)		(53)	
	Isometric Mid-Thigh Pull		Peak Force (N)		(14)
			Relative Peak Force (N.kg <sup>-1</sup> )		(14)
Peak Rate of Force Development (N.s <sup>-1</sup> )				(14)	
<b>Power</b>	Countermovement Jump	Jump Height (cm)	Line Breaks ( <i>r</i> = 0.53)	(14)	
			Dominant Collisions ( <i>r</i> = 0.70)	(14)	
			Carries Over Gain Line ( <i>r</i> = 0.58)	(14)	
		Peak Power (W)	Dominant Collisions ( <i>r</i> = 0.60)	(14)	

	Relative Peak Power (W.kg <sup>-1</sup> )	Line Breaks ( $r = 0.55$ )	(14)
		Carries Over Gain Line ( $r = 0.58$ )	(14)
SL Countermovement Jump	Average Jump Height (cm)	Carries Over Gain Line ( $r = 0.59$ )	(14)
	Average Peak Power (W)	Line Breaks ( $r = 0.56$ )	(14)
		Dominant Collisions ( $r = 0.57$ )	(14)
Power Clean 2-6 RM	Estimated 1RM (kg)	Tackle Breaks ( $r = -0.12$ )	(53)
		Defenders Beaten ( $r = -0.20$ )	(53)
		Carries Over Gain Line ( $r = 0.02$ )	(53)
20 cm Drop Jump	Jump Height (cm)	Tackle Breaks ( $r = 0.53$ )	(14)
		Carries Over Gain Line ( $r = 0.73$ )	(14)
	Peak Power (W)		(14)
	Reactive Strength Index (au)	Line Breaks ( $r = 0.56$ )	(14)
		Dominant Collisions ( $r = 0.59$ )	(14)
		Offloads ( $r = 0.59$ )	(14)
SL 20 cm Drop Jump	Average Jump Height (cm)		(14)
	Average Peak Power (W)		(14)
	Average Reactive Strength Index (au)		(14)
40 cm Drop Jump	Jump Height (cm)	Tries Scored ( $r = 0.63$ )	(14)
	Peak Power (W)		(14)

		Reactive Strength Index (au)		(14)
<b>Speed</b>	10 m Sprint	Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.14$ )	(53)
			Line Breaks ( $r = 0.26$ )	(53)
			Tackle Breaks ( $r = 0.72$ )	(14)
			Tackle Breaks ( $r = 0.17$ )	(53)
			Defenders Beaten ( $r = 0.33$ )	(14)
			Carries Over Gain Line ( $r = 0.65$ )	(14)
		Momentum ( $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$ )		(14)
	20 m Sprint	Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.17$ )	(53)
			Defenders Beaten ( $r = 0.39$ )	(53)
			Metres Advanced ( $r = 0.32$ )	(53)
<b>Aerobic Characteristics</b>	Yo-Yo Intermittent Recovery Test Level 1	Distance Run (m)	Carries Over Gain Line ( $r = 0.61$ )	(14)
<b>Anaerobic Characteristics</b>	Rugby-Specific Repeated	Average Sprint Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.24$ )	(53)
	Speed Test		Activity Rate ( $r = 0.38$ )	(53)
		Fatigue Decrement (%)	Tries Scored ( $r = -0.02$ )	(53)
			Activity Rate ( $r = -0.05$ )	(53)

