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ORIGINAL ARTICLE

Physical Characteristics Explain Ball-Carrying Capability in Sub-Elite Rugby Union Players

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Abstract

Purpose The aims of the present study were two-fold: (i) to investigate the relationship between physical characteristics and the game statistics associated with ball-carrying capability amongst sub-elite rugby union players, and (ii) to predict the level of change in these physical characteristics required to improve the associated game statistic via regression analysis.

Methods Thirty-eight senior professional players (forwards, $n=22$; backs, $n=16$) were assessed for body mass (BM), back squat (BS) single-repetition maximum (1RM) normalised to BM (1RM/BM), 10 m sprint velocity (S10), 10 m sprint momentum (SM10), and the game statistics from 22 games within the 2019/20 RFU Championship season. The relationship between these measures and the predicted level of change in a physical measure required to improve the total number of the associated game statistic by one were assessed by Pearson's correlation coefficient and simple regression analyses.

Results In forwards, an ~11.5% reduction in BM, an ~11.8% improvement in BS 1RM/BM, or an ~11.5% increase in S10 was required to improve the game statistics associated with ball-carrying capability. In backs, a ~19.3% increase in BM or a ~15.6% improvement in SM10 was required.

Conclusions These findings demonstrate that improvements in lower-body relative strength, acceleration performance, and position-specific alterations in body mass are required to maximise the ball-carrying capability and therefore match outcome of sub-elite rugby union players.

Keywords *Speed* · *Acceleration* · *Momentum* · *Strength* · *Body mass*

Introduction

Rugby union is characterised as a high intensity intermittent sport that requires athletes to perform repeated running actions, collisions, and static efforts of differing work to rest periods [22]. The number of tries scored has been identified as a main determinant of match outcome in elite rugby union [12], with winning teams scoring more tries than losing teams in Rugby World Cup match-play [19]. Successful offensive ball-carrying, a motion where the player in possession of the ball challenges and breaks the opposition defensive line, has been highlighted as an important determinant of try scoring success and subsequent match outcome [25]. For instance, Bennett et al. identified several performance indicators associated with ball-carrying capability as accurate predictors of match outcome in the group-phase and knockout-phase of the 2015 Rugby World Cup [9]. Previous notational analysis has quantified successful offensive ball carries by the number of tries scored, line breaks, tackle breaks, offloads, and defenders beaten [13, 23, 28]. Notational analysis provides objective feedback of individual player actions through the frequencies of key performance indicators [13], and matches are typically coded by performance analysts. Therefore, consistency achieved through high inter- and intra-rater reliability amongst performance analysts is essential for effective analysis of match-play statistics.

Research investigating the physical characteristics common amongst effective ball carriers has identified acceleration, maximum sprinting speed, sprint momentum, and contact skills as key determinants of positive phase outcome

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[25]. Specifically, sprint times over 5, 10, 20, 30, and 40 m have presented weak-to-strong correlations with the number of tries scored, line breaks, tackle breaks, and defenders beaten amongst international rugby union [13, 28] and rugby sevens players [23]. These objective data can inform the development of specific physical characteristics with the fundamental aim of optimising the transfer of these physical qualities to on-field performance. Given that most previous studies investigated the relationship between physical characteristics and ball-carrying capability in elite rugby union players (i.e., international level players for a 'High Performance Union, according to Regulation 16 at http://www.worldrugby.org) means that the application of these findings to a sub-elite population (e.g., professional players in the second tier of a High Performance Union) would be inappropriate. Smart et al. proposed the generally weak or trivial correlations observed between physical qualities and game statistics were a result of the uniformly high fitness levels amongst elite players [28]. In comparison, a sub-elite player group might be expected to exhibit far greater inter-individual variation in physical qualities, resulting in stronger correlations between physical characteristics and game statistics. Additionally, further research is required to identify whether the same performance indicators are deemed essential at sub-elite levels.

A novel aspect of one recent study is the inclusion of simple regression analysis to predict the effect of a change in a physical characteristic on an associated game statistic [13]. However, for most of the identified relationships, the magnitude and direction of change in physical performance was deemed beyond that which can be achieved from training [13]. Therefore, the primary aim of the present study was to investigate the relationship between key physical characteristics and the game statistics associated with ball-carrying capability amongst sub-elite rugby union players. In addition, the present study attempted to predict the level of change in these physical characteristics required to improve the associated game statistics via regression analysis. Given the previous relationships established between physical characteristics and ball-carrying capability amongst elite rugby union players, the present study hypothesized that ball-carrying capability would correlate strongly with sprint velocity and sprint momentum.

