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1 sArticle

2 **Influence of playing standard on upper- and lower-** 3 **body strength, power and velocity characteristics of** 4 **elite rugby league players**

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12 **Abstract:** Background: To compare load-velocity and load-power relationships among 1st grade
13 (n=26, age 22.9±4.3 years), academy (n=23, age 17.1±1.0 years) and scholarship (n=16, age 15.4±0.5
14 years) Super League rugby league players. Methods: Participants completed assessments of
15 maximal upper- and lower-body strength (1RM) and peak velocity and power at 20, 40, 60 and 80kg
16 during bench press and squat exercise, in a randomised order. Results: Bench press and squat 1RM
17 were highest for 1st grade compared to other standards (ES=-0.43 to -3.18). Peak velocities during
18 bench and squat were greater in the higher playing standards (ES=-0.39 to -3.72 range), except for
19 squat at 20 and 40kg. Peak power was higher in the better playing standards for all loads and
20 exercises. For all three groups, velocity was correlated to optimal bench press power (r=0.514 to
21 0.766), but only 1RM was related to optimal power (r=0.635) in the scholarship players. Only squat
22 1RM in the academy was related to optimal squat power (r=0.505). Conclusions: Peak velocity and
23 power are key physical qualities to be developed that enable progression from junior elite rugby
24 league to 1st grade. Resistance training should emphasise both maximal strength and velocity
25 components, to optimise upper- and lower-body power in professional rugby league players.

26 **Keywords:** physical qualities, profiling, youth, adult, muscle function

27

28 **1. Introduction**

29 Rugby league is a contact sport that requires players to possess a range of physical qualities for
30 success [1]. Of these qualities, muscular strength and power might assist in the effective execution of
31 several skills that determine performance or player selection. For example, upper-body strength and
32 power have strong relationships (r = 0.72 and 0.70, respectively) with tackling ability [2], while upper-
33 and lower-body strength and power are able to differentiate between playing standards in rugby
34 league players [3,4]. Upper-body power was only different between state and national standard
35 rugby league players at higher external loads of 70 and 80 kg [5], suggesting that power exerted
36 against high external loads is a key discriminator of success in rugby league players. Baker and
37 Newton [6] also reported that upper- and lower-body strength and power characteristics were able
38 to better distinguish between rugby league playing standard than other measures of acceleration,
39 maximal speed and agility.

40 Baker and Nance [7] reported strong correlations between upper-body strength and power (r =
41 0.89) and lower-body strength and power (r = 0.81) in professional rugby league players. However,
42 the relationship between strength and power might well be influenced by playing standard, with
43 lower standard players presenting better associations (r = 0.85) than national standard (r = 0.58)

44 players [3]. This observation suggests that the training emphasis is likely to be different between
45 players of different standards, with important implications for those designing resistance training
46 programmes for the long-term development of rugby players. Regarding the contribution of barbell
47 velocity to power output, Fernandes and colleagues [8] reported that velocity was not related to
48 bench press power in young resistance trained males. During squat exercise, velocity was also
49 moderately correlated ($r = 0.653$) to power in these males [8]. Interestingly, in stronger individuals,
50 velocity appears to underpin adaptation to the lower-body power movements [9]. A study in well-
51 trained rugby league players that determines the contribution of both strength and velocity to power
52 during upper- and lower-body resistance exercises would enable a closer examination of the
53 interplay between these neuromuscular characteristics.

54 While recent studies have examined differences in physical qualities of senior, academy and
55 youth rugby league players [1], measures of maximal strength, load-power and load-velocity
56 between rugby players of different training ages has not been provided before. In rugby union
57 athletes, Hansen and colleagues [10] noted that elite athletes (~26 years) produced higher power
58 during 40 kg jump squat exercise than their junior counterparts (~19 years) from the same team.
59 However, the single load selected by Hansen et al. [10] means that it is unknown if the differences in
60 power exist at lower and higher loading conditions.

