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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*

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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

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movements (often utilised by practitioners within holistic programmes to develop physical performance; 34) have been neglected. To date, only one study has investigated the movement qualities of such players (20), although this was limited to an U14 cohort, thus assessing movement skills within older players and comparisons across age categories is unknown. The ability to perform specific and complex movement patterns (e.g., squatting, lunging, jumping, landing, pushing, pulling and bracing) has been shown to improve an athletic cohort's capacity to tolerate progressive training loads (17) and reduce the risk of injury associated with varied kinetic and kinematic demands of sports training and competition (23, 25). It is also possible that the movement skills of an athlete may enhance athletic performance, due to a greater ability to maintain control of the kinetic chain (16) and a reduction in limiting motor skill factors, such as joint range of motion (previously shown to increase countermovement jump [CMJ] height; 22). Outside of rugby league, movement skills have been shown to differentiate between age categories in Australian football league (AFL; U18 vs. senior; 34) and soccer (U11 vs. U13 vs. U16; 14) athletes.

An athletes' movement skills are predominantly assessed in both practice and research via the Functional Movement Screen (FMS; 7). Despite its wide spread use, the FMS was designed to assess movement competency throughout general non-athletic populations (34), and may not adequately quantify the comprehensive movement patterns performed in elite sport (23). More recently, the athletic ability assessment (AAA) has been designed and utilised specifically for use within a sporting population (17, 34). The AAA may be advantageous over the FMS due to a greater precision in the assessment of movement patterns typically performed in training and competition within elite team-sports (17, 34), thus may pose a useful tool when quantifying the movement qualities of rugby league players, and the development by age. The

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relationships between movement skills and physical qualities have also received little investigation to date (12, 23). Of the few studies to investigate such relationships, weak correlations with speed (20m sprint, *r*=-0.05) and power (vertical jump, *r*=-0.14) have been reported (FMS composite score in a female team-sport cohort; 15). Further research of movement skills and physical qualities is warranted due to potential benefits of understanding how they interact, supporting strength and conditioning interventions, talent development and injury prevention programmes (23, 34).

To this end, the first purpose of this study was to investigate differences in the movement skills and physical qualities between academy and senior rugby league players. The second purpose was to investigate the relationships between AAA-assessed movement skills with physical qualities. It was hypothesized that movement skills and physical qualities would differentiate between age group, with positive correlations between movement with strength and power.

METHODS

Experimental Approach to the Problem

Senior, U19 and U16 year old academy rugby league players were assessed by movement skills (AAA; overhead squat, double lunge, single-leg Romanian deadlift, press-ups, pull-ups and total score) and physical qualities (anthropometric [stature and body mass], strength [IMTP] and lower body power [CMJ]). To evaluate the differences in movement skill and physical qualities by age, players were compared by age category, whilst relationships between movement and physical qualities were assessed using the full data set.

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Subjects

Fifty-five male rugby league players from an English Super League rugby league club participated in the study. The sample included 18 Senior (age; 25.5 ± 4.5 years), 23 U19 (age; 17.7 ± 0.9 years) and 14 U16 (age; 15.3 ± 0.5 years) rugby league players. The cohort had a similar number of forwards and backs in each group (Senior, 8 and 8; U19, 11 and 12; U16, 7 and 7). Due to the small sample, positional differences were not explored. Senior and U19 groups typically undertook five gym and field sessions per week, and U16 undertook two gym and field sessions per week. All subjects were injury free during data collection. All experimental procedures received ethics approval from Leeds Beckett University Ethics Committee. Players over the age of 18 years of age provided informed consent, while those under the age of 18 years of age provided informed assent and parental consent was provided.

Procedures

Testing was completed over two sessions during the same week at the beginning of the pre-season period. The first testing session consisted of power (CMJ) and movement skills (AAA), whilst the second session consisted of strength testing (IMTP). The warm-up for each session was standardised for each age group and consisted of stretching, jogging and bodyweight dynamic movements (squats, lunges, hops and jumps; 29) prior to receiving instructions and a demonstration for each test from the lead researcher. All subjects were given the opportunity to practice each movement for familiarisation purposes prior to testing.

Anthropometry: Body mass and stature were measured to the nearest 0.1kg and 0.1cm respectively. Calibrated scales (SECA Alpha 220, Birmingham, UK) were used to measure body mass, with subjects wearing only shorts. Stature was measured using a

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stadiometer (SECA Alpha, Birmingham, UK), with each subjects' head positioned in the Frankfort plane (21) for postural standardisation.

