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Title_R-354313: Changes in anthropometry and performance, and their inter-relationships, across three seasons in elite youth rugby league players

Running head: Anthropometry and performance among youth rugby league players

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ABSTRACT

This study investigated changes in anthropometry and performance, and their inter-relationships, across three consecutive seasons (under-15 to under-17 age group) in elite youth rugby league players. Each player took part in annual anthropometrical and performance assessments, comprising measurements of stature; body mass; limb lengths and circumference; skinfolds, predicted muscle cross-sectional area (CSA); 20 m speed, counter-movement jump height, vertical power and aerobic power. Lean body mass % changed (P < 0.05) between the under-15 (70.9 ± 5.9 %), under-16 (72.0 ± 5.8 %) and the under-17 age groups (74.1 ± 5.7 %). Likewise, predicted quadriceps muscle cross-sectional area (CSA) also changed (P < 0.05) between each age group (under-15 = 120.9 ± 37.8 cm^2; under-16 = 133.2 ± 36.0 cm^2; under-17 = 154.8 ± 28.3 cm^2). Concomitant changes between the under-15 and under-16 group were found for 20 m speed (3.5 ± 0.1 *cf.* 3.4 ± 0.2 s; P = 0.008) and predicted jumping power (3611.3 ± 327.3 W *cf.* 4081.5 ± 453.9 W; P = 0.003). Both lean body mass and quadriceps muscle CSA consistently, related to both 20 m sprint time and jumping power, with r-values ranging between -0.39 to –0.63 (20 m sprint time) and 0.55 to 0.75 (jumping power). Our findings demonstrate the importance of gains in lean body mass across later-adolescence that support the ability to generate horizontal speed and predicted vertical power. This information should inform the expectations and subsequent training programs of elite rugby league practitioners.

Key words: team sport; speed; power

INTRODUCTION

Rugby league is a contact team sport, played professionally in Australasia (National Rugby League and Europe (Super League). Super League clubs based in the UK are often engaged in talent development programs, co-ordinated by the Rugby Football League (RFL). Between the under-15 and under-16 age group, young players are contracted via Scholarship to an elite Super League club. At this stage, players begin to play competitively for their club and take part in formal competition with other elite clubs. At the final stage of development (16 to 18 years), players reach the Academy squad, which marks their transition from junior to senior standard. During this stage, players may also be accelerated to the full senior squads.

Adult rugby league involves prolonged periods of low-to-moderate intensity movement, interspersed by multiple sprints and contacts with the opposition (18,38,48). Adolescent youth players perform a similar pattern of activities during a match, with a notable 10-min annual increase in match duration. An increase in match duration is accompanied by an inevitable increase in the exposure to physical contacts during match time. Given that body mass and body composition have a known relationship to tackling ability among adult rugby league players (17), the development of such characteristics among adolescent players is clearly warranted.

During later adolescence, a marked development in physical dimensions should be anticipated after the occurrence of peak maturity at approximately 13.8 years (39). Such a period is accompanied by significant increases in serum testosterone over six month intervals and a concomitant increase in stature, body mass and testicular volume (25,47). Increases in circulating growth androgens, such as testosterone and dihydrotestosterone, have an anabolic effect on structural protein production, leading to muscular and skeletal development (8). Among youth sports players, increases in physical size are related to improvements in functional performance in the years after the onset of puberty (3,26,27,40). However, there is currently no data to show the time-course of typical changes in anthropometry and physical performance during later adolescence among elite, youth rugby league players. Developing further understanding of physical growth among adolescent rugby league players and the relationship to performance would help to inform the expectations and subsequent training programs of elite rugby league practitioners. Accordingly, the aim of this study was to monitor changes in selected anthropometrical variables and performance, and their inter-relationships, across three consecutive seasons (under-15 to under-17 age group) among elite rugby league players.

METHODS

Experimental Approach to the Problem

A longitudinal study was performed, whereby elite, youth rugby league players took part in annual anthropometrical and performance assessments. As part of their support program, the players' hydration and nutritional status was regularly monitored and, if required, adjusted (weekly) by sports scientists employed by the club. The assessments were undertaken within the same month of each year, before the start of the competitive playing season, at the same time of day (15:00 – 18:00). At each age group, correlational analyses were performed to establish the relationship between functional performance and various physical dimensions.

