Differences in the Movement Skills and Physical Qualities of Elite Senior & Academy Rugby League Players

Running Head: Movement Skills and Physical Qualities of Rugby League Players.

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Abstract

The aim of the present study was to investigate (a) the differences in the movement skills and physical qualities between academy and senior rugby league players, and (b) the relationships between movement skills and physical qualities. Fifty-five male rugby league players (Senior, n=18; Under 19 n=23; Under 16, n=14) undertook a physical testing battery including anthropometric (stature & body mass), strength (isometric mid-thigh pull; IMTP) and power (countermovement jump; CMJ) qualities, alongside the athletic ability assessment (AAA; comprised of overhead squat, double lunge, single-leg Romanian deadlift, press-up and pull-up exercises). Univariate analysis of variance demonstrated significant ($p<0.001$) differences in body mass, IMTP peak force, CMJ mean power, and AAA movement skills between groups. The greatest observed differences for total movement skills, peak force and mean power were identified between Under 16 and 19 academy age groups. Spearman's rank correlation coefficients demonstrated a significant *moderate* (r=0.31) relationship between peak force and total movement skill. Furthermore, *trivial* (r=0.01) and *small* (r=0.13; r=0.22) relationships were observed between power qualities and total movement skill. These findings highlight that both movement skills and physical qualities differentiate between academy age groups, and provides comparative data for English senior and academy rugby league players.

Key words: *Movement, Strength, Power, Athletic Ability Assessment, Age Group*

INTRODUCTION

Rugby league is an intermittent, high-intensity, collision based team sport requiring players to have well developed physical qualities (28, 29). Research to date has demonstrated lean mass and body composition profiles (31), strength and power qualities (1, 2), and speed and endurance (29, 30) have all been shown to differentiate between elite and sub-elite standards in junior and senior rugby league players.

Although the physical qualities of academy rugby league players have been reported, research to date is not without its limitations. For example, the jump tests employed by Till and colleagues (e.g., 29, 30) to determine lower-body power have been shown to overestimate jump height and the resultant prediction of power (18). Furthermore, whilst various strength assessment methods exist (24), within younger athletes, a method not reliant on the proficiency of a specific movement (e.g., squat) may be preferential to determine any differences in strength between age groups. Recently, within adolescent rugby union an isometric mid-thigh pull (IMTP) has been used (10), thus the application of this assessment method to rugby league players may offer further insight into the specific differences between ages groups. Finally, while studies have investigated the differences between specific age groups (e.g., Under 16, [U16], U17, U18, U19, U20; 24), no study has investigated the differences between academy and first team players, which has implications for coaches and practitioners involved in talent identification and development in progressing academy players to senior levels.

Another key limitation and omission from the current evidence base is the lack of research investigating the movement skills of rugby league players. Whilst physical qualities that underpin match performance have been investigated thoroughly within rugby league (2, 29, 30), the fundamental movement skills that underpin sport-specific

26 movements (often utilised by practitioners within holistic programmes to develop

27 physical performance; 34) have been neglected. To date, only one study has

28 investigated the movement qualities of such players (20), although this was limited to

29 an U14 cohort, thus assessing movement skills within older players and comparisons

30 across age categories is unknown. The ability to perform specific and complex

31 movement patterns (e.g., squatting, lunging, jumping, landing, pushing, pulling and

32 bracing) has been shown to improve an athletic cohort's capacity to tolerate

33 progressive training loads (17) and reduce the risk of injury associated with varied

34 kinetic and kinematic demands of sports training and competition (23, 25). It is also

35 possible that the movement skills of an athlete may enhance athletic performance, due

36 to a greater ability to maintain control of the kinetic chain (16) and a reduction in

37 limiting motor skill factors, such as joint range of motion (previously shown to increase

38 countermovement jump [CMJ] height; 22). Outside of rugby league, movement skills

39 have been shown to differentiate between age categories in Australian football league

40 (AFL; U18 vs. senior; 34) and soccer (U11 vs. U13 vs. U16; 14) athletes.

41   An athletes' movement skills are predominantly assessed in both practice and

42 research via the Functional Movement Screen (FMS; 7). Despite its wide spread use, the

43 FMS was designed to assess movement competency throughout general non-athletic

44 populations (34), and may not adequately quantify the comprehensive movement

45 patterns performed in elite sport (23). More recently, the athletic ability assessment

46 (AAA) has been designed and utilised specifically for use within a sporting population

47 (17, 34). The AAA may be advantageous over the FMS due to a greater precision in the

48 assessment of movement patterns typically performed in training and competition

49 within elite team-sports (17, 34), thus may pose a useful tool when quantifying the

50 movement qualities of rugby league players, and the development by age. The

51 relationships between movement skills and physical qualities have also received little

52 investigation to date (12, 23). Of the few studies to investigate such relationships, weak

53 correlations with speed (20m sprint, r=-0.05) and power (vertical jump, r=-0.14) have

54 been reported (FMS composite score in a female team-sport cohort; 15). Further

55 research of movement skills and physical qualities is warranted due to potential

56 benefits of understanding how they interact, supporting strength and conditioning

57 interventions, talent development and injury prevention programmes (23, 34).

58   To this end, the first purpose of this study was to investigate differences in the

59 movement skills and physical qualities between academy and senior rugby league

60 players. The second purpose was to investigate the relationships between AAA-assessed

61 movement skills with physical qualities. It was hypothesized that movement skills and

62 physical qualities would differentiate between age group, with positive correlations

63 between movement with strength and power.