Isometric Strength: Subjects performed two maximal efforts of the IMTP, on a calibrated force plate and mid-thigh pull rack with immovable barbell (Fitness Technology, Adelaide, Australia), with the greatest peak force recorded as the measure of isometric strength. Subjects wore lifting straps to offset the limitations of grip strength upon the whole-body measure. The rack used had multiple bar increments, each spaced by 3 cm vertically. This allowed for adjustments to be made for subjects to be in a position similar to the 2nd pull of the power clean (inclusive of an upright trunk and knee angle of ~120-130°; 10). Once positioned, following a 3 second countdown, subjects were instructed to pull as hard and fast as possible for approximately 5 seconds (4, 30), which was followed by a 3 minute rest period between efforts (10). Previous research using an academy rugby sample has reported an intraclass correlation (ICC) and coefficient of variation (CV) of r=0.91 and 5.8% respectively for peak force (10), whilst an ICC of r=0.98 has been previously reported in senior rugby league players (32).

Lower Body Power: Two maximal effort CMJ's were performed using a calibrated force plate (Fitness Technology, Adelaide, Australia). Subjects were informed to keep their hands on their hips and to use a self-selected depth before jumping as high as possible, with a minimum of three minutes rest given between efforts (26). Performance outcomes from the CMJ were peak power (W), mean power (W) and maximal jump height (m), which were all manually analysed at a sampling rate of 600Hz using force trace outputs on Ballistic Measurement System (version 2015.0.0) software. Both peak and mean power were recorded in the concentric phase of the CMJ, with peak power calculated as: Power (W) = vertical ground reaction force (N) x vertical

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velocity of the subjects centre of gravity ($m.s^{-1}$) (30). The ICC and CV for the CMJ in an academy rugby sample has been previously reported as r=0.95 and 5% respectively (10), and the ICC as r=0.98 in a senior rugby league population (32).

Movement Skills: The AAA (34) was performed in order to identify the ability of each subject to perform specific motor patterns previously related to sporting performance within AFL. The AAA protocol consisted of an overhead squat, double-lunge, single-leg Romanian deadlift, press-ups and pull-ups (see Table 1 for movement descriptors). Subjects were familiar with the movements due to their inclusion in regular training programmes, whilst demonstrations and specific cues were provided as per the methods of Woods et al. (34). Each movement involved completing five repetitions, except for press-up and pull-up exercises, which had repetition targets of 30 and 10 respectively in order to meet grading criteria. A wooden dowel was used to assist with anatomical positioning.

Each movement was recorded in both frontal and sagittal planes from two metres (using Sony FDR-AX33 cameras) and analysed retrospectively by the lead researcher using movement-specific criteria as per previously reported by Woods et al. (34). The grading of each movement within the AAA is scored using a three-point scale, with three specific criterion per movement used to assess the competency of an athlete (34). The score per movement (a maximum of 9) and total score (a maximum of 63) were then used for analysis, which was completed by the same researcher for each subject. AAA intra-rater reliability was assessed using the kappa statistic (k), consistent with previous AAA research (17, 34). The intra-rater reliability for each component of the AAA was; overhead squat = 0.81, *almost perfect*, left-sided double lunge = 0.79, *substantial*, right-sided double lunge = 0.62, *substantial*, left-sided SL RDL = 0.68,

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substantial, right-sided SL RDL = 0.52, *moderate*, press-up = 0.82, *almost perfect*, and pull-up = 0.87, *almost perfect*.

*** INSERT TABLE 1 NEAR HERE ***

Data Analyses

Data are presented as mean and standard deviation (SD). Data were first log-transformed in order to decrease potential bias arising from non-uniformity error, followed by univariate analysis of variance (ANOVA; using SPSS version 22.0, with an alpha level of $p<0.05$) to investigate overall differences between age groups (i.e., Seniors, U19 and U16), with Bonferroni correction *post-hoc* analyses used where significant differences were observed. Cohen's *d* (8) effect size (ES) values with 90% confidence interval values were determined as <0.2 *trivial*, 0.2 - <0.6 *small*, 0.6 - <1.2 *moderate*, 1.2 - <2.0 *large*, 2.0 - <4.0 *very large*, and >4.0 *extremely large*.