Subjects

Thirteen elite, youth rugby league Scholarship/Academy consented to take part in a three-season longitudinal study, beginning at the under-15 age group (15.1 ± 0.3 y) and subsequently transitioning to the under-16 (16.2 ± 0.3 y) and under-17 age groups (17.0 ± 0.3 y). Consent was also obtained from the players' parent/guardians and the Rugby Football League (RFL) pursuant to law and Institutional Board approval for the study was granted by the Faculty of Applied Health Sciences Ethics Committee. The players followed a supervised training program, attending three-four sessions per week, comprising field-based aerobic training, gym-based resistance training, small-sided rugby games, as well as playing competitively for the club. During the early pre-season stages, the resistance sessions comprised high-volume, low-intensity (i.e. 4-5 sets of 3 x 15 repetitions), using a range of simple multi-joint exercises, such as squats, lunges and bench press. After 3-4 weeks, this was progressed to lower-volume, higher-intensity training (i.e. 3 sets of 3 x 10 repetitions) leading to the start of the season. During this time, the players completed a cycle of additional upper- and lower-body movements (i.e. shoulder-press, wide-grip pull-downs, seated-rows, chin-ups, upright-rows, dumbell-flys, leg-press and deadlifts). The loads used by players were generally increased each year based on their individual progression in technique, strength and body mass. Throughout the competitive season, a maintenance program was administered to the players, comprising short sessions (i.e. 3 x 1-2 sets x 6 repetitions) of functional, power-based movements, such as bench-throws, gladiator twists and a variety of Olympic-style lifts, depending on the experience and technique of the player. Conditioning sessions were based on the movement profiles observed during competition and employed a variety of repeated-sprint and high-intensity interval field sessions. In addition, a variety of small-sided games were delivered by the coaching staff that varied depending on the tactical or technical requirements of the squad. The players were involved in between six to eight competitive matches for the elite club each year, which were played against other elite super league teams in the UK.

Skinfold measurement

Participants were required to stand in an anatomical position whilst being palpated by the researcher for body land marks. Once the appropriate land mark had been located, a total of six skinfold sites, included within the International Society for the Advancement of Kinathropometry (ISAK) standard criteria (37), were marked on the right hand side of the participant's body using a fine point felt tip pen and a tape measure. The sites included; triceps, biceps, sub-scapular, abdomen, front-thigh and pectoral. Skin-folds were measured using pre-calibrated Harpenden (British Indicators, UK) callipers. Each site was measured three times from which the median value was recorded (37). Body fat percentage was predicted using the equation of Jackson and Pollock (30). Intra-tester reliability from two trials performed on different occasions ranged from 1.2% to 3.5% (CV).

Stature, mass and limb length measurement

Stature and seated stature were measured using a portable stadiometer (Seca, Leicester height measure, Hamburg, Germany). For the measurement of seated stature, participants were seated on a flat, hard surfaced bench of a known vertical height, which was used throughout the three-year period. The stretch-stature technique was used in each case with measurements being recorded to the nearest 0.1 cm. Leg length was derived from the subtraction of seated stature form overall stature (34). Body mass was measured using Seca beam scales (Seca, Hamburg, Germany) to the nearest 0.1 kg, with players wearing only the standard squad shorts and socks (the kit being worn was weighed and subsequently deducted from the final result). The approximate length of the humerus was measured through palpation of the acromion, following from the lateral lip to the greater tuberosity, which is inferior to the acromion's internal edge. From this point, the examiner measured the length of the humerus to the lateral epicondyle to complete the measurement, which was recorded with a tape measure on the right hand side of the body to the nearest 0.1 cm. Femur length was obtained by initially seating the participant at the appropriate height in order to reach 90° flexion of the knee joint (which was verified using a goniometer on the right hand side). Femur length was measured as the distance from the anterior superior iliac spine to a square plate positioned on the surface of the patella. Each site was measured three times from which a median value was obtained. Intra-tester reliability (CV%) from two trials, separated by one hour was 1.8% and 1.5% for the humerus and femur measurements, respectively. The maturity of the players (i.e. age at peak height velocity; APHV) required the assessment of stature, body mass, seated stature and leg length, that are substituted into the equation; maturity offset = -9.236 + 0.0002708 · (leg length · sitting height) - 0.001663 · (age · leg length) + 0.007216 · (age · sitting height) + 0.02292 · (weight/height), with R^2 = 0.891, and standard error of estimate = 0.592 (39). The maturity offset values were later subtracted from the chronological age of the players to calculate APHV.