64

65   **METHODS**

66 ***Experimental Approach to the Problem***

67   Senior, U19 and U16 year old academy rugby league players were assessed by

68 movement skills (AAA; overhead squat, double lunge, single-leg Romanian deadlift,

69 press-ups, pull-ups and total score) and physical qualities (anthropometric [stature and

70 body mass], strength [IMTP] and lower body power [CMJ]). To evaluate the differences

71 in movement skill and physical qualities by age, players were compared by age category,

72 whilst relationships between movement and physical qualities were assessed using the

73 full data set.

74

75

76 ***Subjects***

77   Fifty-five male rugby league players from an English Super League rugby league

78 club participated in the study. The sample included 18 Senior (age; 25.5 ± 4.5 years), 23

79 U19 (age; 17.7 ± 0.9 years) and 14 U16 (age; 15.3 ± 0.5 years) rugby league players. The

80 cohort had a similar number of forwards and backs in each group (Senior, 8 and 8; U19,

81 11 and 12; U16, 7 and 7). Due to the small sample, positional differences were not

82 explored. Senior and U19 groups typically undertook five gym and field sessions per

83 week, and U16 undertook two gym and field sessions per week. All subjects were injury

84 free during data collection. All experimental procedures received ethics approval from

85 Leeds Beckett University Ethics Committee. Players over the age of 18 years of age

86 provided informed consent, while those under the age of 18 years of age provided

87 informed assent and parental consent was provided.

88

89 ***Procedures***

90   Testing was completed over two sessions during the same week at the beginning

91 of the pre-season period. The first testing session consisted of power (CMJ) and

92 movement skills (AAA), whilst the second session consisted of strength testing (IMTP).

93 The warm-up for each session was standardised for each age group and consisted of

94 stretching, jogging and bodyweight dynamic movements (squats, lunges, hops and

95 jumps; 29) prior to receiving instructions and a demonstration for each test from the

96 lead researcher. All subjects were given the opportunity to practice each movement for

97 familiarisation purposes prior to testing.

98   *Anthropometry:* Body mass and stature were measured to the nearest 0.1kg and

99 0.1cm respectively. Calibrated scales (SECA Alpha 220, Birmingham, UK) were used to

100 measure body mass, with subjects wearing only shorts. Stature was measured using a

4

101   stadiometer (SECA Alpha, Birmingham, UK), with each subjects' head positioned in the

102   Frankfort plane (21) for postural standardisation.

103   *Isometric Strength:* Subjects performed two maximal efforts of the IMTP, on a

104   calibrated force plate and mid-thigh pull rack with immovable barbell (Fitness

105   Technology, Adelaide, Australia), with the greatest peak force recorded as the measure

106   of isometric strength. Subjects wore lifting straps to offset the limitations of grip

107   strength upon the whole-body measure. The rack used had multiple bar increments,

108   each spaced by 3 cm vertically. This allowed for adjustments to be made for subjects to

109   be in a position similar to the 2nd pull of the power clean (inclusive of an upright trunk

110   and knee angle of ~120-130°; 10). Once positioned, following a 3 second countdown,

111   subjects were instructed to pull as hard and fast as possible for approximately 5

112   seconds (4, 30), which was followed by a 3 minute rest period between efforts (10).

113   Previous research using an academy rugby sample has reported an intraclass

114   correlation (ICC) and coefficient of variation (CV) of r=0.91 and 5.8% respectively for

115   peak force (10), whilst an ICC of r=0.98 has been previously reported in senior rugby

116   league players (32).

117   *Lower Body Power:* Two maximal effort CMJ's were performed using a calibrated

118   force plate (Fitness Technology, Adelaide, Australia). Subjects were informed to keep

119   their hands on their hips and to use a self-selected depth before jumping as high as

120   possible, with a minimum of three minutes rest given between efforts (26).

121   Performance outcomes from the CMJ were peak power (W), mean power (W) and

122   maximal jump height (m), which were all manually analysed at a sampling rate of

123   600Hz using force trace outputs on Ballistic Measurement System (version 2015.0.0)

124   software. Both peak and mean power were recorded in the concentric phase of the CMJ,

125   with peak power calculated as: Power (W) = vertical ground reaction force (N) x vertical

126   velocity of the subjects centre of gravity (m.s^{-1}) (30). The ICC and CV for the CMJ in an

127   academy rugby sample has been previously reported as r=0.95 and 5% respectively

128   (10), and the ICC as r=0.98 in a senior rugby league population (32).

129   *Movement Skills:* The AAA (34) was performed in order to identify the ability of

130   each subject to perform specific motor patterns previously related to sporting

131   performance within AFL. The AAA protocol consisted of an overhead squat, double-

132   lunge, single-leg Romanian deadlift, press-ups and pull-ups (see Table 1 for movement

133   descriptors). Subjects were familiar with the movements due to their inclusion in

134   regular training programmes, whilst demonstrations and specific cues were provided as

135   per the methods of Woods et al. (34). Each movement involved completing five

136   repetitions, except for press-up and pull-up exercises, which had repetition targets of 30

137   and 10 respectively in order to meet grading criteria. A wooden dowel was used to

138   assist with anatomical positioning.