Receiver operating characteristic curves were built and an area under the curve (AUC) produced to examine the discriminant capability of total movement skill and physical qualities. This form of analysis was undertaken to calculate cut-off scores that may discriminate between rugby league age groups, as per previous research in AFL by Woods and Colleagues (34). AUC data refer to the model which best discriminates between groups, whilst sensitivity and specificity are presented as percentages and can be used to classify true-positives and true-negatives (i.e. the number of players above and below the cut-off score within each group).

Spearman's rank correlation coefficients measured relationships between total and individual AAA scores with physical qualities. Correlation coefficients were

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interpreted as; <0.1 *trivial*, 0.1 - <0.3 *small*, 0.3 - <0.5 *moderate*, 0.5 - <0.7 *large*; 0.7 - <0.9 *very large*, 0.9 - <1.0 *nearly perfect*, and 1.00 *perfect* (11).

RESULTS

Anthropometric Characteristics

Table 2 displays the anthropometric characteristics by age group. Significant differences were observed between groups for body mass (p<0.001) and stature (p=0.007). For body mass, significant *moderate* differences were found for Senior *vs.* U19 and U19 *vs.* U16, with a significant *large* (p<0.001) difference observed for Senior *vs.* U16. For stature, the Senior group were *moderately* taller than both U19 (p=0.040) and U16 (p=0.013) age groups. A *small*, non-significant (p=1.000) difference was observed between the U19 and U16 groups for stature. AUC data presented in Table 5 show that the receiver operating curves were maximized with body mass values of 78.0 kg and 83.1 kg between U16's with U19 and Senior players respectively, and 86.7 kg between U19 and Senior players. For stature, the values that provided the most definitive discrimination between U16 with U19 and Senior players were 179.4 cm and 183.2 cm respectively, and 183.3 cm between U19 and Senior players (Table 5).

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Athletic Movement Skills

Table 3 shows the differences in movement skills between Senior, U19 and U16 rugby league players. There were significant differences between groups for the AAA total (p=0.005), right-sided lunge (p<0.001), right-sided RDL (p=0.043), press-ups (p=0.009) and chins (p=0.023). For AAA total Senior subjects demonstrated a non-significant (p=0.271) *small* difference in comparison with the U19s, and U19s showed *moderate* significant (p=0.043) greater AAA total compared to U16s. The senior group demonstrated a significant *moderately* (p=0.002) greater AAA total than the U16 group. Significant *large* differences were observed for the right-sided lunge in favour of Senior vs. U16 and U19 vs. and U16 subjects. All respective *p* values are shown in Table 3. The Senior group also had a *moderately* greater skill in the right-sided RDL than the U19 group, with a non-significant *small* greater difference observed in comparison to U16 subjects. Senior subjects had a significantly *moderately* greater skill to perform press-ups and pull-ups in comparison to the U16 group, whilst the U19's were also significantly *moderately* greater at pull-ups than U16 subjects. Non-significant *trivial* and *small* effect sizes were observed for the overhead squat, left-sided lunge and left-sided RDL between age groups. Receiver operating curve data presented in Table 5 demonstrate that the AAA total scores that provided the greatest discrimination between U16's with U19 and Senior players were 39.5/63 and 39.5/63 respectively, and 44.0/63 between U19 and Senior groups.

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Strength Qualities

Table 4 displays strength and power measures by age group. Significant (p<0.001) differences were observed between groups for peak force. Differences in peak force for Seniors vs. U19 (p<0.001) and U16 (p<0.001) subjects were *large* and *extremely large*, whilst the difference between the U19 and U16 groups was *very large* (p<0.001). Table 5 shows cut-off scores for strength by age group. Receiver operating curves presented in Table 5 demonstrate that the IMTP peak force values that provided the greatest discrimination between U16's with U19 and Senior players were 2644.9 N and 2728.5 N respectively, and 3402.6 N between U19 and Senior groups.

Lower Body Power Qualities

Table 4 shows differences for both peak and mean power between age groups. Significant *moderate* differences were observed for peak power for Senior vs. U16 (p=0.015) and U19 *vs.* U16 (p=0.047) comparisons, with a non-significant *small* difference for Senior *vs.* U19 (p=0.509) groups. Mean power displayed significant *large* and *moderate* differences for Senior vs. U16 (p<0.001), and U19 vs. U16 (p=0.008) groups. Senior players also demonstrated a significant (p=0.007) *moderately* greater mean power in comparison to U19 subjects. There were no significant differences for jump height between groups, and only *trivial* and *small* ES were identified (Table 4).