Circumference measurement and predicted muscle cross-sectional area (CSA)

Circumference measurements were taken from each player in accordance with the guidelines of Malina et al. (34) and Mandleco (36). These included: chest, quadriceps, mid upper-arm (bicep), and calf circumferences, recorded on the right-hand side of the body where appropriate. The participants were firstly marked using a fine-point felt tip pen and subsequently measured using a measuring tape to the nearest 0.1 cm on the appropriate anatomical landmarks. The median value of three measurements was recorded. The quadriceps and calf circumferences required the participant to stand with their right hip, knee and ankle flexed in front of them, placing their foot in a 90° position on a bench (verified using a goniometer). The measurement of the mid-line of the quadriceps was obtained half-way between the greater trochanter and the lateral epicondyle. Whilst in this position, the maximum circumference of the calf was also recorded. The measurement of the upper-arm circumference was obtained with the participant in the anatomical position. The upper-arm circumference was identified as the mid-point of the humerus measurement previously described. The chest circumference was taken by horizontally passing the measuring tape around the body of the participant at the level of the nipples. The reliability (CV%) was established as: quadriceps = 2.3%; upper arm = 1.2%; calf = 1.1%; chest = 1.4% The muscle cross-sectional area (CSA) of the right quadriceps region was predicted using the multiple regression equation of Housh et al. (28), whereby; CSA = (4.68 × quadriceps circumference) – (0.64 × quadriceps skinfold) - 22.69. The equation of Housh and colleagues has an error of between 5 cm^2 and 14.3 cm^2 for quadriceps muscle CSA and has been suggested as a viable indirect alternative to criterion measurements in young athletic populations (28).

Counter-movement jump (CMJ) height and predicted vertical power

Maintaining a stance at shoulder width, participants flexed their knees in a rapid downward motion, reaching approximately 90º, before rapidly extending their knees and driving in an upward motion to complete the jump. The participants performed three jumps with the highest jump used for analysis. CMJ height (cm) was calculated as the difference between landing and take-off time recorded using a timing mat system (Just Jump System, Probotics

Inc., Huntsville, AL). Vertical power (W) was estimated based on the equation; CMJ power (W) = 61.9 × jump height (cm) + 36.0 × body mass (kg) – 1822. This equation was selected since reports have demonstrated no systematic difference to power recorded on a force platform (9). The reliability of the CMJ height was 2.1% (CV).

20 m sprinting speed

The protocol consisted of two maximal sprint efforts, starting from a standing position, separated by a period of three minutes of recovery. The sprinting course was marked with a pre-measured (tape measure) straight painted line, upon which timing gates were positioned at 0 and 20 m. Timing gate height was set at 60 cm (12). On both occasions, participants were instructed to start sprinting from 30 cm behind the first timing gate, from their preferred foot, until they had passed through the final gate. A split time was recorded at 20 m from a wireless receiver (Brower timing systems, Utah, USA) accurate to 0.01 s. The best time performed by participants over each interval was recorded for statistical analysis. The CV% for sprinting time was 1.4%

Aerobic endurance

Maximal aerobic endurance was estimated using the multistage fitness test (33). Players were required to run back and forth between two cones placed 20 m apart, keeping in time with a series of audio signals played through a CD player. The frequency of the signals and subsequent running speed was progressed by 0.138 $m{\cdot}s^{-1}$ (0.5 $km{\cdot}h^{-1}$) increments, starting from 2.22 $m{\cdot}s^{-1}$ (8 $km{\cdot}h^{-1}$), until participants reached volitional exhaustion. Maximal aerobic capacity ($\dot{V}O_{2max}$) was later determined using a linear regression equation (41). Among rugby league players ranging between the ages of 15 to 18 years, the intra-class correlation coefficient for test re-test reliability and typical error of measurement for the multistage fitness test have previously been reported as 0.9% and 3.1%, respectively (20).

Statistical analyses

After the appropriate diagnostic checks for normality and sphericity, one-way repeated-measures analyses of variance (one-way RM-ANOVA) were used to identify overall differences in measurements of anthropometry and performance amongst the players competing within the under-15, -16 and -17 age groups. Specific differences were identified using paired *t*-tests and a Benjamini Hochberg false discovery rate adjustment to control the type I error rate (6). Pearson's correlation coefficient (r) was used to assess the bivariate relationships between each anthropometric variable (aside from individual skinfold measurements) and the tests of physical performance for each year of competition. The r-value was interpreted according to Cohen (11) where 0.1 = poor, 0.3 = moderate and 0.5 > = strong. Data analysis was performed with the SPSS version 19.