139   Each movement was recorded in both frontal and sagittal planes from two metres

140   (using Sony FDR-AX33 cameras) and analysed retrospectively by the lead researcher

141   using movement-specific criteria as per previously reported by Woods et al. (34). The

142   grading of each movement within the AAA is scored using a three-point scale, with three

143   specific criterion per movement used to assess the competency of an athlete (34). The

144   score per movement (a maximum of 9) and total score (a maximum of 63) were then

145   used for analysis, which was completed by the same researcher for each subject. AAA

146   intra-rater reliability was assessed using the kappa statistic (*k*), consistent with

147   previous AAA research (17, 34). The intra-rater reliability for each component of the

148   AAA was; overhead squat = 0.81, *almost perfect*, left-sided double lunge = 0.79,

149   *substantial*, right-sided double lunge = 0.62, *substantial*, left-sided SL RDL = 0.68,

150 *substantial*, right-sided SL RDL = 0.52, *moderate*, press-up = 0.82, *almost perfect*, and

151 pull-up = 0.87, *almost perfect*.

152

153   *** INSERT TABLE 1 NEAR HERE ***

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155 **Data Analyses**

156   Data are presented as mean and standard deviation (SD). Data were first log-

157 transformed in order to decrease potential bias arising from non-uniformity error,

158 followed by univariate analysis of variance (ANOVA; using SPSS version 22.0, with an

159 alpha level of $p<0.05$) to investigate overall differences between age groups (i.e., Seniors,

160 U19 and U16), with Bonferroni correction *post-hoc* analyses used where significant

161 differences were observed. Cohen's *d* (8) effect size (ES) values with 90% confidence

162 interval values were determined as <0.2 *trivial*, 0.2 - <0.6 *small*, 0.6 - <1.2 *moderate*, 1.2

163 - <2.0 *large*, 2.0 - <4.0 *very large*, and >4.0 *extremely large*.

164   Receiver operating characteristic curves were built and an area under the curve

165 (AUC) produced to examine the discriminant capability of total movement skill and

166 physical qualities. This form of analysis was undertaken to calculate cut-off scores that

167 may discriminate between rugby league age groups, as per previous research in AFL by

168 Woods and Colleagues (34). AUC data refer to the model which best discriminates

169 between groups, whilst sensitivity and specificity are presented as percentages and can

170 be used to classify true-positives and true-negatives (i.e. the number of players above

171 and below the cut-off score within each group).

172   Spearman's rank correlation coefficients measured relationships between total

173 and individual AAA scores with physical qualities. Correlation coefficients were

7

174 interpreted as; <0.1 *trivial*, 0.1 - <0.3 *small*, 0.3 - <0.5 *moderate*, 0.5 - <0.7 *large*; 0.7 -

175 <0.9 *very large*, 0.9 - <1.0 *nearly perfect*, and 1.00 *perfect* (11).

176

177 **RESULTS**

178

179 ***Anthropometric Characteristics***

180   Table 2 displays the anthropometric characteristics by age group. Significant

181 differences were observed between groups for body mass ($p<0.001$) and stature

182 ($p=0.007$). For body mass, significant *moderate* differences were found for Senior *vs.*

183 U19 and U19 *vs.* U16, with a significant *large* ($p<0.001$) difference observed for Senior

184 *vs.* U16. For stature, the Senior group were *moderately* taller than both U19 ($p=0.040$)

185 and U16 ($p=0.013$) age groups. A *small*, non-significant ($p=1.000$) difference was

186 observed between the U19 and U16 groups for stature. AUC data presented in Table 5

187 show that the receiver operating curves were maximized with body mass values of 78.0

188 kg and 83.1 kg between U16's with U19 and Senior players respectively, and 86.7 kg

189 between U19 and Senior players. For stature, the values that provided the most

190 definitive discrimination between U16 with U19 and Senior players were 179.4 cm and

191 183.2 cm respectively, and 183.3 cm between U19 and Senior players (Table 5).

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193   *** INSERT TABLE 2 NEAR HERE ***

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198 ***Athletic Movement Skills***

199   Table 3 shows the differences in movement skills between Senior, U19 and U16

200 rugby league players. There were significant differences between groups for the AAA

201 total (p=0.005), right-sided lunge (p<0.001), right-sided RDL (p=0.043), press-ups

202 (p=0.009) and chins (p=0.023). For AAA total Senior subjects demonstrated a non-

203 significant (p=0.271) *small* difference in comparison with the U19s, and U19s showed

204 *moderate* significant (p=0.043) greater AAA total compared to U16s. The senior group

205 demonstrated a significant *moderately* (p=0.002) greater AAA total than the U16 group.

206 Significant *large* differences were observed for the right-sided lunge in favour of Senior

207 vs. U16 and U19 vs. and U16 subjects. All respective *p* values are shown in Table 3. The

208 Senior group also had a *moderately* greater skill in the right-sided RDL than the U19

209 group, with a non-significant *small* greater difference observed in comparison to U16

210 subjects. Senior subjects had a significantly *moderately* greater skill to perform press-

211 ups and pull-ups in comparison to the U16 group, whilst the U19's were also

212 significantly *moderately* greater at pull-ups than U16 subjects. Non-significant *trivial*

213 and *small* effect sizes were observed for the overhead squat, left-sided lunge and left-

214 sided RDL between age groups. Receiver operating curve data presented in Table 5

215 demonstrate that the AAA total scores that provided the greatest discrimination

216 between U16's with U19 and Senior players were 39.5/63 and 39.5/63 respectively,

217 and 44.0/63 between U19 and Senior groups.