Methods

Participants

Thirty-eight senior, sub-elite professional players from a RFU Championship rugby union squad (forwards $n=22$, age: 28.3 ± 2.6 years, height: 1.9 ± 0.07 m, body mass: 114.05 ± 4.58 kg; backs; $n=16$, age: 25.2 ± 2.1 years, height: 1.86 ± 0.06 m, body mass: 96.13 ± 8.48 kg) participated in this study. Our cohort was defined as "sub-elite" due to their playing status in the second tier of a High Performance Union. All players were in full-time training and considered injury-free by the medical department. As these data were acquired as a condition of player monitoring, in which players are routinely assessed over the course of the competitive season, ethical approval was not required [36]. Nevertheless, the present study conformed to the recommendations of the Declaration of Helsinki [3].

Study Design

Physical testing occurred across two sessions at the end of the pre-season. The first testing session occurred two weeks prior to the first competitive fixture of the 2019/20 RFU Championship season. Each player was required to complete basic anthropometric measurements (stature and body mass), one-repetition maximum (1RM) back squat and bench press, maximal bilateral vertical countermovement jump (CMJ), and 10 m sprint assessments. Only the basic anthropometric measurements, countermovement jump, and 10 m sprint assessments were repeated in the second testing session carried out seven days after the first testing session for the purpose of assessing the test-retest reproducibility of these measurements. There was no requirement for a familiarisation session prior to data collection as all participants were regularly exposed to the tasks and methods of assessment across the pre-season period [1]. Verbal encouragement was provided throughout the testing sessions by the club performance staff to maximise performance. Twenty-two matches from the 2019/20 RFU Championship season were analyzed for game statistics related to ball-carrying capability via notational analysis.

Strength Assessments

Following the collection of basic anthropometric measurements and completion of a standardised warm up, each player was required to complete a barbell back squat and bench press 1RM to assess maximal lower-body and upper-body strength, respectively [16]. For each exercise, players were instructed to complete three warm up sets with incremental loads. A maximum of two 1RM attempts at any one load was permitted. If the player was unsuccessful in their 1RM attempt, the previous successful attempt was taken as their 1RM load. In consultation with each player, following a successful 1RM attempt, the barbell weight was increased between 2.5 and 5 kg until no further weight could be lifted. Rest periods comprised passive recovery of min between warm up sets and 3 min between 1RM attempts [5]. For the back squat, each player was instructed to descend in a controlled manner until the hip joint was at least level or slightly below the knee joint before ascending to the starting position. Each player used a self-selected foot position and weightlifting belts were not permitted. For bench press, each player was instructed to lower the bar to the chest (with elbows at approximately 45°) before returning to the start position where elbows were fully extended but not locked [28]. Each player's feet were to remain in contact with the floor, the lower back and buttocks had to remain in contact with the bench throughout the lift and bouncing the bar off the chest was not permitted. A spotter was present for each exercise and aided the player in lifting the bar off the rack prior to completing the lift [23]. Each exercise was assessed for correct technique by a qualified strength and conditioning practitioner and only repetitions performed unassisted with correct technique were documented. Each player's absolute 1RM (kg) for each lift was normalised to body mass to calculate the individual's relative 1RM (kg/kg). Both absolute and relative 1RMs for each lift was used in further statistical analyses.

Countermovement Jump Assessment

The countermovement jump assessment required each player to complete three maximal bilateral vertical countermovement jumps (CMJs) on the JumpMat Pro (JumpMat, Sydney, Australia) with one minute's rest between attempts. Each player was instructed to perform all jumps with arms akimbo and to maintain full extension of the lower limbs throughout the flight phase of the jump [13]. Jump height for each trial was documented and peak power was calculated from the greatest jump height recorded according to the following equation [24]:

$$\textbf{Peak Power (W)} = 60.7 \times \text{Jump Height (cm)} + 45.3 \times \text{Body Mass (kg)} - 2055$$

The maximum jump height and peak power obtained across both testing sessions were used in further statistical analyses.