RESULTS

There was a significant age group effect on stature ($F_{(2,24)} = 12.321$, $P < 0.001$), with the group growing taller between the under-15 and under-16 age groups (179.2 ± 4.6 cm *cf.* 179.9 ± 4.5 cm, respectively; $P = 0.004$) (Figure 1). An age group effect was also found for seated stature ($F_{(2,24)} = 14.624$, $P < 0.001$), with follow-up paired *t*-tests showing specific differences between the under-15 group and under-16 groups (93.4 ± 2.3 cm *cf.* 94.5 ± 2.2 cm, respectively; $P = 0.003$). Whilst there was an incremental trend for leg length, there were no significant age group effects ($F_{(2,24)}$ = 1.395, P = 0.267) (Table 1). Femur length increased over time ($F_{(2,24)}$ = 5.261, P = 0.013) with specific differences between the under-15 group and under-16 group (44.2 ± 1.9 cm *cf.* 45.2 ± 2.2 cm, respectively; P = 0.003) and the under-15 and under-17 group (44.2 ± 1.9 cm *cf.* 45.3 ± 2.5 cm, respectively; P = 0.004). No changes in humerus length were observed over time ($F_{(2,24)}$ = 0.91, P = 0.913) (Table 1). The APHV increased on an annual basis ($F_{(2,24)}$ = 100.766, P < 0.001), with differences observed from the under-15 group to -16 group (1.31 ± 5.48 y *cf.* 1.73 ± 0.27 y, respectively; P < 0.001), followed by the under-16 group to under-17 group (1.73 ± 0.27*cf.* 2.16 ± 0.31 y, respectively; P < 0.001) (Table 1).

**********************Table 1 near here**********************

As shown in Figure 1, quadricep circumference changed over time ($F_{(2,24)}$ = 3.866, P = 0.035) between the under-15 group and under-17 group (58.1 ± 3.9 cm *cf.* 59.9 ± 4.7 cm, respectively; P = 0.040) and the under-16 group and under-17 group (58.1 ± 3.9 cm *cf.* 59.9 ± 4.7 cm, respectively; P = 0.043). The ANOVA also revealed age group effects for chest circumference ($F_{(2,24)}$ = 5.402, P = 0.012), which were a result of annual changes between the under-16 and under-17 group (103.0 ± 6.2 cm *cf.* 105.3 ± 5.4 cm, respectively; P = 0.006) and between the under-15 group and under-17 group (102.2 ± 5.8 cm *cf.* 105.3 ± 5.4 cm, respectively; P = 0.013) (Table 1). Whilst the upper-arm circumference ($F_{(2,24)}$ = 1.138, P = 0.337) and calf circumference ($F_{(2,24)}$ = 1.448, P = 0.225) did not change over time (Table 1), predicted quadriceps muscle cross-sectional area (CSA) did show age group-related changes ($F_{(2,24)}$ = 11.140, P < 0.001) (Figure 1). Paired *t*-tests showed that there were differences between the under-15 and under-16 group (120.9 ± 37.8 cm^2 *cf.* 133.2 ± 36.0 cm^2, respectively; P = 0.015), the under-16 and under-17 group (133.2 ± 36.0 cm^2 *cf.* 154.8 ± 28.3 cm^2, respectively; P = 0.006) and the under-15 and under-17 group (120.9 ± 37.8 cm^2 *cf.* 154.8 ± 28.3 cm^2, respectively; P = 0.004) (Figure 1).

Body mass changed over time ($F_{(2,24)}$ = 2.339, P = 0.011) between the under-15 group and under-17 group (81.9 ± 9.1 kg *cf.* 86.3 ± 9.4 kg, respectively; P = 0.017) and the under-15 group and -16 group (81.9 ± 9.1 kg *cf.* 86.1 ± 6.0 kg, respectively; P = 0.020) (Table 1). Accordingly, lean body mass % also changed over time ($F_{(2,24)}$ = 6.522, P = 0.005) with differences found between under-15 and the under-16 group (70.9 ± 5.9 % *cf.* 72.0 ± 5.8 %, respectively; P = 0.033 under-16 group and under-17 group (72.0 ± 5.8 % *cf.* 74.1 ± 5.7 %, respectively; P = 0.007) and the under-15 group and the under-17 group (70.9 ± 5.9 % *cf.* 74.1 ± 5.7 %, respectively; P = 0.008) (Table 2).

**********************Figure 1 near here**********************

**********************Table 2 near here**********************

As demonstrated in Table 2, the ANOVA showed an age group effect for the tricep skinfold ($F_{(2,24)}$ = 5.595, P = 0.010) with a specific decrease in skinfold thickness between the under-16 group and under-17 group (12.7 ± 4.1 mm *cf.* 10.4 ± 3.0 mm, respectively; P = 0.001) and between the under-15 group and under-17 group (12.8 ± 5.5 mm *cf.* 10.4 ± 3.0 mm, respectively; P = 0.048). There were further time effects present for the quadricep skinfold (*F*