218

219   *** INSERT TABLE 3 NEAR HERE ***

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221

Strength Qualities

222

223   Table 4 displays strength and power measures by age group. Significant ($p<0.001$)

224 differences were observed between groups for peak force. Differences in peak force for

225 Seniors vs. U19 ($p<0.001$) and U16 ($p<0.001$) subjects were *large* and *extremely large*,

226 whilst the difference between the U19 and U16 groups was *very large* ($p<0.001$). Table

227 5 shows cut-off scores for strength by age group. Receiver operating curves presented

228 in Table 5 demonstrate that the IMTP peak force values that provided the greatest

229 discrimination between U16's with U19 and Senior players were 2644.9 N and 2728.5 N

230 respectively, and 3402.6 N between U19 and Senior groups.

Lower Body Power Qualities

231

232   Table 4 shows differences for both peak and mean power between age groups.

233 Significant *moderate* differences were observed for peak power for Senior vs. U16

234 ($p=0.015$) and U19 *vs.* U16 ($p=0.047$) comparisons, with a non-significant *small*

235 difference for Senior *vs.* U19 ($p=0.509$) groups. Mean power displayed significant *large*

236 and *moderate* differences for Senior vs. U16 ($p<0.001$), and U19 vs. U16 ($p=0.008$)

237 groups. Senior players also demonstrated a significant ($p=0.007$) *moderately* greater

238 mean power in comparison to U19 subjects. There were no significant differences for

239 jump height between groups, and only *trivial* and *small* ES were identified (Table 4).

240   Receiver operating curves were maximized with peak power values of 3721.3 W

241 and 4645.8 W between U16's with U19 and Senior players respectively, and 4779.5 W

242 between U19 and Senior players (Table 5). For mean power, the values that provided

243 the most definitive discrimination between U16's with U19 and Senior players were

244 1025.1 W and 1171.7 W respectively, and 1247.1 W between U19 and Senior groups

245 (Table 5). As presented in Table 5, receiver operating characteristic curve data

246 demonstrated that the jump height values that provided the greatest discrimination

247 between U16's with U19 and Senior players were 0.34 m and 0.34 m respectively, and

248 0.38 m between U19 and Senior groups.

249

250   *** INSERT TABLE 4 NEAR HERE ***

251

252   *** INSERT TABLE 5 NEAR HERE ***

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254 ***Movement, Strength and Lower-Body Power Relationships.***

255   Table 6 displays the relationships between movement skills, strength and lower-

256 body power. The AAA total score was *moderately* (p=0.023) related to peak force,

257 although only *small* and *trivial* correlations were observed between AAA total and other

258 physical qualities. A significant *large* (p<0.001) correlation was observed between peak

259 force and the right-sided lunge, whilst a significant *moderate* (p=0.023) correlation was

260 identified for peak force with press-ups. Significant *moderate* (p=0.001) and negatively

261 *small* (p=0.048) correlations were identified between mean power with the right-sided

262 lunge and left-sided RDL. No significant relationships were identified for both peak

263 power and jump height when compared with the AAA measures, with only *small* and

264 *trivial* effects observed.

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266   *** INSERT TABLE 6 NEAR HERE ***

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268

269

DISCUSSION

271   This is the first study to (a) compare the movement skills and physical qualities of

272 elite senior and academy rugby league players, and (b) report the relationships between

273 AAA-assessed movements with physical qualities. Overall findings showed that

274 movement and physical qualities differentiated between Senior, U19 and U16 rugby

275 league players; supported by receiver operating characteristic curves, which

276 determined novel comparative cut-off scores for movement skill and physical qualities

277 between groups. Specifically, the greatest differences in movement, anthropometry,

278 strength and power occurred between the U16 and U19 groups.

279   When movement skills were correlated with physical qualities, findings suggested

280 that total movement was correlated with strength but not power qualities, whilst

281 specific movements demonstrated limited correlation with strength and power

282 performance. Such findings suggest that movement and physical qualities can

283 differentiate between age categories in rugby league, and strength may be related to

284 movement skills.

285

286 ***Movement differences between Age Groups***

287   Movement skills assessed via the AAA, demonstrated overall significant

288 differences across age groups, which supports the hypothesis that movement skills

289 would differentiate across age groups. Novel data are presented for total and specific

290 movement skills, which may be used as normative scores in academy and senior rugby

291 league players for assessing movement skills.

292   Between groups, *small* differences were observed between Senior and U19s, and

293 *moderate* differences between U19s and U16s players for total movement skill. This

294 suggests that as players commence a structured training programme (e.g., at U16),

295   improvements in movement skills occur, although not beyond U19. This may be due to

296   movement skills being adequate at U19, or alternatively a change in focus of the

297   strength and conditioning staff as player's transition into a more performance (i.e.,

298   Senior) focused, as opposed to development (i.e., U16 and U19) environment. The *small*

299   difference between Senior and U19s players in this study differ from those previously

300   investigated in AFL, whereby Woods and Colleagues (34) reported significantly lower

301   total AAA for U18 AFL players when compared with senior counterparts. It is proposed

302   that these contrasting findings may be a reflection of different gameplay demands

303   between rugby league and AFL, whereby AFL is characterised by greater running

304   demands and fewer collisions than rugby league (6).