61 The primary aim of this study was to provide a detailed comparison of the load-velocity and
62 load-power relationship among rugby league players of different playing standards within the same
63 club. A secondary aim is to establish the contribution of strength and velocity to upper and lower
64 body power in rugby league players.

65 2. Materials and Methods

66 2.1. Participants

67 Twenty-six first grade (age 22.9 ± 4.3 years), 23 academy (age 17.1 ± 1.0 years) and 16 scholarship
68 (age 15.4 ± 0.5 years) rugby league players competing in the Super League were recruited for the
69 study. These groups comprised the entire playing squad of each team, with only injured players
70 exempt from taking part in the study. All participants regularly performed bench press and squats
71 as part of their resistance training programme. Participants completed informed consent and a pre-
72 test health questionnaire for the study, which was approved by the Ethics Committee of the host
73 institution. Parental consent was attained for those under 18 years.

74 2.2. Design

75 Participants completed measurements of body mass and body composition followed by
76 maximal bench press and squat exercise. Thereafter, participants completed 3 repetitions of bench
77 press and squat at 4 absolute loads (20, 40, 60 and 80 kg). Only four of the scholarship players could
78 perform the 80 kg bench press, meaning only their data from 20-60 kg was analysed. We opted to use
79 absolute loading conditions, rather than relative, as this better reflects match demands. That is,
80 players are required to express velocity and power against absolute loads, irrespective of their
81 individual strength. Such an approach has been adopted previously [3-7]. The testing battery was
82 performed at the end of an 8-week pre-season training phase focussing on maximal strength and
83 power development. The testing battery had been performed previously with the players meaning
84 they were habituated to the procedures.

85 2.3. Procedures

86 2.3.1. Physical measurements

87 Body mass was determined using calibrated digital scales (Seca 813; Seca, Hamburg, Germany)
88 and body composition estimated from the sum of skinfold thickness (mm) from bicep, triceps,
89 pectoral, subscapular, iliac crest, supraspinale, abdominal, front thigh and medial calf. Skinfold
90 thickness was taken twice (Harpenden, Holtain, Crymych, Dyfed, United Kingdom) at each site and

91 if the difference between measurements were < 5% the mean score was used for analysis. Where the
92 difference was ≥ 5% a third measurement was taken, and the median value was used for analysis.

93 2.3.2. Strength testing

94 Participants' maximum strength on bench press exercise was assessed directly using a
95 standardised 1RM protocol [10]. For safety reasons, 1RM during squat exercise was predicted from a
96 3RM as detailed by Baker and Newton [6]. This method estimates maximal strength on the basis that
97 a 3RM is 93% of the 1RM (i.e. (3RM load / 93)*100) [12]. Previous data indicates that this method
98 provides a reliable assessment of maximal strength (intraclass correlation coefficients and coefficient
99 of variation (CV) of 0.91 and 3.6%, respectively) [2]. Relative upper and lower body strength was
100 calculated by dividing 1RM by body mass.

101 2.3.3. Assessment of peak velocity and power

102 Peak velocity and power were determined during bench press and squat exercise at four
103 absolute loads; 20, 40, 60 and 80 kg. Loads were applied in a randomised order with measurements
104 of peak velocity and power being recorded using the FitroDyne rotary encoder (Fitronic, Bratislava,
105 Slovakia) attached via nylon cord directly under the end of a barbell. The FitroDyne provides reliable
106 measures of peak velocity (CV = 2.1 to 8.8%) and power (CV = 2.2 to 8.5%) at a range of external loads
107 [13].

108 For bench press exercise, participants held the barbell with a prone grip and lowered it to their
109 chest before pushing maximally. During squat exercise, participants descended with the barbell
110 across their shoulder until their hips were below the knee joint and then ascended as rapidly as
111 possible until their knees were at full extension. Three repetitions of each exercise were performed at
112 each load with rest intervals of 2 minutes between repetitions. The average of three repetitions was
113 selected for analysis.