$_{(2,24)}$ = 4.113, P = 0.029) which was attributable to a reduction in skinfold thickness between the under-15 group and under-17 group (19.8 ± 8.0 mm *cf.* 16.1 ± 5.7 mm, respectively; P = 0.038) and the under-16 and under-17 group (18.0 ± 6.7 mm *cf.* 16.1 ± 5.7 mm, respectively; P = 0.038). No significant time effects were apparent for the bicep skinfold ($F_{(2,24)}$ = 1.709, P = 0.202), the sub-scapula skinfold ($F_{(2,24)}$ = 0.564, P = 0.576), the abdominal skinfold ($F_{(2,24)}$ = 0.731, P = 0.492) and the pectoral skinfold ($F_{(2,24)}$ = 0.840, P = 0.444). There were no no changes in the sum of six skinfolds ($F_{(2,24)}$ = 0.755, P = 0.481) or the predicted percentage of body fat ($F_{(2,24)}$ = 0.307, P = 0.739) between the age groups.

There were age-group effects for 20 m sprint time ($F_{(2,24)}$ = 11.9, P < 0.001), with *post-hoc* tests revealing differences between the under-15 group and under-16 group (3.5 ± 0.1 *cf.* 3.4 ± 0.2 s, respectively; P = 0.008). There were further differences between the under-15 group and under-17 group for 20 m sprint time (3.5 ± 0.1 c.f. 3.3 ± 0.1 s, respectively; P < 0.001) (Table 3). However, no differences (P > 0.05) were found in sprint time between the under-17 group and the under-16 group. There were no age group effects for countermovement jump height ($F_{(2,24)}$ = 1.409, P = 0.906); however, there were differences for predicted vertical power between age groups ($F_{(2,24)}$ = 14.845, P < 0.001). An age group effect was found for predicted $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) ($F_{(2,24)}$ = 5.789, P < 0.001), which was attributable to lower values in the under-16 group compared to the under-17 group (48.3 ± 3.6 ml·kg^{-1}·min^{-1} *cf.* 52.2 ± 3.5 ml·kg^{-1}·min^{-1}, respectively; P < 0.001) and in the under-15 group compared to the under-17 group (48.1 ± 3.4 ml·kg^{-1}·min^{-1} *cf.* 52.2 ± 3.5 ml·kg^{-1}·min^{-1}, respectively; P < 0.014). As with all other performance measurements, *post-hoc* tests showed differences between the under-15 group and under-16 group (3611.3 ± 327.3 W *cf.* 4081.5 ± 453.9 W, respectively; P = 0.003) and the under-15 group and under-17 group in favour of the older age groups (3611.3 ± 327.3 W *cf.* 4141.3 ± 397.1 W, respectively; P < 0.001).

**********************Table 3 near here**********************

During each age group, lean body mass was strongly related to predicted vertical power, with annually developing *r*-values of 0.55 (under-15), 0.67 (under 16) and 0.70 (under 17) (Table 4). Similarly, quadricep CSA was strongly related to vertical jump power, with annually developing *r*-values of 0.67 (under-15), 0.68 (under-16) and 0.75 (under-17). There were further moderate-strong (inverse) relationships between 20 m sprint time and quadriceps CSA, with *r*-values developing each year from -0.41 (under-15), -0.55 (under-16) and -0.63 (under-17). Similarly, lean body mass was also inversely related to 20 m sprint time at the under-15 (r = -0.39), under-16 (r = -0.48) and under-17 age groups (r = -0.57). Predicted $\dot{V}O_{2max}$ and CMJ were not related ($P < 0.05$) to any of the anthropometrical variables at any age group.

**********************Table 4 near here**********************

DISCUSSION

This is the first study to document longitudinal developments in physical performance and anthropometric dimensions during late adolescence in rugby league players. Notably, the period between the under-15 and the under-16 age groups showed the greatest improvements in short, powerful movements. For example, there were reductions (faster) in 20 m sprinting time and concomitant increases in predicted vertical power between these age groups (Table 3). Interestingly, between the under-16 and under-17 age groups (later period), there were no differences in speed or vertical power, yet an improvement in predicted $\dot{V}O_{2max}$ was observed. That improvement in aerobic and anaerobic fitness qualities occurred at distinctly different time points during the late adolescence of rugby league players provides a useful insight for practitioners. Fundamentally, our findings inform practitioners of when to expect developments in speed and power, which have been shown to relate to tackling performance among adult rugby league players (17). Furthermore, the later developments in aerobic power are likely to support high-intensity running during matches as player's progress toward the professional level (18).