305   Differences between the current findings and those of Woods et al. (34) may also

306   be due to the involvement of U19 rugby league players in a professional academy for

307   several years compared to U18 AFL players, who had not previously been involved in a

308   talent development programme. This may also explain the difference in the current

309   study between U16 and U19 players, whereby U16 players had limited training

310   experience. As such, findings suggest that the movement skills of players requires

311   training and may be trainable, although may not continue to develop into senior levels,

312   given the *small* difference between Senior and U19 players (35). Additionally, although

313   significant differences were observed for AAA total by age group, receiver operating

314   characteristic curves reported high percentages of false positives (i.e. 57% and 50% for

315   U16's) when assessed by individual scores. This finding demonstrates that the

316   movement skill of rugby league players is highly variable when assessed by age group,

317   potentially due to factors such as position, training experience and maturation status

318   (27). This finding supports the need for a holistic approach to maximise athletic

319   potential in rugby league, specifically by the individual prescription of training exercises

320   and modalities (17).

321   When movement skills were considered by individual tests, age group differences

322   demonstrated significant effects for right-sided lunge, right-sided RDL, press-ups and

323   pull-ups but not overhead squat, left-sided lunge or RDL. The overhead squat was the

324   lowest scoring movement for the Senior group within the present study (6.2 ± 1.3), and

325   was lower than previously reported in U18 (7.5 ± 1.5) and Senior (7.5 ± 1.3) AFL

326   players (34). Therefore, it is proposed that the lack of difference for the overhead squat

327   was based on the inability of senior players to adequately perform the movement

328   (which is heavily reliant upon mobility and stability of the shoulders; 6, 34). The

329   authors suggest that this is a result of the intermittent collision nature of rugby league,

330   whereby the shoulders have been reported to be the most frequently injured

331   anatomical site during match-play (5, 13). Specifically, collision-based shoulder trauma

332   has been suggested to negatively effect structural adaptations, therefore limiting

333   mobility (i.e. inducing hypomobility; 5, 23). Furthermore, a common theme between the

334   overhead squat, lunge and SL RDL is the assessment of hip control (see Table 1; 34).

335   These findings demonstrate that required total and individual movement skills vary

336   between sports, possibly based upon the demands of training and gameplay (35).

337   Given the cross sectional nature of this study, it is not possible to determine if the

338   individual AAA tests that differentiated by age group (right-sided lunge, right-sided RDL,

339   press-ups and pull-ups) was an adaptation to specific training programmes, or if players

340   possessing greater movement skills progress through a rugby league system. Given the

341   specificity of the exercises involved in the AAA, and their similarity to what a strength

342   and conditioning coach may prescribe, it would be more likely that improvements are

343 an adaptation to training programmes. As such, it would appear advantageous for

344 younger players (e.g., U16) to focus on the efficacy of specific movements, to ensure

345 competence. Practitioners should be aware that not all movement skill tests improve or

346 possibly require improvement (given the limited difference to Senior players), although

347 movement skills should feature as part of a practitioners testing battery, to ensure the

348 holistic physical development of youth athletes.

349

350 ***Differences in Physical Qualities between Age Groups***

351 For physical qualities, the findings support the hypothesis that anthropometry,

352 strength and power would differentiate by age group with greater qualities in the

353 Senior players. This study presents novel data for strength (peak force) and power

354 (peak and mean) as these physical qualities were assessed via a force plate in contrast

355 to popular isointerial (i.e. 1RM squat) and jump mat assessments (26) therefore

356 improving the methodologies for assessing physical qualities in rugby league players.

357 *Moderate* differences were observed across consecutive age groups for body mass,

358 which is consistent with previous research in rugby league academy cohorts (26).

359 However, the observed *moderate* greater stature between U19 and senior cohorts

360 contrasts maturation-based research in academy rugby league players (whereby little

361 growth is expected post-18 years; 27). This finding may be explained by current talent

362 identification programmes; a finding supported by research in AFL (6) and more

363 recently by Till, Jones and Geeson-Brown (30), who reported that taller, heavier and

364 leaner anthropometric profiles positively affect talent development and career

365 attainment within rugby league. Novel cut-off scores presented within the current study

366 support these findings, whereby increased body mass and stature values differentiated

367　between age groups (i.e. 78.0 kg [U19 vs. U16,], 83.1 kg [Senior vs. U16], and 86.7 kg

368　[Senior vs. U19]; Table 5).

369　　For strength, *large* differences were observed in IMTP peak force across the three

370　age categories. Additionally, peak force values of 2644.9 N (U19 vs. U16), 3402.6 N

371　(Senior vs. U19), and 2728.5 N (Senior vs. U16) are presented as novel cut-off scores

372　that provide the greatest definitive discrimination between rugby league age groups.

373　Although this assessment has not been previously used in academy rugby league

374　players, these strength differences across age categories are consistent with previous

375　research in rugby league (1, 2, 26) that have used isoinertial assessments. These

376　differences are likely explained by increased resistance training exposure between the

377　three age groups in addition to increased androgen levels during adolescence (14).

378　Physiologically, such exposures to resistance training (i.e. increased frequency, volume

379　& intensity) between U16 and U19 playing levels may increase inter-muscular

380　coordination, muscle fibre activation, and muscle fibre recruitment (19). Vingren and

381　Colleagues (36) reported that adolescent males do not benefit from exercise-related

382　acute increases in testosterone until post-puberty, offering further explanation for the

383　magnitude of physical differences between the U19 and U16 cohorts.