114 2.4. Statistical analyses

115 Differences in dependent variables were examined using Bayesian analysis that employed the
116 effect size (ES) with associated 90% confidence intervals (CI) [14]. This method is a form of 'calibrated'
117 Bayes inference with a dispersed uniform prior. Moreover, this approach allowed for a more practical
118 and meaningful explanation of the data that is deemed more useful to the coach and athlete when
119 determining the magnitude of the differences. Thresholds for the magnitude of the observed
120 difference for each variable were determined as the within-participant standard deviation in that
121 variable × 0.2, 0.6 and 1.2 for a small, moderate and large effect, respectively [15]. Threshold
122 probabilities for a meaningful effect based on the 90% CI were: <0.5% most unlikely, 0.5–5% very
123 unlikely, 5–25% unlikely, 25–75% possibly, 75–95% likely, 95–99.5% very likely, >99.5% most likely.
124 Effects with CI across a likely small positive or negative difference were classified as unclear [14]. All
125 calculations were completed using predesigned spreadsheets (www.sportsci.org). Data are presented
126 as ES ± CI. **Readers should be aware of the recent debate regarding the use of this approach,
127 particularly concerning the error rates (see Sainani [16] and www.sportsci.org).** Partial correlation
128 coefficients were calculated to provide an estimation of the contribution of maximal velocity (at 20
129 kg) and 1RM to power at the load that optimised power (40 and 80 kg for bench press and squat,
130 respectively). For all partial correlations, the variables not being analysed were controlled for (e.g.
131 the relationship between velocity and power, controlling for 1RM). Alpha was set at 0.05. These data
132 were analysed in SPSS (Version 24, IBM SPSS Inc., Chicago, IL, USA).

133 3. Results

134 3.1. Physical characteristics

135 There were small to large differences in body mass between groups with mean values higher in
136 the first grade compared to other groups (Table 1). Sum of skinfolds was moderately lower in the

137 first grade compared to academy players, but no differences were observed for any other comparison.
 138 Moderate to larger differences in absolute (kg) and relative to body mass (kg·bm⁻¹) bench press and
 139 squat strength reflected better performance in higher playing standards.