The larger improvements between the under-15 and under-16 age groups in functional tests of performance should be expected owing to the anticipated rate of physical growth at this age (7). At the age of 15, the players were approximately one year post-peak height velocity (on average), which has been associated with significant increases in serum testosterone and concurrent increases physical size (25,47). Such changes reflect a post-pubertal period of muscular development, resulting in increased sprinting, jumping and (3, 22,26). Indeed the progressively stronger relationships found between 20 m sprint time and both quadriceps muscle CSA and lean body mass at each age group (Table 4), highlights the importance of muscular growth to short term, maximal sprint performance. Whilst limited by their cross-sectional design, research with regional standard rugby league players has also shown differences in short explosive movements, such as vertical jumping (4.8% to 17.8%; 15,16,45) and 10 m sprint performance (1.6% to 2.7%; 15,16,45) between the earlier ages of either 14 to 15 and 15 to 16 years. However, between the later age groups of 16 and 18, reports from Australia have showed no change in various parameters of performance, such as speed, agility and aerobic capacity (15,16). Such findings are in partial agreement with the current study and signify a delayed developmental period in maximal, short-term performance during later adolescent years.

An important development between the under-15 and under-16 groups appears to be the predicted power output from the vertical jump performance. This was not the case with absolute values for countermovement jumping, which has been reported as a predictor of selection in other related sports, such as Australian Football (32). Moreover, there was a strong relationship between both lean body mass and quadriceps muscle CSA at each age group (Table 4). These relationships are consistent with changes in peak explosive power, which may be developed from an increase in type II muscle fibre composition and neuromuscular firing patterns (amongst other factors) as a function of biological maturity (1,42). Such relationships also highlight the intimate relationship between muscle volume and anaerobic performance at post-pubertal stages (4). Indeed, cross-sectional muscle area is dictated by the number of sarcomeres arranged in parallel, which, in turn, is related to the force production of the muscle (1). Therefore, the increase in quadriceps CSA, and subsequent number of sarcomeres in series, increases the time available for actin and myosin interaction, thus increasing the force and eventual power production of the muscle during shortening sequences (2). Predicted vertical power represents an additional dimension of relative short-term, power output and supports the assertion that gains in lower-limb power development should be considered in accordance with concomitant developments in fat-free, propulsive mass. Given that CMJ height did not improve at any age group, our findings might indicate the future scope to apply ‘ratio’ techniques to performance assessment with youth rugby league players. That is, the assessment of performance measures in relation to anthropometric variables, such as body mass and stature (13). Adopting such an approach might help to better understand the development of short, maximal performance among youth rugby league players.

The 8% increase in predicted $\dot{V}O_{2max}$ between the under-16 and -17 age groups represents a large progression in aerobic power. Similar improvements have been reported among 18 year- old soccer players, along with increases (6.7%) in running economy (23). Our findings provide evidence of the time-point that improvements in shuttle running performance can be expected and are similar to data published on elite male field hockey players of the same age group (14). Indeed, among adolescent boys, changes in absolute $\dot{V}O_{2max}$ continue into later adolescence (4,5). While changes in aerobic power are often attributed to concurrent increases in lean body mass, we found no relationship between these measurements. Therefore, it is likely that more specific alterations in muscle morphology and metabolism explain the marked increase in aerobic power at later adolescent years (8).

This is the first study to evaluate the longitudinal development of anthropometric characteristics among youth rugby league players during later adolescence. This period coincided with an increase in stature, seated stature and femur length during the first transitional period, followed by a lagged increase in quadriceps circumference, chest circumference, lean body mass and predicted muscle CSA of the quadriceps among the under-16 to under-17 age groups. The biological events that occur during the post-pubertal years are complex and include changes in the nervous and endocrine systems that, in turn, co-ordinate anthropometric and physiological alterations (34). The observed patterns, which showed a change in various indications of bone length (stature, seated stature and femur length) during post-PHV stages, are consistent with the normal male growth curves presented by previous authors and represent the anticipated slowing of growth velocity during later teenage years (31,43). However, the initial age (~15 y) of the current participants was marginally greater (~1-2 y) compared to the starting age reported within previous longitudinal or cross-sectional rugby league studies (16,45) or other team-based sports (29, 40), thereby increasing the likelihood of advanced biological maturity. Indeed, the height velocity demonstrated between the under-15, -16 and -17 age groups (mean change < 1 $cm \cdot year^{-1}$) was much smaller than expected for players in comparable age ranges in field hockey (14) and soccer (40). This is perhaps related to the later initial measurement of stature which was approximately 3 cm larger than the aforementioned reports, coupled with the likelihood of advanced biological maturity among players in British-based youth rugby league (45).