384　　For mean power, *moderate* differences were observed between consecutive age

385　groups (1025.1 W, U19 vs. U16; 1171.7 W, Senior vs. U19), with *moderate* (3721.3 W,

386　U16 vs. U19) and *small* (4778.5 W, U19 vs. Senior) differences observed for peak power.

387　In contrast to previous research, jump height did not significantly differentiate between

388　age groups and values were lower than previously reported within academy rugby

389　league players (26). Additionally, there was no differences observed by cut-off scores

390　for jump height between U19 vs. U16 (0.34 m) and Senior vs. U16 (0.34 m) comparisons.

391   These findings may be explained in part by the overestimation of power by jump mat

392   equations in contrast to the force plate used within the present study (18). These

393   findings support the use of force plate technology as a more appropriate measure of

394   power output in academy and senior rugby league players.

395   Although a decrease in the magnitude of physical differences was observed

396   between cohorts as chronological age increased (i.e. peak force; U19 vs. U16 [*very large*],

397   Senior vs. U19 [*large*]), significant increases in body mass and the longitudinal exposure

398   to specific strength and conditioning training practises have been proposed to attenuate

399   a possible 'strength ceiling' in senior athletes (2).

400

401   ***Relationships between Physical Qualities and Movement***

402   The findings of this study demonstrate that overall, significant *moderate*

403   relationships were observed for peak force with total movement skill and press-ups,

404   and a *large* relationship with the right-sided lunge movement pattern. Despite the

405   strength assessment within this study being isometric in nature, these findings

406   demonstrate the positive role that strength has on the complex dynamic interactions

407   that predispose movement. It has been suggested that strength contributes to stability

408   and co-ordination, and has previously shown to improve motor skill performance in

409   adolescents (i.e. running, jumping and throwing; 3). Specifically, this may occur due to

410   greater eccentric work demands within stabilization tasks, with strength directly

411   contributing to muscle stiffness, shown to aid joint stability (33).

412   Similarly to peak force, mean power was *moderately* correlated with the right-

413   sided lunge, and had a *small* correlation with the left-sided SL RDL. Although this

414   provides further suggestions that hip control and joint alignment skills may be of

415   significance to physical qualities in rugby league, no further relationships were

416 observed between power qualities with any movement skill. The lack of observed

417 relationships between total movement skill and power qualities contrast the present

418 relationship between peak force and movement skill, due to the inherent association

419 between strength and power (19). It is therefore suggested that current movement

420 screens (i.e. AAA, FMS) neglect the scientifically accepted principle that

421 power=force*velocity (12) by abstaining from the inclusion of velocity-based

422 assessment criteria. However, whilst it is acknowledged that the primary aim of

423 movement assessment is to establish movement proficiency (16, 17), holistic training

424 programmes should differentiate between athletes who demonstrate good and poor

425 skills. This is supported by the variance in AAA scores by discriminant analyses within

426 the present study, therefore it is suggested that those who demonstrate greater

427 movement skills may benefit from velocity-based criteria upon assessment (i.e.

428 increasing the difficulty of the movement after basic proficiency has been acquired).

429   A key finding of the present study is that the right-sided lunge appears to have the

430 largest correlation with athletic performance (i.e. strength and power) in an elite rugby

431 league cohort when assessed using the AAA (Table 5). Interestingly, the lunge is the

432 only movement to include a velocity-based criteria within the AAA (i.e. controlled vs.

433 jerking; Table 1), whilst previous research has also shown this to be a key movement

434 pattern in relation to strength and power qualities in athletic cohorts (9, 14, 15). This is

435 unsurprising, given the importance of peak force and mean power, and resultant

436 maximum concentric velocity skills within team-sports (19), which are all associated

437 with the lunge movement (9). Therefore, based on the present findings it is proposed

438 that the lunge movement pattern should be an addition to training programmes and

439 assessments to enhance both movement and physical qualities within the context of

440 talent development in rugby athletes.

441

Conclusion

443   In conclusion, novel normative data are presented for strength, lower body power

444   and movement for elite rugby league players by age group within senior and academy

445   levels. Strength, lower body power and movement skill differences are greatest between

446   academy age groups, emphasising the importance of effective strength and conditioning

447   programming during this period. Additionally, body mass, strength (i.e. IMTP peak

448   force) and mean power were able to distinguish between age groups with the highest

449   degrees of accuracy. Despite the inherent relationship between strength and power,

450   movement was only significantly related to strength. As a result, future research should

451   address the assessment of velocity-based criteria within movement screening.

452

453   **PRACTICAL APPLICATIONS**

454   The present findings provide normative data for anthropometric, strength and

455   lower-body power qualities, and also movement skills for elite Super League rugby

456   players. Findings highlight that significant differences exist between Senior and U16

457   players for multiple physical qualities and movement skills, although these appear to

458   improve by the greatest magnitude between academy (U16, U19) age groups. These

459   findings have important implications for the talent development of rugby league players,

460   whereby data may be used to set targets and impact training protocols for rugby league

461   players by age and skill level.

462   Novel comparative cut-off scores for movement skills and physical qualities are

463   presented in an elite rugby league sample using receiver operating curve analyses.