Receiver operating curves were maximized with peak power values of 3721.3 W and 4645.8 W between U16's with U19 and Senior players respectively, and 4779.5 W between U19 and Senior players (Table 5). For mean power, the values that provided the most definitive discrimination between U16's with U19 and Senior players were 1025.1 W and 1171.7 W respectively, and 1247.1 W between U19 and Senior groups (Table 5). As presented in Table 5, receiver operating characteristic curve data

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demonstrated that the jump height values that provided the greatest discrimination between U16's with U19 and Senior players were 0.34 m and 0.34 m respectively, and 0.38 m between U19 and Senior groups.

*** INSERT TABLE 4 NEAR HERE ***

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Movement, Strength and Lower-Body Power Relationships.

Table 6 displays the relationships between movement skills, strength and lower-body power. The AAA total score was *moderately* (p=0.023) related to peak force, although only *small* and *trivial* correlations were observed between AAA total and other physical qualities. A significant *large* (p<0.001) correlation was observed between peak force and the right-sided lunge, whilst a significant *moderate* (p=0.023) correlation was identified for peak force with press-ups. Significant *moderate* (p=0.001) and negatively *small* (p=0.048) correlations were identified between mean power with the right-sided lunge and left-sided RDL. No significant relationships were identified for both peak power and jump height when compared with the AAA measures, with only *small* and *trivial* effects observed.

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DISCUSSION

This is the first study to (a) compare the movement skills and physical qualities of elite senior and academy rugby league players, and (b) report the relationships between AAA-assessed movements with physical qualities. Overall findings showed that movement and physical qualities differentiated between Senior, U19 and U16 rugby league players; supported by receiver operating characteristic curves, which determined novel comparative cut-off scores for movement skill and physical qualities between groups. Specifically, the greatest differences in movement, anthropometry, strength and power occurred between the U16 and U19 groups.

When movement skills were correlated with physical qualities, findings suggested that total movement was correlated with strength but not power qualities, whilst specific movements demonstrated limited correlation with strength and power performance. Such findings suggest that movement and physical qualities can differentiate between age categories in rugby league, and strength may be related to movement skills.

Movement differences between Age Groups

Movement skills assessed via the AAA, demonstrated overall significant differences across age groups, which supports the hypothesis that movement skills would differentiate across age groups. Novel data are presented for total and specific movement skills, which may be used as normative scores in academy and senior rugby league players for assessing movement skills.

Between groups, *small* differences were observed between Senior and U19s, and *moderate* differences between U19s and U16s players for total movement skill. This suggests that as players commence a structured training programme (e.g., at U16),

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improvements in movement skills occur, although not beyond U19. This may be due to movement skills being adequate at U19, or alternatively a change in focus of the strength and conditioning staff as player's transition into a more performance (i.e., Senior) focused, as opposed to development (i.e., U16 and U19) environment. The *small* difference between Senior and U19s players in this study differ from those previously investigated in AFL, whereby Woods and Colleagues (34) reported significantly lower total AAA for U18 AFL players when compared with senior counterparts. It is proposed that these contrasting findings may be a reflection of different gameplay demands between rugby league and AFL, whereby AFL is characterised by greater running demands and fewer collisions than rugby league (6).

Differences between the current findings and those of Woods et al. (34) may also be due to the involvement of U19 rugby league players in a professional academy for several years compared to U18 AFL players, who had not previously been involved in a talent development programme. This may also explain the difference in the current study between U16 and U19 players, whereby U16 players had limited training experience. As such, findings suggest that the movement skills of players requires training and may be trainable, although may not continue to develop into senior levels, given the *small* difference between Senior and U19 players (35). Additionally, although significant differences were observed for AAA total by age group, receiver operating characteristic curves reported high percentages of false positives (i.e. 57% and 50% for U16's) when assessed by individual scores. This finding demonstrates that the movement skill of rugby league players is highly variable when assessed by age group, potentially due to factors such as position, training experience and maturation status (27). This finding supports the need for a holistic approach to maximise athletic

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potential in rugby league, specifically by the individual prescription of training exercises and modalities (17).