Sprint Assessment

The time taken to cover 10 m from a stationary start was used to assess acceleration performance. Following the completion of a standardised warm up, each player was required to complete three maximal 10 m sprints, with 3 minutes' rest between attempts. All sprints were performed in rugby boots on a 4G artificial rugby pitch. Participants started in a two-point crouched position with their preferred foot forward on a mark 0.5 m behind the first timing gate. Single beam timing gates (Brower Timing System, Salt Lake City, Utah, USA) were positioned at the start (0 m) and at 10 m. Each participant was instructed to sprint maximally to beyond the final timing gate and the fastest time recorded was used for further analysis. Average sprint velocity (m/s) was calculated by dividing the 10 m distance by the time taken. Sprint momentum (kg·m/s) was calculated by multiplying the participant's body mass by the average sprint velocity [13]. The greatest average sprint velocity and average sprint momentum from both testing sessions were used for further statistical analyses.

Table 1 Operational definitions of game statistics used in analysis

Game Statistic	Definition
Tries Scored	Number of tries scored by an individual player
Line Breaks	Number of times the ball carrier breaks the defensive line
Tackle Breaks	Number of times the ball carrier breaks an unsuccessful tackle
Defenders Beaten	Number of tackles evaded by the ball carrier
Dominant Collisions	Number of collisions in attack where the player makes ground after the collision
Handling Turnovers	Number of handling errors incurred by the ball carrier – including knock-ons, forward passes and balls dropped behind which does not result in a penalty
Total Turnovers	Number of times the ball carrier turns over the ball to the opposition

Game Statistics

The game statistics associated with ball-carrying capability performed by each player from all 2019/20 RFU Championship fixtures ($n=22$) were collated by the club's experienced performance analyst (more than five years' experience as a performance analyst within rugby union [13]) using NacSport Pro video analysis software (NacSport Pro, NacSport, Spain). The operational definitions for the game statistics used for the analysis (tries scored, line breaks, tackle breaks, defenders beaten, dominant collisions, handling turnovers, total turnovers) are included in Table 1 [13, 23, 28]. Only individuals with ≥ 10 min game time were included in the analysis to reduce the large random variation associated with individuals who come on as replacements in the final stages of matches [13]. Each game statistic was collated for each player and normalized to game time [13] to be used in further statistical analyses:

$$\textbf{Reported Value} = 80 \times (\text{Observed Value} \div \text{Minutes Played}).$$

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Test-retest Reproducibility of Measurements

Test-retest reproducibility for the CMJ and 10 m sprint assessments was established in all 38 players, who completed the assessments on two occasions, interspersed by seven days. Measurements were performed by the same investigator.

Statistical Analysis

Players were grouped according to position (forwards vs. backs). Means and standard deviations were calculated for each physical characteristic and game statistic. The differences between position groups for each measure were compared using independent t-tests. Pearson's correlation coefficients (r) were calculated (following Shapiro-Wilk test for normal distribution of data) to assess the relationships between each physical characteristic and game statistic for each position group. Each correlation coefficient was calculated using an approach that provided a reduced weighting to matches that were played at later dates following the testing session [28]. The value of each game statistic was a weighted mean derived with a weighting factor $e^{-w/t}$, where e was the normalised game statistic, w was the time in weeks between the testing session and the game, and t (a time constant) was assigned a chosen value (1, 4, 12, and 20 weeks). The entire analysis was repeated for each value of t, and the correlations are presented for the value of t that reported the largest correlations [28]. Cohen's scale was used to interpret the magnitudes of the correlation coefficients: <0.1 = trivial, 0.1–0.3 = small, 0.3–0.5 = moderate, and > 0.5 = large [11]. Finally, simple regression analysis was performed for each moderate-to-large relationship ($r > 0.3$) to predict the effect of a change in a physical characteristic on the associated game statistic [13]. Inter-day reproducibility of the CMJ and sprint assessments was expressed as typical error (TE), coefficient of variation (CV) and intra-class correlation coefficient (ICC, model: two-way mixed; type: absolute agreement) with 95% confidence intervals (CIs). All statistical analyses were performed using SPSS software (version 26, IBM Corp., Armonk, N.Y., USA) with significance set at $P < 0.05$.

Results

Positional Differences

The means and standard deviations for all physical characteristics are shown in Table 2. The forwards were found to be significantly older [$P = 0.028$, $d = 1.31$, 95% CI (1.7, 2.6)], heavier [$P = 0.001$, $d = 2.63$, 95% CI (13.59, 22.25)], and produced greater absolute back squat [$P = 0.027$, $d = 0.74$, 95% CI (1.47, 22.67)] and bench press 1RMs [$P = 0.006$, $d = 0.98$, 95% CI (3.39, 21.66)], CMJ peak power [$P = 0.002$, $d = 1.11$, 95% CI (162.45, 634.29)], and 10 m sprint momentum [$P = 0.001$, $d = 1.72$, 95% CI (43.17, 93.98)]. In comparison, the backs generated significantly greater relative back squat [$P = 0.001$, $d = 1.13$, 95% CI (0.09, 0.34)] and bench press 1RMs [$P = 0.036$, $d = 0.70$, 95% CI (0.01, 0.21)], CMJ height [$P = 0.028$, $d = 0.75$, 95% CI (0.45, 0.75)], and 10 m sprint velocity [$P = 0.001$, $d = 1.57$, 95% CI (0.48, 0.79)].