464   These provide comparable cut-off scores that definitively discriminate between

465   multiple levels of talent development programmes in elite rugby league (i.e. U16, U19

466 and Senior levels). Given the importance of physical qualities within rugby league, the

467 relationship between strength and movement demonstrates a rationale for the

468 inclusion of movement skills within academy talent development programmes.

469

470 **ACKNOWLEDGMENTS**

473

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582

Table 1. The modified-AAA, used for movement competency assessment (adapted from Woods et al., 2016a).

Movement	Assessment Points	1	2	3
Overhead Squat	Upper Quadrant Triple Flexion Hip Control	Perfect hands above head/feet Perfect SQT to parallel Neutral spine throughout	Hands above head/feet SQT to parallel (compensatory) Loss of control at end of range	Unable to achieve position Unable to achieve position Excessive deviation
Double Lunge	Hip, Knee, Ankle Hip Control Take-off Control	Alignment during movement Neutral hip position Control	Slight deviation Slight deviation Jerking	Poor alignment Excessive flex/ext Excessive deviation
SL RDL	TB control Upper Quadrant x30 reps	Perfect control/alignment Perfect form/symmetry Hits target count	Perfect control/alignment for some Inconsistent -	Poor body control for all reps Poor scap. positioning for every rep < x 30
Press-Up	Scap rhythm TB control ×10 reps	Perfect form/symmetry Perfect control/alignment Hits target count	Inconsistent – some perfect Perfect control/alignment for some -	Unable to achieve position Poor body control for all reps < x 10
Pull-Ups	Hip Control – Frontal Hip Control – Sagittal Hinge range	Maintain neutral spine No rotation Achieves parallel	Slight flex/ext through hips Slight rotation at end of range Can dissociate but not reach parallel	Excessive flex/ext on SL stance Excessive rotation Cannot dissociate hips from trunk

Note: Scap, scapula; flex, flexion; ext, extension; reps, repetitions.

Table 2. Anthropometric differences between Senior, Under-19 and Under-16 rugby league players.

	Senior	U19	U16	ANOVA	Senior vs. 19 Cohen's *d*	U19 vs. U16 Cohen's *d*	Senior vs. 16 Cohen's *d*
Body Mass (kg)	97.1 ± 12.6	87.0 ± 8.8	78.3 ± 12.4	<0.001	*p*=0.027 0.93; ±0.54 *Moderate*	*p*=0.046 0.83; ±0.58 *Moderate*	*p*<0.001 1.47; ±0.65 *Large*
Stature (cm)	184.9 ± 7.9	179.6 ± 5.5	177.8 ± 5.2	0.007	*p*=0.040 0.78; ±0.54 *Moderate*	*p*=0.714 0.33; ±0.56 *Small*	*p*=0.013 1.01; ±0.62 *Moderate*

Table 3. Differences in movement skills between Senior, Under 19 and Under 16 rugby league players.

	Senior	U19	U16	ANOVA	Senior vs. 19 Cohen's d	U19 vs. U16 Cohen's d	Senior vs. 16 Cohen's d
OH Squat	6.2 ± 1.3	6.1 ± 0.9	6.1 ± 1.5	0.915	*p*=0.839 0.09; ±0.59 *Trivial*	*p*=0.879 0.00; ±0.56 *Trivial*	*p*=0.745 0.07; ±0.59 *Trivial*
Lunge – R	7.5 ± 1.1	7.0 ± 0.8	5.7 ± 1.0	<0.001	*p*=0.164 0.51; ±0.52 *Small*	*p*<0.001 1.46; ±0.63 *Large*	*p*<0.001 1.67; ±0.68 *Large*
Lunge – L	6.6 ± 1.1	7.0 ± 0.9	6.4 ± 1.2	0.155	*p*=0.228 -0.40; 0.52 *Small*	*p*=0.084 0.58; ±0.59 *Small*	*p*=0.554 0.17; ±0.49 *Trivial*
SL RDL – R	6.7 ± 1.5	5.9 ± 1.0	5.9 ± 1.2	0.043	*p*=0.063 0.65; ±0.53 *Moderate*	*p*=0.958 0.00; ±0.56 *Trivial*	*p*=0.090 0.59; ±0.61 *Small*
SL RDL – L	6.2 ± 1.7	5.7 ± 1.3	6.3 ± 1.0	0.431	*p*=0.394 0.27; ±0.52 *Small*	*p*=0.217 0.00; ±0.57 *Trivial*	*p*=0.669 0.28; ±0.59 *Small*
Press-Ups	7.2 ± 1.5	6.4 ± 1.6	5.4 ± 1.4	0.009	*p*=0.181 0.49; ±0.54 *Small*	*p*=0.047 0.63; ±0.57 *Moderate*	*p*=0.003 1.19; ±0.64 *Moderate*
Pull-Ups	6.8 ± 1.9	6.3 ± 2.0	5.0 ± 1.6	0.023	*p*=0.542 0.25; 0.52 *Small*	*p*=0.046 0.69; 0.57 *Moderate*	*p*=0.016 0.99; 0.62 *Moderate*
AAA Total	47.2 ± 6.1	44.4 ± 4.8	40.8 ± 6.2	0.005	*p*=0.169 0.51; 0.53 *Small*	*p*=0.043 0.66; ±0.58 *Moderate*	*p*=0.002 1.01; 0.63 *Moderate*

Note: OH Squat, overhead squat, Lunge – R, right-sided lunge, Lunge – L, left-sided lunge, SL RDL – R, right-sided single-leg Romanian deadlift, SL RDL – L, left-sided single-leg Romanian deadlift, AAA Total, total movement skills.