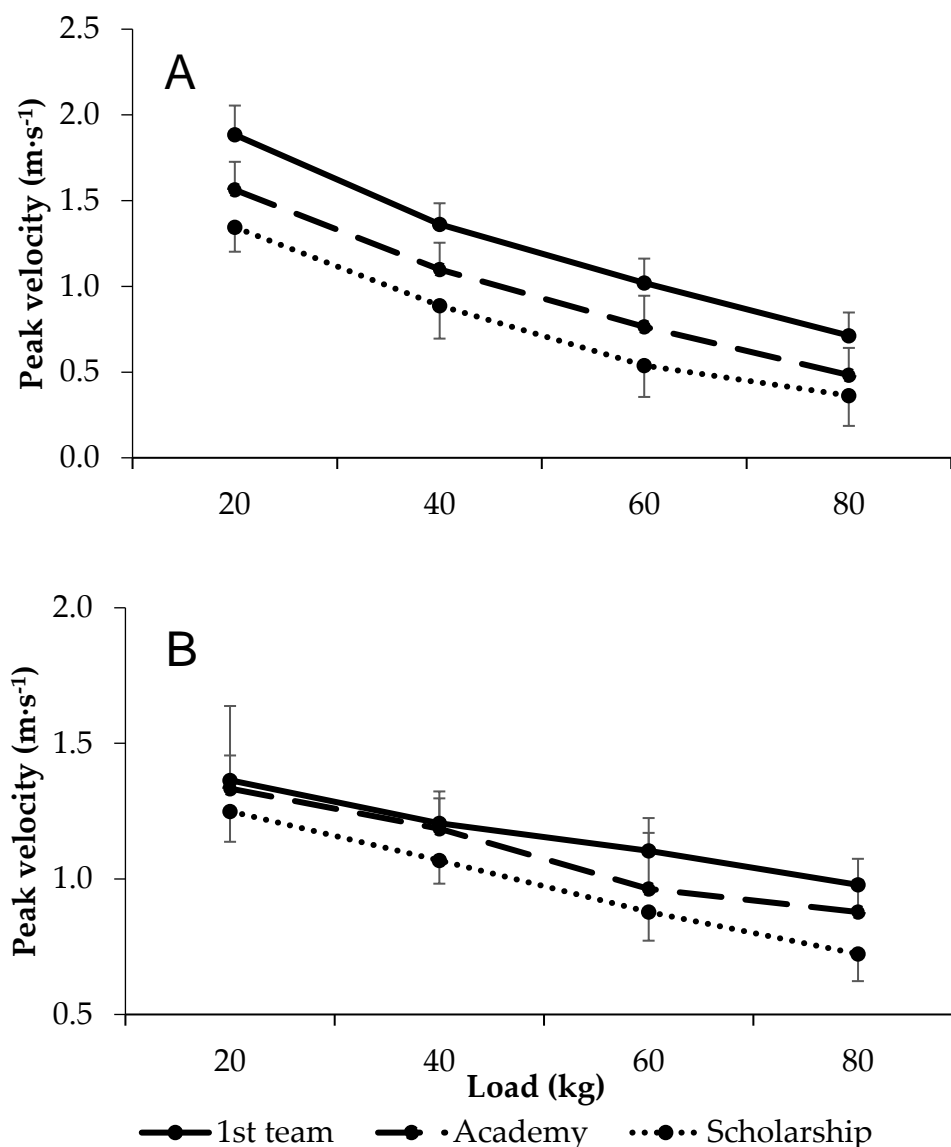
140 **Table 1.** Biometric characteristics (mean± SD) of the 1st team, academy and scholarship players.
 141 Qualitative descriptor, effect size ± 90% confidence intervals are noted in the effect size column.

				Effect size		
	1st grade (n=26)	U'19s (n=23)	U'16s (n=16)	1st v Academy	1st v Scholarship	Academy v Scholarship
Mass (kg)	94.6 ± 9.5	85.9 ± 10.4	79.7 ± 10.8	-0.89 ± 0.49 <i>Very likely</i>	-1.52 ± 0.57 <i>Most likely</i>	-0.58 ± 0.55 <i>Likely</i>
Sum of skinfolds (mm)	81.0 ± 14.7	90.7 ± 23.9	88.2 ± 29.3	0.65 ± 0.64 <i>Likely</i>	0.48 ± 0.90 <i>Unclear</i>	-0.10 ± 0.60 <i>Unclear</i>
Bench press 1RM (kg)	135.2 ± 16.2	111.5 ± 14.3	82.2 ± 12.6	-1.42 ± 0.44 <i>Most likely</i>	-3.18 ± 0.46 <i>Most likely</i>	-1.98 ± 0.50 <i>Most likely</i>
Relative bench press 1RM (kg·bm ⁻¹)	1.43 ± 0.14	1.30 ± 0.15	1.03 ± 0.12	-0.87 ± 0.50 <i>Very likely</i>	-2.76 ± 0.47 <i>Most likely</i>	-1.71 ± 0.46 <i>Most likely</i>
Squat 1RM (kg)	183.3 ± 20.6	174.3 ± 27.0	140.0 ± 22.2	-0.43 ± 0.53 <i>Possibly</i>	-2.04 ± 0.56 <i>Most likely</i>	-1.23 ± 0.48 <i>Most likely</i>
Relative squat 1RM (kg·bm ⁻¹)	1.94 ± 0.22	2.04 ± 0.26	1.78 ± 0.32	-0.78 ± 0.92 <i>Likely</i>	-0.71 ± 0.70 <i>Likely</i>	-0.94 ± 0.61 <i>Very likely</i>