Table 2 Physical characteristics of senior sub-elite rugby union players ($n = 38$). Data are mean ± SD

Variables	Forwards ($n = 22$)	Backs ($n = 16$)
Age (years)	28.3 ± 2.6*	25.2 ± 2.1
Stature (m)	1.90 ± 0.07	1.86 ± 0.06
Body Mass (kg)	114 ± 4.6**	96 ± 8.5
Absolute Back Squat 1RM (kg)	204 ± 13.2*	191 ± 19.0
Relative Back Squat 1RM (kg/kg)	1.79 ± 0.14*	2.00 ± 0.23
Absolute Bench Press 1RM (kg)	142 ± 15.2*	129 ± 10.3
Relative Bench Press 1RM (kg/kg)	1.24 ± 0.14*	1.35 ± 0.17
Countermovement Jump Height (cm)	40.83 ± 5.2*	44.82 ± 5.4
Countermovement Jump Peak Power (W)	5590 ± 332*	5020 ± 383
10 m Sprint Time (s)	1.78 ± 0.07**	1.68 ± 0.06
10 m Sprint Velocity (m/s)	5.63 ± 0.22**	5.97 ± 0.21
10 m Sprint Momentum (kg/m/s)	642 ± 28.0**	573 ± 48.9

* $P < 0.05$, ** $P < 0.001$ different to Backs

The Relationships Between Physical Characteristics and Game Statistics

The Pearson's correlation coefficients are displayed in Tables 3 and 4 for the forwards and backs, respectively. The correlation coefficients presented are those derived using the 20-week time constant, as this tended to produce the strongest correlations and allowed a fair representation of an individual player's form [28]. Moderate-to-strong correlations were observed between a number of game statistics associated with ball-carrying capability and body mass, relative back squat 1RM, 10 m sprint velocity or 10 m sprint momentum amongst both position groups (Tables 3 and 4).

Predicting the Effect of a Change in Physical Characteristics on Game Statistics

The use of simple regression analysis to predict the effect of a change in a physical characteristic on the associated game statistic revealed several significant effects. The relationships that were considered to be practically achievable (i.e.,

Table 3 Pearson's correlation coefficients between physical performance measures and game statistics associated with ball-carrying capability for the forward positions ($n = 22$). Significant correlations are highlighted in bold