Table 4. Strength & Power qualities between Senior, under-19 and under-16 rugby league players.

	Senior	U19	U16	ANOVA	Senior vs. 19 Cohen's *d* (± 90%CL)	U19 vs. U16 Cohen's d	Senior vs. 16 Cohen's d
IMTP Peak Force (N)	3851 ± 503	3272 ± 329	2157 ± 218	<0.001	*p*<0.001 1.37; ±0.57 *Large*	*p*<0.001 3.73; ±0.91 *Very Large*	*p*<0.001 4.08; ±1.02 *Extremely Large*
CMJ Peak Power (W)	4709 ± 1396	4330 ± 501	3760 ± 599	0.034	*p*=0.509 0.37; ±0.62 *Small*	*p*=0.047 1.03; ±0.59 *Moderate*	*p*=0.015 0.82; ±0.61 *Moderate*
CMJ Mean Power (W)	1356 ± 235	1177 ± 139	1026 ± 139	<0.001	*p*=0.007 0.94; ±0.55 *Moderate*	*p*=0.008 1.06; 0.59 *Moderate*	*p*<0.001 1.62; ±0.68 *Large*
CMJ Jump Height (m)	0.34 ± 0.11	0.33 ± 0.05	0.32 ± 0.06	0.616	*p*=0.630 0.12, ±0.52 *Trivial*	*p*=0.492 0.18; ±0.56 *Trivial*	*p*=0.819 0.21; ±0.59 *Small*

Note: IMTP, isometric mid-thigh pull; CMJ, countermovement Jump.

Table 5. Receiver operating curves between Senior, Under-19 and Under-16 rugby league players.

		Cut-Off Score	AUC	Sensitivity	Specificity
Body Mass (kg)	Senior vs. U19	86.7	75%	89%	52%
	Senior vs. U16	83.1	84%	100%	50%
	U19 vs. U16	78.0	71%	83%	57%
Stature (cm)	Senior vs. U19	183.3	75%	72%	74%
	Senior vs. U16	183.2	79%	72%	93%
	U19 vs. U16	179.4	61%	57%	44%
AAA Total	Senior vs. U19	44.0	63%	68%	66%
	Senior vs. U16	39.5	76%	100%	50%
	U19 vs. U16	37.5	68%	100%	67%
IMTP Peak Force (N)	Senior vs. U19	3402.6	83%	83%	65%
	Senior vs. U16	2728.5	100%	100%	100%
	U19 vs. U16	2644.9	100%	100%	100%
CMJ Peak Power (W)	Senior vs. U19	4778.5	62%	61%	83%
	Senior vs. U16	4645.8	71%	61%	93%
	U19 vs. U16	3721.3	75%	91%	50%
CMJ Mean Power (W)	Senior vs. U19	1247.1	75%	83%	61%
	Senior vs. U16	1171.7	88%	78%	93%
	U19 vs. U16	1025.1	80%	91%	64%
CMJ Jump Height (m)	Senior vs. U19	0.38	59%	50%	78%
	Senior vs. U16	0.34	62%	67%	71%
	U19 vs. U16	0.34	58%	52%	71%

Table 6. Relationships between movement and strength and power in rugby league players

	OH Squat	Lunge - R	Lunge - L	SL RDL - R	SL RDL - L	Press-Ups	Pull Ups	AAA total
Peak Force (N)	*r*=-0.00; *Trivial*; *p*=0.991	*r*=0.55; Moderate; *p*<0.001	*r*=0.15; *Small*; *p*=0.272	*r*=0.01; *Trivial*; *p*=0.951	*r*=-0.19; *Small*; *p*=0.169	*r*=0.31; *Moderate*; *p*=0.023	*r*=0.22; *Small*; *p*=0.113	*r*=0.31; *Moderate*; *p*=0.023
Peak Power (W)	*r*=-0.24; *Small*; *p*=0.080	*r*=0.25; *Small*; *p*=0.067	*r*=-0.01; *Trivial*; *p*=0.931	*r*=-0.00; *Trivial*; *p*=0.981	*r*=-0.16; *Small*; *p*=0.258			*r*=0.13; *Small*; *p*=0.356
Mean Power (W)	*r*=-0.18; *Small*; *p*=0.186	*r*=0.42; *Moderate*; *p*=0.001	*r*=-0.00; *Trivial*; *p*=0.987	*r*=-0.09; *Trivial*; *p*=0.536	*r*=-0.27; *Small*; *p*=0.048			*r*=0.01; *Trivial*; *p*=0.932
Jump Height (m)	*r*=0.06; *Trivial*; *p*=0.678	*r*=0.11; *Small*; *p*=0.424	*r*=0.13; *Small*; *p*=0.356	*r*=0.16; *Small*; *p*=0.254	*r*=-0.03; *Trivial*; *p*=0.824			*r*=0.22; *Small*; *p*=0.105

Note: OH Squat, overhead squat, Lunge – R, right-sided lunge, Lunge – L, left-sided lunge, SL RDL – R, right-sided single-leg Romanian deadlift, SL RDL – L, left-sided single-leg Romanian deadlift, AAA Total, total movement skill.