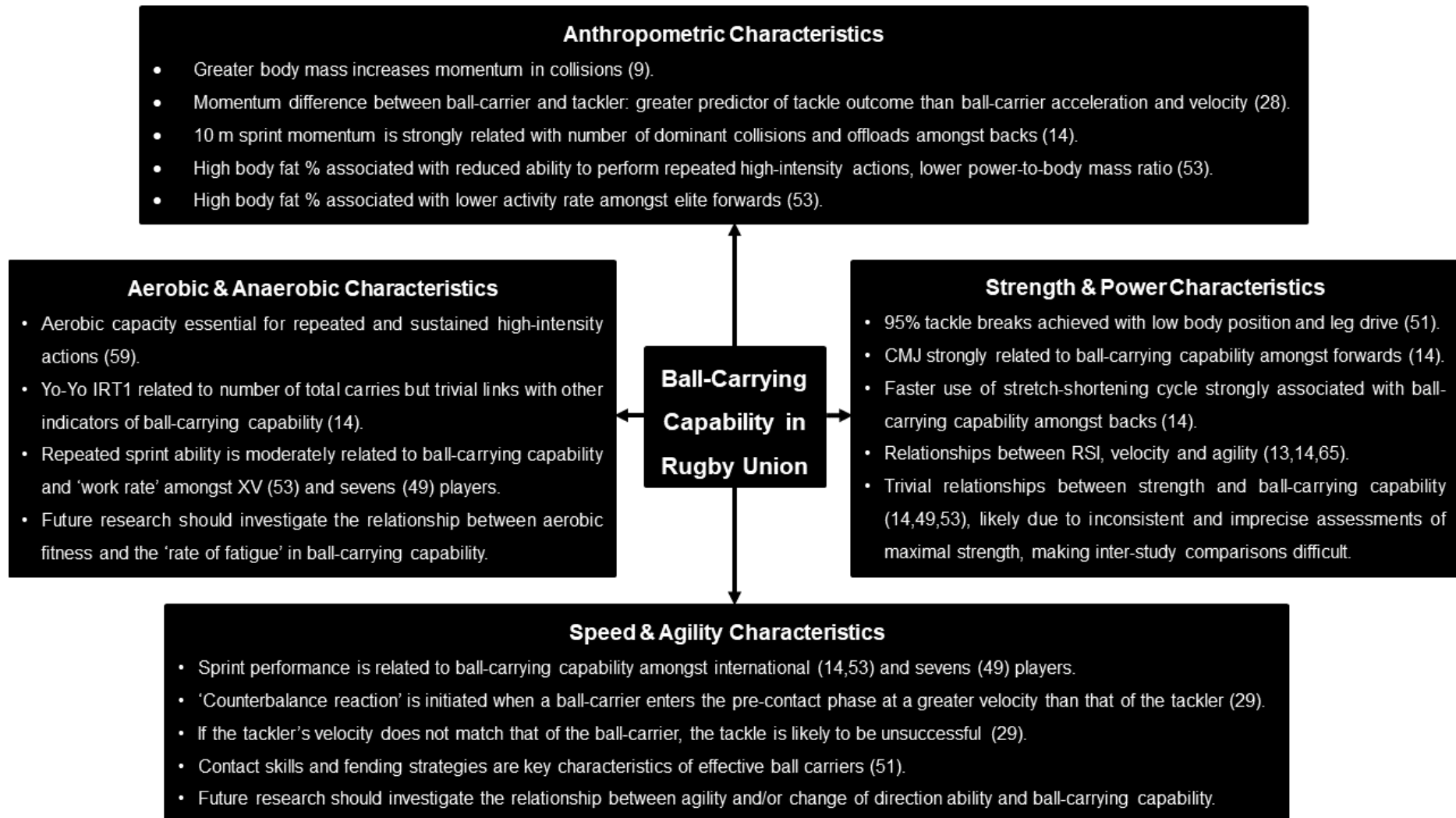
**Table 3** - Physical characteristics, testing protocols, outcome measures and associated game statistics ( $r$ ) amongst elite rugby union backs and rugby sevens players reported in studies.

Characteristic	Test	Output Measure	Associated Game Statistic	Reference
<b>Anthropometric Characteristics</b>	Body Mass	Body Mass (kg)	Dominant Collisions ( $r = 0.92$ )	(14)
	Sum of 8 Skinfolds	Body Fat Percentage (%)	Activity Rate ( $r = 0.10$ )	(53)
		Fat Free Mass (kg)		(53)
<b>Strength</b>	Box-Squat 2-6 RM	Estimated 1RM (kg)	Tackle Breaks ( $r = -0.02$ )	(53)
			Defenders Beaten ( $r = -0.03$ )	(53)
			Carries Over Gain Line ( $r = 0.08$ )	(53)
	Bench Press 2-6 RM	Estimated 1RM (kg)	Defenders Beaten ( $r = 0.16$ )	(48)
				(53)
	Chin-Ups 2-6 RM	Estimated 1RM (kg)		(48,53)
	Isometric Mid-Thigh Pull		Peak Force (N)	Offloads ( $r = 0.62$ )
Relative Peak Force ( $N.kg^{-1}$ )			Carries Over Gain Line ( $r = 0.53$ )	(14)
Peak Rate of Force Development ( $N.s^{-1}$ )				(14)
<b>Power</b>	Countermovement Jump	Jump Height (cm)		(14)
		Peak Power (W)	Defenders Beaten ( $r = 0.11$ )	(48)
			Dominant Collisions ( $r = 0.75$ )	(14)