Variables	Tries Scored	Line Breaks	Tackle Breaks	Defenders Beaten	Dominant Collisions	Handling Turnovers	Total Turnovers
Body Mass (kg)	$\mathbf{r=-0.57}$ $\mathbf{P=0.01}$	$\mathbf{r=-0.54}$ $\mathbf{P=0.01}$	$r=-0.29$ $P=0.18$	$\mathbf{r=-0.45}$ $\mathbf{P=0.04}$	$\mathbf{r=-0.54}$ $\mathbf{P=0.01}$	$r=-0.54$ $P=0.10$	$r=-0.72$ $P=0.07$
Absolute Back Squat 1RM (kg)	$r=0.25$ $P=0.26$	$r=0.15$ $P=0.52$	$r=0.13$ $P=0.57$	$r=0.41$ $P=0.12$	$r=0.34$ $P=0.12$	$r=0.25$ $P=0.26$	$r=0.19$ $P=0.39$
Relative Back Squat 1RM (kg/kg)	$r=\mathbf{0.45}$ $P=\mathbf{0.04}$	$r=0.33$ $P=0.15$	$r=\mathbf{0.42}$ $P=\mathbf{0.05}$	$r=0.32$ $P=0.15$	$r=0.43$ $P=0.49$	$r=0.42$ $P=0.52$	$r=0.44$ $P=0.43$
Absolute Bench Press 1RM (kg)	$r=-0.06$ $P=0.80$	$r=0.05$ $P=0.82$	$r=-0.09$ $P=0.70$	$r=0.19$ $P=0.40$	$r=-0.20$ $P=0.37$	$r=-0.80$ $P=0.72$	$r=0.09$ $P=0.69$
Relative Bench Press 1RM (kg/kg)	$r=0.27$ $P=0.23$	$r=0.33$ $P=0.13$	$r=0.22$ $P=0.34$	$r=0.40$ $P=0.16$	$r=-0.02$ $P=0.92$	$r=0.21$ $P=0.34$	$r=0.47$ $P=0.27$
Countermovement Jump Height (cm)	$r=0.42$ $P=0.06$	$r=0.28$ $P=0.21$	$r=0.44$ $P=0.06$	$r=0.35$ $P=0.11$	$r=0.24$ $P=0.28$	$r=0.21$ $P=0.35$	$r=0.15$ $P=0.51$
Countermovement Jump Peak Power (W)	$r=0.12$ $P=0.58$	$r=0.01$ $P=0.97$	$r=0.16$ $P=0.48$	$r=0.12$ $P=0.60$	$r=0.09$ $P=0.70$	$r=-0.06$ $P=0.78$	$r=-0.21$ $P=0.34$
10 m Sprint Velocity (m/s)	$r=\mathbf{0.54}$ $P=\mathbf{0.01}$	$r=0.76$ $P=0.06$	$r=\mathbf{0.55}$ $P=\mathbf{0.01}$	$r=\mathbf{0.43}$ $P=\mathbf{0.05}$	$r=\mathbf{0.72}$ $P=\mathbf{0.001}$	$r=0.14$ $P=0.54$	$r=0.22$ $P=0.32$
10 m Sprint Momentum (kg·m/s)	$r=0.03$ $P=0.90$	$r=0.10$ $P=0.57$	$r=0.15$ $P=0.50$	$r=0.13$ $P=0.48$	$r=0.34$ $P=0.28$	$r=-0.37$ $P=0.09$	$r=-0.46$ $P=0.08$

< 20%) for the forwards were as follows; to increase the number of tries scored by one would require a 7.7% reduction in body mass, an 11.8% increase in relative back squat 1RM, or a 7.1% improvement in 10 m sprint velocity. To increase the number of line breaks by one would require an 11.5% reduction in body mass. To increase the number of tackle breaks by one, a 4.9% increase in relative back squat 1RM or an 11.5% improvement in 10 m sprint velocity was required. To increase the number of defenders beaten by one, a 3.4% reduction in body mass, or a 3.4% improvement in 10 m sprint velocity was required. To increase the number of dominant collisions by one, a 1.0% reduction in body mass or a 1.4% improvement in 10 m sprint velocity was required.

For the backs, to increase the number of tackle breaks by one, a 19.3% increase in body mass or a 15.6% increase in 10 m sprint momentum was required. To increase the number of dominant collisions by one would require a 5.2% increase in body mass or a 4.3% increase in 10 m sprint momentum.

Table 4 Pearson's correlation coefficients between measures of physical performance and game statistics associated with ball carrying capability for the back positions ($n = 16$). Significant correlations are highlighted in bold