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144 **3.2. Peak velocity**

145 There were large differences in peak velocity for bench press at all loads, with first grade
 146 outperforming both academy and scholarship, while academy were also greater than scholarship
 147 players. Conversely, differences in peak velocity during squat exercise between first grade and
 148 academy players was small at 20 and 40 kg, despite large differences at 60 and 80 kg. Similarly, there
 149 were small differences in squat peak velocity at 20 kg between first grade and scholarship players,
 150 but large differences at 40, 60 and 80 kg. Moreover, the comparison between first grade and
 151 scholarship players reflected widening group differences with an increasing load. Analysis of
 152 academy and scholarship players' data revealed small to moderate differences in squat peak velocity.
 153 All data are shown in Table 2.



154

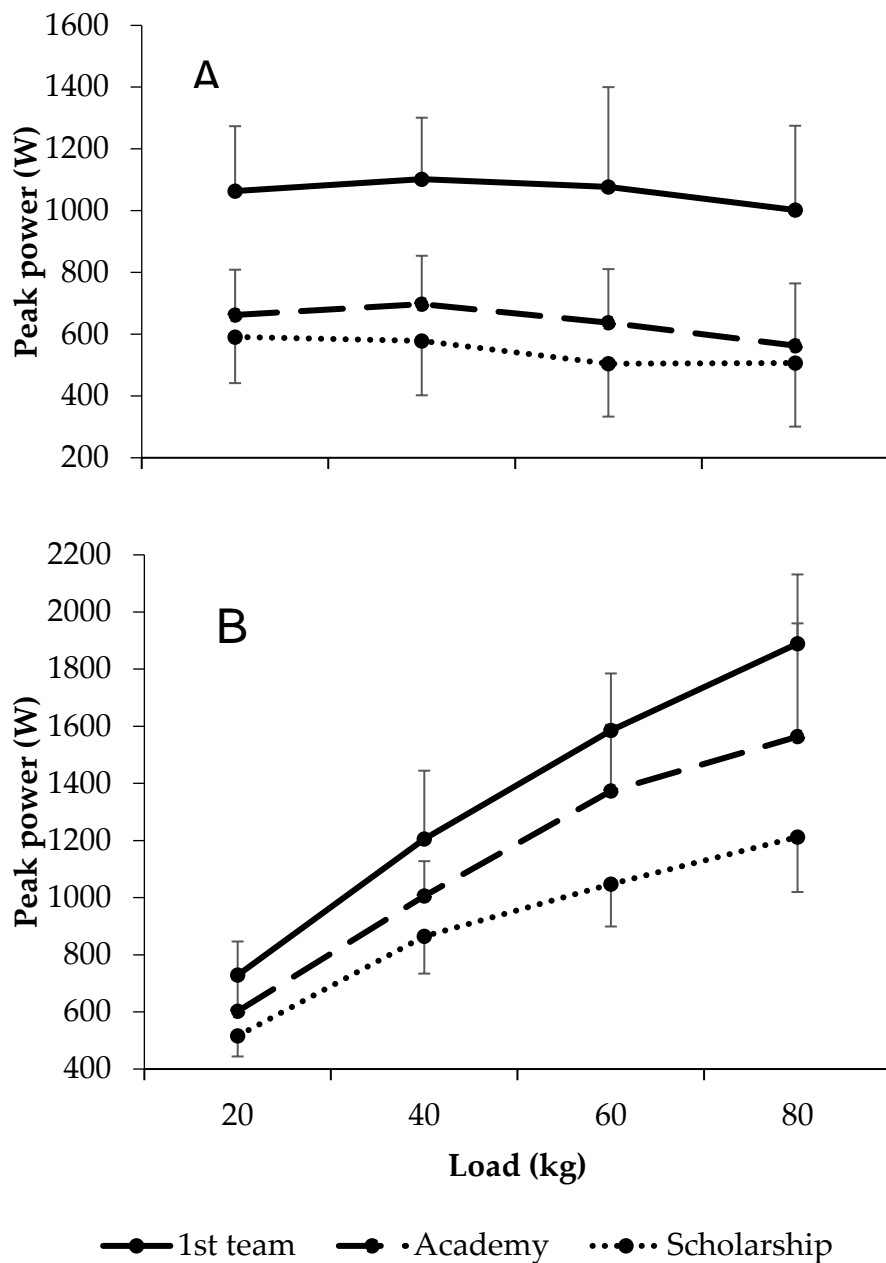
155

156 **Figure 1.** Load-velocity relationships in 1st team, academy and scholarship players during (A) bench
157 press and (B) squat exercise. .

158 *3.3. Peak power*

159 Large differences in bench press peak power were observed between first grade academy and
160 scholarship players at all external loads. The small to moderate differences in bench press peak
161 velocity between academy and scholarship players at 20 and 40 kg were accompanied by large
162 differences at 60 kg. For all comparisons, the magnitude of the differences between groups were not
163 related to the external load.

164 For squat peak power, differences between all comparisons and at all external loads were large,
165 except for 20 kg between academy and scholarship players where differences were moderate. The
166 magnitude of the differences between groups only appeared to differ across external loads in the first
167 grade versus scholarship comparison (i.e. greater differences with increasing external load).