The body mass of the rugby league cohort was 81.9 kg and increased by 4.2 $kg \cdot year^{-1}$ at the first transitional stage. This matches the rate reported in previous longitudinal studies but highlights the superior mass of rugby league players compared to that of normal populations (~60-67 kg; 43,44) or samples of soccer (~58 kg; 35), hockey (58 kg; 14) and basketball players (~67 kg; 10) of the same chronological age. Notwithstanding the discrepancies between different skinfold sites and body composition estimations, the body fat percentage and sum of six skinfolds in the current study was also similar to previous research among youth rugby league players (45). Therefore, the most logical mechanisms accounting for such similarities in body mass velocity between the age groups of the under-15 group and -16 group may be related to changes in fat-free mass dimensions. Indeed, changes in quadriceps and chest circumference are also consistent with training-induced adaptations and were likely related to the annually-phased resistance training programs undertaken by the players. The training of the current cohort consisted of specific hypertrophy cycles during non-competitive stages, that were similar to programs that develop muscle CSA with team sports participants of this type (21). The large gains from 71.8% to 74.1% in fat-free mass (2.3% increase) over later adolescence in Scholarship rugby league players develops at a rate beyond that in other sports, such as soccer, where less than a 1% change in fat-free mass has been reported between the same age groups (29,47). These findings have relevance for rugby league practitioners and show that increases in quadriceps muscle CSA, upper arm circumference and, consequently, both fat and lean body mass distinguishes young rugby league players from other team sports players.

PRACTICAL APPLICATIONS

This study demonstrates the time-course of change in physical development and performance among elite youth rugby league players across later adolescence. This information can be used to gain a greater understanding of player development patterns in youth rugby league. For example, the notable gains in lean body mass appear to characterize youth rugby league players and are much larger than previously demonstrated in other team sports, such as soccer and field hockey (29,47). Such changes, coupled with the increase in predicted muscle mass of the quadriceps, supports the ability to generate horizontal speed and predicted vertical power. The later gain in aerobic capacity provides practitioners with a notion of when to expect changes of this type. The continual use of each of the field-based measurement techniques utilised in the current study would be beneficial to clubs wishing to monitor changes in performance across age-groups. Future research should consider evaluating the efficacy of training interventions across similar time-periods in order to further understand their influence on physical development and performance that have been demonstrated herein.

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Figure 1. Average and individual annual data plots for stature (panel A), quadriceps circumference (circ; panel B) and quadriceps cross-sectional area (CSA; panel C) (n = 13).

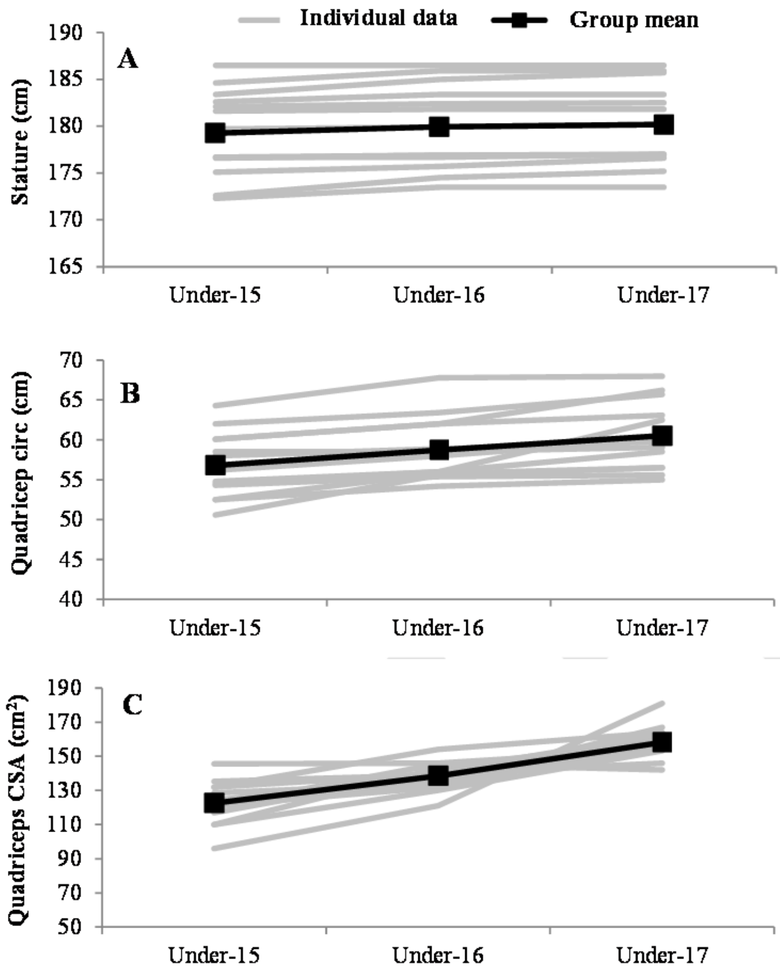
Individual data
Group mean
A
Stature (cm)
190
185
180
175
170
165
Under-15
Under-16
Under-17
B
Quadricep circ (cm)
70
65
60
55
50
45
40
Under-15
Under-16
Under-17
C
Quadriceps CSA (cm²)
190
170
150
130
110
90
70
50
Under-15
Under-16
Under-17

Table 1. Annual data (mean ± SD) for age, stature, body mass, circumferences and limb lengths across three consecutive youth rugby league age groups (n = 13).