Variables	Tries Scored	Line Breaks	Tackle Breaks	Defenders Beaten	Dominant Collisions	Handling Turnovers	Total Turnovers
Body Mass (kg)	$r=-0.08$ $P=0.76$	$r=-0.11$ $P=0.68$	$r=\mathbf{0.57}$ $P=\mathbf{0.02}$	$r=0.32$ $P=0.24$	$r=\mathbf{0.77}$ $P=\mathbf{0.001}$	$r=-0.36$ $P=0.17$	$r=-0.44$ $P=0.09$
Absolute Back Squat 1RM (kg)	$r=0.05$ $P=0.86$	$r=0.42$ $P=0.34$	$r=0.29$ $P=0.28$	$r=0.20$ $P=0.45$	$r=0.34$ $P=0.20$	$r=0.24$ $P=0.36$	$r=0.22$ $P=0.41$
Relative Back Squat 1RM (kg/kg^{-1})	$r=\mathbf{0.53}$ $P=\mathbf{0.03}$	$r=0.43$ $P=0.10$	$r=\mathbf{0.73}$ $P=\mathbf{0.001}$	$r=0.12$ $P=0.67$	$r=0.73$ $P=0.06$	$r=0.48$ $P=0.65$	$r=0.54$ $P=0.32$
Absolute Bench Press 1RM (kg)	$r=0.53$ $P=0.34$	$r=0.59$ $P=0.39$	$r=0.33$ $P=0.21$	$r=0.26$ $P=0.33$	$r=0.19$ $P=0.47$	$r=-0.11$ $P=0.69$	$r=-0.23$ $P=0.34$
Relative Bench Press 1RM (kg/kg^{-1})	$r=0.42$ $P=0.10$	$r=0.49$ $P=0.53$	$r=-0.38$ $P=0.15$	$r=-0.07$ $P=0.80$	$r=-0.28$ $P=0.30$	$r=0.18$ $P=0.52$	$r=0.14$ $P=0.62$
Countermovement Jump Height (cm)	$r=0.08$ $P=0.78$	$r=0.01$ $P=0.98$	$r=-0.22$ $P=0.42$	$r=-0.04$ $P=0.89$	$r=-0.23$ $P=0.40$	$r=0.10$ $P=0.70$	$r=0.18$ $P=0.51$
Countermovement Jump Peak Power (W)	$r=0.02$ $P=0.99$	$r=-0.08$ $P=0.76$	$r=0.42$ $P=0.10$	$r=0.22$ $P=0.42$	$r=0.26$ $P=0.34$	$r=-0.19$ $P=0.47$	$r=-0.29$ $P=0.48$
10 m Sprint Velocity (m/s)	$r=0.24$ $P=0.38$	$r=0.24$ $P=0.37$	$r=-0.33$ $P=0.21$	$r=0.08$ $P=0.78$	$r=-0.27$ $P=0.32$	$r=-0.05$ $P=0.99$	$r=0.06$ $P=0.83$
10 m Sprint Momentum (kg m/s)	$r=0.02$ $P=0.96$	$r=-0.01$ $P=0.97$	$r=0.47$ $P=0.03$	$r=0.36$ $P=0.17$	$r=0.66$ $P=0.001$	$r=-0.37$ $P=0.16$	$r=-0.43$ $P=0.10$

Test-retest Reliability

A high degree of reliability was observed for CMJ height (TE = 1.04 cm, CV = 2.49%) and 10 m sprint time (TE = 0.03 s, CV = 1.56%). The ICC for CMJ height was 0.97 with 95% CIs from 0.93 to 0.98, and the ICC for 10 m sprint time was 0.89 with 95% CIs from 0.79 to 0.94.

Discussion

The primary aim of the present study was to examine the relationship between measured physical characteristics and game statistics from competitive sub-elite rugby union match-play, in order to evaluate which physical qualities underpin ball-carrying capability. For the forwards, body mass, relative back squat 1RM, and 10 m sprint velocity presented the most significant correlations with the game statistics associated with ball-carrying capability. In comparison, body mass, relative back squat 1RM, and 10 m sprint momentum presented the most meaningful correlations with game statistics for the backs. These findings may possess significant implications for strength and conditioning practitioners when structuring position group specific training to improve player performance and ultimately match outcome.

Table 2 illustrates the positional group differences for each physical measure. The forwards were significantly older and heavier than the backs, in accordance with findings amongst elite rugby union players [26]. Furthermore, the forwards also produced significantly greater CMJ peak power and 10 m sprint momentum. In comparison, the backs were significantly faster than the forwards and generated significantly greater CMJ height. These findings are consistent with previous literature examining the position differences amongst sub-elite rugby union players [21].

Tables 3 and 4 demonstrate the Pearson's correlation coefficients between the physical performance measures and the game statistics associated with ball-carrying capability amongst the forwards and the backs, respectively. Measures of acceleration have previously been reported to present small-to-moderate correlations with the game statistics associated with ball-carrying capability amongst elite rugby union players, irrespective of position [13, 28]. However, in the present study, 10 m sprint velocity was significantly correlated with the number of tries scored, tackle breaks, defenders beaten, and dominant collisions amongst the forwards, only. The ability to accelerate rapidly is of high importance to the forward positions, as previous research has shown significantly more tackle breaks occur when the ball carrier's velocity exceeds the tackler's velocity in contact [17]. The use of simple linear regression highlighted an ~ 11.5% improvement in 10 m sprint velocity was required to increase the number of tries scored, tackle breaks, defenders beaten, and dominant collisions by one. In elite level rugby union players, improvements of ~ 4% in 10 m acceleration performance have been reported following 6-weeks of resisted sled sprint training [34]. At the sub-elite level, however, slower 10 m acceleration times compared to elite [27] suggest that greater performance gains are achievable, although this remains to be shown.