		Offloads ( $r = 0.69$ )	(14)
	Relative Peak Power ( $\text{W}\cdot\text{kg}^{-1}$ )		(14)
Countermovement Jump (50 kg)	Peak Power (W)	Defenders Beaten ( $r = 0.06$ )	(48)
SL Countermovement Jump	Average Jump Height (cm)		(14)
	Average Peak Power (W)	Dominant Collisions ( $r = 0.79$ ) Offloads ( $r = 0.73$ )	(14) (14)
Horizontal Jump	Jump Distance (cm)	Defenders Beaten ( $r = 0.47$ )	(48)
Power Clean 2-6 RM	Estimated 1RM (kg)	Tackle Breaks ( $r = 0.01$ )	(53)
		Defenders Beaten ( $r = -0.03$ )	(53)
		Carries Over Gain Line ( $r = 0.08$ )	(53)
20 cm Drop Jump	Jump Height (cm)		(14)
	Peak Power (W)		(14)
	Reactive Strength Index (au)	Tries Scored ( $r = 0.62$ )	(14)
SL 20 cm Drop Jump	Average Jump Height (cm)		(14)
	Average Peak Power (W)		(14)
	Average Reactive Strength Index (au)	Tries Scored ( $r = 0.61$ ) Line Breaks ( $r = 0.62$ )	(14) (14)
40 cm Drop Jump	Jump Height (cm)		(14)
	Peak Power (W)		(14)

		Reactive Strength Index (au)	Tries Scored ( $r = 0.64$ )	(14)
			Line Breaks ( $r = 0.62$ )	(14)
<b>Speed</b>	5 m Sprint	Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.17$ )	(48)
			Line Breaks ( $r = 0.35$ )	(48)
			Defenders Beaten ( $r = 0.27$ )	(48)
	10 m Sprint	Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.12$ )	(53)
			Tries Scored ( $r = 0.27$ )	(48)
			Line Breaks ( $r = 0.25$ )	(53)
			Line Breaks ( $r = 0.47$ )	(48)
			Defenders Beaten ( $r = 0.20$ )	(53)
			Defenders Beaten ( $r = 0.41$ )	(48)
Tackle Breaks ( $r = 0.15$ )			(53)	
Carries Over Gain Line ( $r = -0.03$ )			(53)	
Metres Advanced ( $r = 0.13$ )	(53)			
		Momentum ( $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.37$ )	(48)
			Line Breaks ( $r = 0.32$ )	(48)
			Defenders Beaten ( $r = 0.30$ )	(48)
			Dominant Collisions ( $r = 0.86$ )	(14)
			Offloads ( $r = 0.78$ )	(14)

	30 m Sprint	Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.16$ )	(53)
			Defenders Beaten ( $r = 0.25$ )	(53)
			Metres Advanced ( $r = 0.13$ )	(53)
<b>Aerobic Characteristics</b>	40 m Sprint	Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.25$ )	(48)
			Line Breaks ( $r = 0.51$ )	(48)
			Defenders Beaten ( $r = 0.50$ )	(48)
	Yo-Yo Intermittent Recovery Test Level 1	Distance Run (m)		(14)
	Multi-Stage Fitness Test	Distance Run (m)	Activity Rate ( $r = 0.36$ )	(48)
<b>Anaerobic Characteristics</b>	Rugby-Specific Repeated Speed Test	Average Sprint Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.09$ )	(53)
			Activity Rate ( $r = 0.03$ )	(53)
	Fatigue Decrement (%)	Tries Scored ( $r = 0.21$ )	(53)	
		Activity Rate ( $r = -0.17$ )	(53)	
10 x 40 m Repeat Sprint Ability Test	Average Sprint Velocity ( $\text{m}\cdot\text{s}^{-1}$ )	Tries Scored ( $r = 0.31$ )	(48)	
		Activity Rate ( $r = 0.39$ )	(48)	



**Figure 1.** A summary of the main findings of the literature review, providing guidance for coaches on which physical characteristics should be prioritised to optimise ball-carrying capability in rugby union players, and guidance for researchers on which physical characteristics require further investigation.