	Under-15			Under-16			Under-17		
Age (y)	15.1	±	0.3	16.2	±	0.3	17.0	±	0.3
Seated stature (cm)	93.4	±	2.3	94.6	±	1.9*	94.7	±	2.1*
Leg length (cm)	85.3	±	4.2	85.7	±	4.0	85.7	±	3.9
Body mass (kg)	81.9	±	9.1	86.1	±	6.0*	86.3	±	9.4*
Upper-arm circ (cm)	33.6	±	2.0	33.9	±	2.6	34.4	±	2.6
Calf circ (cm)	38.5	±	2.6	39.1	±	2.8	39.0	±	3.1
Chest circ (cm)	102.2	±	5.8	103.0	±	6.2	105.3	±	5.4*†
Femur length (cm)	44.2	±	1.8	45.2	±	2.2*	45.3	±	2.5*
Humerus length (cm)	34.9	±	1.2	34.9	±	1.2	34.9	±	1.5
Maturity offset (y)	1.04	±	0.40	1.73	±	0.27*	2.16	±	0.31*†

Note: circ = circumference; * = sig. different (P < 0.05) from under-15 age group; † = sig. different from under-16 age group. Age was not considered as an outcome variable.

Table 2. Annual data (mean ± SD) for skinfolds, predicted body fat and lean body mass across three consecutive youth rugby league age groups (*n* = 13).

	Under-15	Under-16	Under-17
Bicep SKF (mm)	6.0 ± 2.0	6.8 ± 2.1	6.1 ± 1.8
Tricep SKF (mm)	12.8 ± 5.5	12.7 ± 4.1*	10.4 ± 3.0*†
Sub-scapular SKF (mm)	15.1 ± 7.4	14.8 ± 5.0	13.8 ± 4.3
Abdominal SKF (mm)	20.8 ± 8.1	20.2 ± 7.7	22.4 ± 7.0
Pectoral SKF (mm)	9.4 ± 3.1	8.5 ± 2.7	9.0 ± 2.7
Quadricep SKF (mm)	19.8 ± 8.0	18.0 ± 6.7*	16.1 ± 5.7*†
Sum of 6 SKF (mm)	83.9 ± 30.3	81.0 ± 25.0	77.8 ± 20.8
Predicted body fat (%)	13.1 ± 5.0	13.4 ± 4.4	13.7 ± 4.0
Lean body mass (%)	70.9 ± 5.9	72.0 ± 5.8*	74.1 ± 5.7*†

Note: SKF = skinfold; * = sig. different ($P < 0.05$) from under-15 age group; † = sig. different from under-16 age group.

Table 3. Annual performance data (mean ± SD) for across three consecutive youth rugby league age groups (*n* = 13).

	Under-15	Under-16	Under-17
20 m sprint time (s)	3.5 ± 0.1	3.4 ± 0.2*	3.3 ± 0.1*
CMJ height (cm)	47.0 ± 3.0	47.3 ± 4.9	47.6 ± 5.5
Predicted vertical power (W)	3611.3 ± 327.3	4081.5 ± 454.9*	4141.3 ± 397.1*
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	48.1 ± 3.4	48.3 ± 3.6	52.2 ± 3.5*†

Note: CMJ = counter-movement jump; * = sig. different ($P < 0.05$) from under-15 age group; † = sig. different from under-16 age group.

Table 4. Relationships between selected anthropometric and performance variables

		Pearson correlation coefficient *r* (*P*-value)	
		Quadricep CSA (cm^2)	Lean Body Mass (%)
Under-15	20 m Sprint time (s)	-0.41(0.022)	-0.39 (0.034)
	Predicted vertical power (W)	0.67 (0.014)	0.55 (0.011)
Under-16	20 m Sprint time (s)	-0.55 (0.010)	-0.48 (0.017)
	Predicted vertical power (W)	0.68 (0.006)	0.67 (0.001)
Under-17	20 m Sprint time (s)	-0.63 (< 0.001)	-0.57 (0.002)
	Predicted vertical power (W)	0.70 (< 0.001)	0.75 (< 0.001)