Surprisingly, the present study identified no significant relationship between 10 m sprint velocity and game statistics amongst backs. Smart et al. proposed the backs, particularly the back three, possess a reduced reliance on acceleration, as they predominantly receive the ball in motion (frequently at high speeds) [27]. Furthermore, the back positions perform a greater number of longer distance sprints (30–40 m), reach greater average and maximum sprinting speeds, and cover a greater total distance within high-speed zones (> 23 km/h) in comparison to forwards [4, 22]. Therefore, the findings of the present study suggest that backs may be more reliant on maximum sprinting speed, rather than acceleration *per se*, to evade defenders and achieve positive phase outcomes. This theory is further reinforced by Ungureanu et al. examining the relationship between specific game-related technical and tactical key performance indicators and running activities amongst elite under-20 rugby union players [31]. Ungureanu et al. demonstrated explosive distance (distance covered by a player when their acceleration is above 2.5 m/s) was only associated with technical and tactical key performance indicators amongst the forward positions, as the forwards are typically more involved in game situations with or close to the ball where space is limited [31]. A clear limitation of the present study is the absence of 20–40 m sprint time assessments, and such data are more representative of the average distance per sprint performed by backs [21]. Therefore, we propose that future studies include measurements of 40 m sprint performance in their testing batteries to assess the relationship between maximum sprint velocity and ball-carrying capability amongst the backs.

The present study reported that body mass correlated strongly with tackle breaks and dominant collisions amongst backs. These findings are believed to be a direct result of the association between body mass and momentum [29]. Momentum is the product of an individual's mass and velocity, and the difference in momentum between ball carrier and tackler has been proposed to play a much greater role in the prediction of tackle outcome than the ball carrier's velocity [18]. This theory is supported by the moderate-to-large correlations observed between 10 m sprint momentum and the number of tackle breaks and dominant collisions amongst backs. Despite the lack of a relationship observed between 10 m sprint velocity and ball-carrying capability, this finding illustrates the contribution of body mass to sprint momentum, as well as the importance of sprint momentum to achieving positive phase outcomes when the back positions are presented with limited space and contact situations. In contrast, the forwards presented no significant correlations between 10 m sprint momentum and any game statistic. However, 10 m sprint momentum may not be an applicable measure for the forward positions [13], as time motion analysis has demonstrated that forwards typically perform a greater number of shorter distance sprints with an average distance per sprint of < 10 m [15]. In addition, the forwards have been shown to possess a reduced average distance per carry in comparison to the backs [8], proposed to be a result of receiving the ball in limited space and from a stationary start [31]. Furthermore, Cunningham et al. used the time taken to drive a weighted tackle sled over 5 m to assess contact/collision performance amongst elite rugby union forwards and demonstrated a significant correlation between this assessment and the number of dominant collisions [13]. Therefore, further research may wish to assess 5 m sprint momentum to examine the hypothesis that 5 m sprint momentum may be more strongly correlated with ball-carrying capability amongst forwards.

Sprint momentum appears to be more adjustable than sprint speed, with maximum sprinting speed tending to peak for rugby union players in their mid-20s. In contrast, momentum continued to improve amongst academy and senior players in association with increased body mass [6, 14]. Despite the contribution of body mass to sprint momentum, the present study identified moderate-to-large inverse correlations between body mass and the number of tries scored, line breaks, defenders beaten, and dominant collisions amongst forwards. Smart et al. previously reported an inverse relationship between percentage body fat and activity rate amongst forwards, proposing higher levels of body fat may be related to a reduced work rate [28]. Excess body fat has previously been shown to have a detrimental effect on performance by increasing metabolic demands, reducing the body's ability to dissipate heat, and subsequently reducing an individual's ability to perform repeated high-intensity actions [27]. Moreover, higher levels of body fat have been associated with a reduced power-to-body mass ratio, subsequently reducing an individual's ability to position themselves in optimal attacking and defensive positions [35]. The present study identified an ~ 11.5% reduction in body mass was required to increase the number of tries scored, line breaks, defenders beaten, and dominant collisions by one amongst forwards. Argus et al. reported a ~ 9.5% reduction in fat mass and a ~ 2.2% improvement in fat free mass amongst senior professional rugby union players following a 4-week pre-season training period [2]. Thus, an ~ 11.5% reduction in body mass is likely achievable in sub-elite players. However, any proposed reduction in body mass must be measured against the potential implications for other physical qualities (e.g., sprint momentum), as well as other performance indicators within rugby union (e.g., tackles, scrummaging). For example, the greater body mass of the forwards has been proposed to act as a protective mechanism from impact injuries as these positions are involved in 68% of all collisions during an international test match [10]. Furthermore, James et al. identified the principal performance indicators for the forward positions were ball-carrying, tackling, and set-piece play (e.g., mauls, lineouts, and scrums) [20]. Unfortunately, body composition was not assessed in the present study, and the lack of correlation between sprint momentum and ball-carrying capability, as well as the inverse relationship between body mass and ball-carrying capability in the forwards may well be linked to excess fat mass. Barr et al. reported a strong correlation between lean body mass, maximum sprint velocity and sprint momentum [7]. Therefore, reductions in fat mass and increases in lean muscle mass (achieved via strength training) with the overall intention to maintain or increase body mass would enhance sprint capabilities via improvements in power-to-body mass ratio and subsequent sprint momentum [6, 7]. In addition, improvements in power-to-body mass ratio via increased lean muscle mass may have significant implications on additional key performance indicators amongst forwards, including tackling and set-piece play [27, 28]. Further research should include body composition assessment to better inform whether improvements in ball-carrying capability can be achieved by fat mass reduction (and/or increases in lean mass), and what implications this may have for tackling and set-piece play.