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Figure 2. Load-power relationships in 1st team, academy and scholarship players during (A) bench press and (B) squat exercise.



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Table 2. Qualitative interpretation and ES ± confidence interval for the interpretation of dependent variables during bench press and squat exercise.

		20 kg		40 kg		60 kg		80 kg	
		Velocity	Power	Velocity	Power	Velocity	Power	Velocity	Power
1st grade v Academy	Bench press	-1.83 ± 0.46 <i>Most likely</i>	-1.85 ± 0.40 <i>Most likely</i>	-2.06 ± 0.54 <i>Most likely</i>	-1.97 ± 0.42 <i>Most likely</i>	-1.76 ± 0.54 <i>Most likely</i>	-1.32 ± 0.37 <i>Most likely</i>	-1.66 ± 0.55 <i>Most likely</i>	-1.56 ± 0.44 <i>Most likely</i>
	Squat	-0.11 ± 0.36 <i>Unclear</i>	-1.04 ± 0.45 <i>Most likely</i>	-0.17 ± 0.46 <i>Unclear</i>	-0.81 ± 0.37 <i>Most likely</i>	-1.14 ± 0.67 <i>Very likely</i>	-1.03 ± 0.51 <i>Most likely</i>	-1.01 ± 0.52 <i>Very likely</i>	-1.31 ± 0.65 <i>Most likely</i>
1st grade v scholarship	Bench press	-3.07 ± 0.47 <i>Most likely</i>	-2.17 ± 0.43 <i>Most likely</i>	-3.72 ± 0.72 <i>Most likely</i>	-2.55 ± 0.49 <i>Most likely</i>	-3.32 ± 0.65 <i>Most likely</i>	-1.72 ± 0.39 <i>Most likely</i>		
	Squat	-0.41 ± 0.36 <i>Unclear</i>	-1.75 ± 0.41 <i>Most likely</i>	-1.13 ± 0.44 <i>Most likely</i>	-1.39 ± 0.39 <i>Most likely</i>	-1.82 ± 0.48 <i>Most likely</i>	-2.61 ± 0.44 <i>Most likely</i>	-3.11 ± 0.54 <i>Most likely</i>	-2.71 ± 0.46 <i>Most likely</i>
Academy v Scholarship	Bench press	-1.29 ± 0.49 <i>Most likely</i>	-0.47 ± 0.54 <i>Likely</i>	-1.31 ± 0.61 <i>Most likely</i>	-0.73 ± 0.57 <i>Likely</i>	-1.21 ± 0.55 <i>Most likely</i>	-0.75 ± 0.54 <i>Very likely</i>		
	Squat	-0.66 ± 0.51 <i>Likely</i>	-0.75 ± 0.43 <i>Very likely</i>	-1.00 ± 0.46 <i>Most likely</i>	-1.11 ± 0.55 <i>Most likely</i>	-0.39 ± 0.40 <i>Likely</i>	-1.35 ± 0.43 <i>Most likely</i>	-1.28 ± 0.49 <i>Most likely</i>	-0.85 ± 0.39 <i>Most likely</i>