When movement skills were considered by individual tests, age group differences demonstrated significant effects for right-sided lunge, right-sided RDL, press-ups and pull-ups but not overhead squat, left-sided lunge or RDL. The overhead squat was the lowest scoring movement for the Senior group within the present study (6.2 ± 1.3), and was lower than previously reported in U18 (7.5 ± 1.5) and Senior (7.5 ± 1.3) AFL players (34). Therefore, it is proposed that the lack of difference for the overhead squat was based on the inability of senior players to adequately perform the movement (which is heavily reliant upon mobility and stability of the shoulders; 6, 34). The authors suggest that this is a result of the intermittent collision nature of rugby league, whereby the shoulders have been reported to be the most frequently injured anatomical site during match-play (5, 13). Specifically, collision-based shoulder trauma has been suggested to negatively effect structural adaptations, therefore limiting mobility (i.e. inducing hypomobility; 5, 23). Furthermore, a common theme between the overhead squat, lunge and SL RDL is the assessment of hip control (see Table 1; 34). These findings demonstrate that required total and individual movement skills vary between sports, possibly based upon the demands of training and gameplay (35).

Given the cross sectional nature of this study, it is not possible to determine if the individual AAA tests that differentiated by age group (right-sided lunge, right-sided RDL, press-ups and pull-ups) was an adaptation to specific training programmes, or if players possessing greater movement skills progress through a rugby league system. Given the specificity of the exercises involved in the AAA, and their similarity to what a strength and conditioning coach may prescribe, it would be more likely that improvements are

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an adaptation to training programmes. As such, it would appear advantageous for younger players (e.g., U16) to focus on the efficacy of specific movements, to ensure competence. Practitioners should be aware that not all movement skill tests improve or possibly require improvement (given the limited difference to Senior players), although movement skills should feature as part of a practitioners testing battery, to ensure the holistic physical development of youth athletes.

Differences in Physical Qualities between Age Groups

For physical qualities, the findings support the hypothesis that anthropometry, strength and power would differentiate by age group with greater qualities in the Senior players. This study presents novel data for strength (peak force) and power (peak and mean) as these physical qualities were assessed via a force plate in contrast to popular isointerial (i.e. 1RM squat) and jump mat assessments (26) therefore improving the methodologies for assessing physical qualities in rugby league players.

Moderate differences were observed across consecutive age groups for body mass, which is consistent with previous research in rugby league academy cohorts (26). However, the observed *moderate* greater stature between U19 and senior cohorts contrasts maturation-based research in academy rugby league players (whereby little growth is expected post-18 years; 27). This finding may be explained by current talent identification programmes; a finding supported by research in AFL (6) and more recently by Till, Jones and Geeson-Brown (30), who reported that taller, heavier and leaner anthropometric profiles positively affect talent development and career attainment within rugby league. Novel cut-off scores presented within the current study support these findings, whereby increased body mass and stature values differentiated

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between age groups (i.e. 78.0 kg [U19 vs. U16,], 83.1 kg [Senior vs. U16], and 86.7 kg [Senior vs. U19]; Table 5).

For strength, *large* differences were observed in IMTP peak force across the three age categories. Additionally, peak force values of 2644.9 N (U19 vs. U16), 3402.6 N (Senior vs. U19), and 2728.5 N (Senior vs. U16) are presented as novel cut-off scores that provide the greatest definitive discrimination between rugby league age groups. Although this assessment has not been previously used in academy rugby league players, these strength differences across age categories are consistent with previous research in rugby league (1, 2, 26) that have used isoinertial assessments. These differences are likely explained by increased resistance training exposure between the three age groups in addition to increased androgen levels during adolescence (14). Physiologically, such exposures to resistance training (i.e. increased frequency, volume & intensity) between U16 and U19 playing levels may increase inter-muscular coordination, muscle fibre activation, and muscle fibre recruitment (19). Vingren and Colleagues (36) reported that adolescent males do not benefit from exercise-related acute increases in testosterone until post-puberty, offering further explanation for the magnitude of physical differences between the U19 and U16 cohorts.

For mean power, *moderate* differences were observed between consecutive age groups (1025.1 W, U19 vs. U16; 1171.7 W, Senior vs. U19), with *moderate* (3721.3 W, U16 vs. U19) and *small* (4778.5 W, U19 vs. Senior) differences observed for peak power. In contrast to previous research, jump height did not significantly differentiate between age groups and values were lower than previously reported within academy rugby league players (26). Additionally, there was no differences observed by cut-off scores for jump height between U19 vs. U16 (0.34 m) and Senior vs. U16 (0.34 m) comparisons.