In addition to the positive implications of improving lean body mass on ball-carrying capability, the present study identified a ~ 19.3% increase in body mass or a ~ 15.6% improvement in 10 m sprint momentum was required to increase the number of tackle breaks and dominant collisions by one amongst backs. Barr et al. previously reported a training-induced ~ 5% increase in maximal sprint momentum in senior international rugby union players over a training period of two years [6]. It is plausible that larger increases might be expected in sub-elite players. Ungureanu et al. identified a ~ 3% increase in maximal sprint momentum in junior sub-elite rugby union players over the course of one competitive season following a concurrent training programme [32]. Therefore, applied practitioners working with these athletes should aim to utilize individualized periodization models to increase players' body mass via methods such as muscle hypertrophy training [7], whilst improving speed performance, to increase momentum and subsequent ball-carrying capability.

Research investigating the characteristics common amongst effective ball carriers in Super Rugby (a professional men's rugby union club competition that has involved teams from Australia, New Zealand, and South Africa) identified 95% of tackle breaks were achieved with a combination of low body position and strong leg drive [35]. The moderate-to-large relationships we observed between relative back squat 1RM and the number of tries scored and tackle breaks amongst both position groups are novel findings. Maximum lower-body relative strength has previously been shown to be a main determinant of acceleration and maximum sprinting speed [37], primarily due to the large associations between relative strength and rate of force development [7, 30, 37]. The present study highlighted an ~11.8% improvement in relative back squat 1RM was required to increase the number of tries scored and tackle breaks by one for forwards. In elite level rugby union players, improvements of ~9.5% in relative back squat 1RM have been reported over the course of a full competitive season [1], so our ~11.8% increase is feasible in sub-elite players. Weakley et al. identified a ~5.4% increase in back squat 3-RM in senior semi-professional rugby union players following a 4-week training cycle [33]. Therefore, strength and conditioning practitioners may wish to set training goals to enhance relative lower-body strength amongst the forwards in order to improve the ball-carrying capabilities of this position group. For the backs, the necessary improvements in relative back squat 1RM were deemed practically unachievable (> 20%) and further investigation is required to ascertain the direct effect of an improvement in physical performance on ball-carrying capability.

Although the present study highlights a number of novel findings that we believe will impact applied practice and future research in rugby union, certain limitations are acknowledged. The participants of the present study came from a single RFU Championship squad, therefore, the generalisation of findings to all sub-elite rugby union players may not be appropriate. Furthermore, the number of participants ($n = 38$) meant that individual position analysis could not be conducted with appropriate statistical power. Future research may wish to identify the differences in physical measures between individual positions (e.g., front row vs. second row vs. back row vs. inside backs vs. outside backs). There are also limitations in the methodology of the present study, including the absence of maximum velocity (i.e., 40 m sprint) or body composition assessments. These variables would strengthen the recommendations made for strength and conditioning practitioners to enhance ball-carrying capability via improvements in physical performance.

Conclusions

The present study is the first to identify the relationship between physical characteristics and game statistics related to ball-carrying capability in sub-elite rugby union players. For both position groups (forwards and backs), body mass, maximum lower-body relative strength, and 10 m sprint performance (velocity for forwards; momentum for backs) presented the most meaningful correlations with the game statistics related to ball-carrying capability. Therefore, strength and conditioning practitioners should seek to improve these positional group specific qualities to maximise the transfer of these physical characteristics to on-field performance. This study is also the first to demonstrate the alterations in physical characteristics required to achieve the improvements in ball-carrying capability in sub-elite rugby union players.

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Declarations

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