174

175 **3.4. Partial correlations**

176 When controlling for bench press velocity, 1RM was only correlated with optimal power in the
177 scholarship players ($r = 0.635$, $P < 0.05$, Table 3). Correlations for 20 kg velocity to optimal power were
178 moderate to strong in all groups ($r = 0.514$ to 0.788 , $P < 0.05$). For squat exercise, only 1RM was
179 correlated to optimal power ($r = 0.505$, $P < 0.05$) in the academy group.

180 **Table 3.** Partial correlations for velocity (controlling for 1RM) and 1RM (controlling for velocity) with
181 optimal power.

	Bench press		Squat	
	1RM	Velocity	1RM	Velocity
1st team	0.310	0.514*	0.365	0.117
Academy	0.310	0.546*	0.505*	0.256
Scholarship	0.635*	0.788*	0.332	0.484

182 *denotes significant correlation ($P < 0.05$).

183 **4. Discussion**

184 This is the first study to provide a detailed analysis of the load-velocity and load-power
185 relationships between rugby league players of different playing standards. These findings indicate
186 that peak velocity and power are key descriptors of playing standard in rugby league players and
187 thus provide a training progression for academy and scholarship players.

188 First grade players had a greater body mass than both academy and scholarship players, with
189 academy values being higher than scholarship. This is similar to previous reports of an increased
190 body mass with playing standard [10,17–19] and likely reflects differences in maturation [20,21]. The
191 lower body mass alongside higher sum of skinfolds in the academy players compared to their first
192 grade counterparts would indicate a higher amount of fat mass and lower fat-free mass. Furthermore,
193 sum of skinfolds was not different for any other comparison. In support, Till and colleagues [22]

194 observed comparable skinfold values across 15 to 20 year old rugby league players. That body mass
195 increased with playing standard but sum of skinfolds did not for the 1st cf. scholarship and academy
196 compared to scholarship suggests a greater fat-free mass in the higher playing standards. A greater
197 fat-free mass in the higher playing standards might be owing to the players resistance training
198 exposure. For example, the scholarship and academy players exposure to resistance training was
199 recent (< 2 years) whilst the 1st grade players had been regularly resistance training for longer (> 7
200 years). Importantly, a lower skinfold thickness score is associated with enhanced skill related
201 performance (e.g. sprinting, change of direction [23]) but also supports the importance of a higher
202 mass coupled with faster sprint speeds in senior player to optimise momentum into the collision [1].

203 As expected, the 1st grade had greater absolute and relative upper- and lower-body strength
204 than academy and scholarship players. Scholarship players were also weaker, in both absolute and
205 relative terms, than academy players for both exercises. Comparable differences in upper- [3,4,21,22]
206 and lower-body [6,10,21,22] strength, between playing standards, have been reported previously.
207 Like body mass, these strength differences might be explained by maturity and training age of the
208 participants. A greater fat-free mass in senior players, indicated by a higher body mass and lower
209 skinfold thickness, might also contribute to the higher force production in senior players [24,25].
210 Together, these data reaffirm that upper- and lower-body maximum strength are key descriptors of
211 playing standard between rugby league athletes.