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These findings may be explained in part by the overestimation of power by jump mat equations in contrast to the force plate used within the present study (18). These findings support the use of force plate technology as a more appropriate measure of power output in academy and senior rugby league players.

Although a decrease in the magnitude of physical differences was observed between cohorts as chronological age increased (i.e. peak force; U19 vs. U16 [*very large*], Senior vs. U19 [*large*]), significant increases in body mass and the longitudinal exposure to specific strength and conditioning training practises have been proposed to attenuate a possible 'strength ceiling' in senior athletes (2).

Relationships between Physical Qualities and Movement

The findings of this study demonstrate that overall, significant *moderate* relationships were observed for peak force with total movement skill and press-ups, and a *large* relationship with the right-sided lunge movement pattern. Despite the strength assessment within this study being isometric in nature, these findings demonstrate the positive role that strength has on the complex dynamic interactions that predispose movement. It has been suggested that strength contributes to stability and co-ordination, and has previously shown to improve motor skill performance in adolescents (i.e. running, jumping and throwing; 3). Specifically, this may occur due to greater eccentric work demands within stabilization tasks, with strength directly contributing to muscle stiffness, shown to aid joint stability (33).

Similarly to peak force, mean power was *moderately* correlated with the right-sided lunge, and had a *small* correlation with the left-sided SL RDL. Although this provides further suggestions that hip control and joint alignment skills may be of significance to physical qualities in rugby league, no further relationships were

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observed between power qualities with any movement skill. The lack of observed relationships between total movement skill and power qualities contrast the present relationship between peak force and movement skill, due to the inherent association between strength and power (19). It is therefore suggested that current movement screens (i.e. AAA, FMS) neglect the scientifically accepted principle that power=force*velocity (12) by abstaining from the inclusion of velocity-based assessment criteria. However, whilst it is acknowledged that the primary aim of movement assessment is to establish movement proficiency (16, 17), holistic training programmes should differentiate between athletes who demonstrate good and poor skills. This is supported by the variance in AAA scores by discriminant analyses within the present study, therefore it is suggested that those who demonstrate greater movement skills may benefit from velocity-based criteria upon assessment (i.e. increasing the difficulty of the movement after basic proficiency has been acquired).

A key finding of the present study is that the right-sided lunge appears to have the largest correlation with athletic performance (i.e. strength and power) in an elite rugby league cohort when assessed using the AAA (Table 5). Interestingly, the lunge is the only movement to include a velocity-based criteria within the AAA (i.e. controlled vs. jerking; Table 1), whilst previous research has also shown this to be a key movement pattern in relation to strength and power qualities in athletic cohorts (9, 14, 15). This is unsurprising, given the importance of peak force and mean power, and resultant maximum concentric velocity skills within team-sports (19), which are all associated with the lunge movement (9). Therefore, based on the present findings it is proposed that the lunge movement pattern should be an addition to training programmes and assessments to enhance both movement and physical qualities within the context of talent development in rugby athletes.

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Conclusion

In conclusion, novel normative data are presented for strength, lower body power and movement for elite rugby league players by age group within senior and academy levels. Strength, lower body power and movement skill differences are greatest between academy age groups, emphasising the importance of effective strength and conditioning programming during this period. Additionally, body mass, strength (i.e. IMTP peak force) and mean power were able to distinguish between age groups with the highest degrees of accuracy. Despite the inherent relationship between strength and power, movement was only significantly related to strength. As a result, future research should address the assessment of velocity-based criteria within movement screening.

PRACTICAL APPLICATIONS

The present findings provide normative data for anthropometric, strength and lower-body power qualities, and also movement skills for elite Super League rugby players. Findings highlight that significant differences exist between Senior and U16 players for multiple physical qualities and movement skills, although these appear to improve by the greatest magnitude between academy (U16, U19) age groups. These findings have important implications for the talent development of rugby league players, whereby data may be used to set targets and impact training protocols for rugby league players by age and skill level.

Novel comparative cut-off scores for movement skills and physical qualities are presented in an elite rugby league sample using receiver operating curve analyses. These provide comparable cut-off scores that definitively discriminate between multiple levels of talent development programmes in elite rugby league (i.e. U16, U19

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and Senior levels). Given the importance of physical qualities within rugby league, the relationship between strength and movement demonstrates a rationale for the inclusion of movement skills within academy talent development programmes.

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TABLES

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.

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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*

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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.

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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.

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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%

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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.

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