212 Excluding squat at 20 kg for all groups and 40 kg between first grade and academy, peak velocity
213 typically demonstrated moderate to large differences between groups. To our knowledge, no study
214 has examined upper-body pushing velocity across different playing standards. As such, we report,
215 for the first time, that bench press velocity is able to distinguish between rugby league players of
216 different training ages. That lower-body velocity is able to differentiate between playing standard is
217 in support of a previous investigation in rugby union [10] but contrasts reports in Australian rules
218 players where there were no differences observed between higher and lower standards [26]. Notably,
219 our study expands on previous work in that velocity was determined a range of external loads rather
220 than unloaded [26] or single-loaded [10] conditions. Rugby league players are expected to produce
221 efforts against a range of loaded conditions e.g. sprinting, tackling. These differences in velocity
222 might be explained the greater strength with higher playing standards, and thus the absolute
223 loadings accounting for a lower percentage of 1RM in the higher playing standards. Moreover,
224 morphological (e.g. greater amount of type 2 fibres, pennation angle) and neurological (e.g. decreased
225 antagonist coactivation, motor unit synchronisation) differences [6,24,25,27] might provide a more
226 mechanistic explanation of the differences observed in the current study. Practically, strength and
227 conditioning coaches should aim to improve upper- and lower-body velocity at a range of external
228 loads as players progress from lower to higher playing standards.

229 Peak power, similar to strength, reflected playing standard for all exercises and loads. That is,
230 the first grade expressed higher peak powers than the academy and scholarship players, with
231 academy values being greater than scholarship. These data support previous observations in both
232 upper [3,4,21] and lower-body power [4,6,10,21,26]. Given that power is the product of force
233 (strength) and velocity, these differences between playing standards are likely owing to the
234 differences in strength and velocity between groups. Therefore, the higher power with playing
235 standard can be explained by greater lean mass, maturation, training age and, plausibly,
236 morphological and neurological differences [6,20-23,27]. Collectively, these data suggest that the
237 enhancement of power, alongside other physical qualities [1], is a pathway for progression in rugby
238 league players.

239 For bench press, strength was moderately correlated to optimal power in the scholarship
240 players, but not first grade or academy players. The notion that the relationship between strength
241 and power is decreased with playing standard has been observed previously [4,21]. These data
242 suggest that once players are relatively strong enough (i.e. a 1RM of > 1.3 kg·bm⁻¹, as for the 1st grade
243 and academy players) then other physical attributes must be focused upon. Indeed, the relationship
244 between velocity and optimal power was moderate to strong for the first grade, academy and
245 scholarship players ($r = 0.514, 0.546$ and 0.788 , respectively). Only one study [8] has generated

246 comparable data whereby velocity was strongly correlated to optimal power during bench press in
247 young resistance trained males. This suggests that high peak powers are achieved through greater
248 velocity in better playing standards. During squat exercise, only the academy players strength was
249 correlated to optimal power. This reaffirms previous data [7] but contrasts observations of no
250 relationship between lower-body strength with power [21]. The reason for the weak associations
251 between lower-body strength with optimal power in the current study is unclear. Other factors, such
252 as rate of force development [28], might be of more importance in these populations and future
253 studies should determine this empirically.

254 5. Conclusions

255 Irrespective of the external load, both load-velocity and load-power relationships during bench
256 press and squat exercise reflect playing standard in professional rugby league players. Regardless,
257 when increasing squat peak power, academy players should aim to increase their maximal lower-
258 body strength. Early training focus for upper- and lower-body training should emphasise the
259 development of maximal force generation. As players progress towards senior rugby, resistance
260 training should also include developing a player's ability to exert maximal barbell velocity and power
261 during a bench press and back squat against a range of external loads.

262 **Author Contributions:** Conceptualization, LM and CT; Methodology, LM, MD and CT; Formal Analysis, JFTF;
263 Data Curation, JFTF; Writing – Original Draft Preparation, JFTF, LM; Writing – Review & Editing, JFTF, MD,
264 LM and CT; Supervision, MD and CT

265 **Conflicts of Interest:** The authors declare no conflict of interest.

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