The longitudinal development of anthropometric and physical characteristics within academy rugby league players

ABSTRACT

The purpose of the present study was to evaluate the annual and long-term (i.e., 4 year) development of anthropometric and physical characteristics in academy (16-20 years) rugby league players. Players were assessed at the start of pre-season over a six year period and were required to be assessed on consecutive years to be included in the study (Under 16-17, *n*=35; Under 17-18, *n*=44; Under 18-19, *n*=35; Under 19-20, *n*=16). A subset of 15 players were assessed for long-term changes over 4 years (Under 16-19). Anthropometric (height, body mass, sum of four skinfolds) and physical (10 and 20 m sprint, 10 m momentum, vertical jump, yo-yo intermittent recovery test level 1, 1-RM squat, bench press and prone row) assessments were collected. Paired t-tests and repeated measures MANOVA demonstrated significant annual (e.g., Body mass, U16 = 76.4±8.4, U17 = 81.3±8.3 kg; $p<0.001$, $d=0.59$) and long-term (e.g., vertical jump, Under 16 = 44.1±3.8, Under 19 = 52.1±5.3 cm; $p<0.001$, $d=1.74$) changes in anthropometric and physical characteristics. Greater percentage changes were identified between the Under 16-17 age categories compared to the other ages (e.g., 1-RM squat, U16-17 = 22.5±19.5 vs U18-19 = 4.8±6.4%). Findings demonstrate the annual and long-term development of anthropometric and physical characteristics in academy rugby league players establishing greater changes occur at younger ages upon the commencement of a structured training programme within an academy. Coaches should understand the long-term development of physical characteristics and use longitudinal methods for monitoring and evaluating player performance and development.

Key Words: Anthropometry, strength, fitness, player development, player evaluation

INTRODUCTION

The role of the strength and conditioning coach within the long-term development of youth athletes is to advance the physical characteristics required for sports performance. This long-term development process usually involves the implementation of performance tests to objectively determine and monitor performance adaptations (1). Practitioners should use comparative data for monitoring and evaluating the development of youth athletes to assist in identifying player's strengths and weaknesses, talent identification and selection, evaluating training interventions and prescribing training programmes (26). This comparative data can be drawn from two distinct types of data collection; cross-sectional and longitudinal. Currently, research and practical application of the measurement and evaluation of physical performance predominantly utilize cross-sectional analyses within annual-age cohorts (31, 35) and as such little is known about the developmental pathways of athletes (22), which requires longitudinal observations. Prospective longitudinal studies require the collection of data from the same individuals for two or more distinct periods (7) but studies of this type are limited due to the difficulties of collecting such data (e.g., financial costs, player availability, methodological issues; 23). However, longitudinal data collection on the same individuals can inform coaches of the expected changes within and between athletes having implications for long-term player development (1, 7).

Research in rugby league has predominantly reported the anthropometric and physical characteristics of junior (13-20 years) rugby league players from the UK (19, 27, 28, 33) and Australia (9, 11, 12, 13) using cross-sectional approaches. This research has shown that anthropometric and physical characteristics increase across annual-age categories (i.e., Under 13 to Under 14; 11, 27, 33) and playing level (i.e., Regional to National players; 9, 12, 28) and differ between playing positions (i.e., between forwards and backs; 19, 33). Recent research (36) has also suggested that acceleration, speed and body mass are related to ball carrying ability during match play in academy (i.e., Under 15–17) rugby league players. Therefore, the development of anthropometric and physical characteristics is deemed important for the long-term development of academy rugby league players (30, 32).

Currently, longitudinal investigations within academy rugby league players are limited to either evaluating seasonal change (8, 34) or tracking annual performance within players aged between 13-15 years (29, 30, 31). Recent comparisons of the seasonal changes in anthropometric and physical characteristics between Under 14, 16, 18 and 20 rugby league players (34) demonstrated that younger (i.e., 14s and 16s) players increased body mass (i.e., Under 14s = 7.4±4.3 vs. Under 20s = 1.2±3.3%) and vertical jump (i.e., Under 16s = 9.2±10.7 vs. Under 18s = 1.6±7.4%) performance more than older (i.e., 18s and 20s) players who demonstrated greater improvements in Yo-Yo endurance (i.e., Under 14s = 0.0±52.2 vs. Under 18s = 23.7±31.8%) and 20 m sprint (i.e., Under 16s = -0.1±2.7 vs. Under 20s = -1.9±1.2%) performance. In addition greater strength changes were identified in Under 18 compared to Under 20s (i.e., 1RM squat – 15.8±13.8 vs. 6.5±10.7%). Longitudinal tracking of anthropometric and physical characteristics (29, 30, 31) has provided comparative data of the expected annual changes in performance between 13 and 15 years of age, whilst highlighting the changing and developing performance trajectories of junior players. This research showed greater annual performance improvements between the Under 13s and 14s age groups compared to the Under 14s and 15s (29) with later maturing players improving anthropometric and physical characteristics across the 2 year period more than earlier maturing players (30, 31). These findings can be explained by the fact that younger players are nearer the period of maturation, resulting in increases in body size and growth androgens (e.g., testosterone) leading to muscular and skeletal development (4). In addition, younger players are more likely to have a lower training age / history that may result in greater adaptations to training (6).

A limitation of the existing longitudinal research within rugby league (29, 30, 31) is that data collection ceased at the Under 15s age category and therefore no longitudinal data is available that tracks player characteristics on an annual basis within academy rugby league players (i.e., 16-20 years). An understanding of the longitudinal development of anthropometric and physical characteristics would allow a greater appreciation for player development on an annual and long-term basis (i.e., 4 years) whilst also considering inter-player variability due to the individual and non-linear development of physical performance (31, 35). Therefore, the initial purpose of this study was to evaluate the annual development of anthropometric and physical characteristics in academy rugby league players aged between 16 and 20 years. The second purpose was then to evaluate the long-term (i.e., 4 years) development of anthropometric and physical characteristics of a subset of players while considering inter-player variability. In the UK, 4 years is the maximum duration that players are within a professional rugby league clubs academy system. It was hypothesized that annual improvements in anthropometric and physical characteristics would occur with greater percentage improvements evident at the younger age categories. In addition, it was hypothesized that large increases in anthropometric and physical characteristics would occur over a long-term (i.e., 4 year) period with large inter-player variability evident.

METHODS

Experimental Approach to the Problem

Rugby league players from an English Super League club's academy performed a testing battery at the start of each pre-season over a six-year period (2007-2012). Players were assessed on anthropometric (height, body mass and sum of four skinfolds) and physical (10 and 20 m sprint, 10 m momentum, vertical jump, Yo-Yo intermittent recovery test level 1, one repetition max [1-RM] back squat, bench press and prone row) characteristics across 5 annual-age categories (Under 16s-20s). Players that were assessed on consecutive years were investigated for their change in performance between seasons to evaluate the longitudinal development of anthropometric and physical characteristics within academy rugby league players. Players that were assessed on 4 consecutive years (Under 16s–19s) were analysed for their long-term development of characteristics.

Subjects

To be included in the study, players were required to be assessed at consecutive age categories (i.e., Under 16 and Under 17). This resulted in a total number of 65 subjects, which differed between annual-age categories (i.e., Under 16-17, n=35; Under 17-18, n=44; Under 18-19, n=35; Under 19-20, n=16). A subset of subjects were identified who were assessed on four consecutive years from the Under 16 to Under 19 age categories (n=15).

For the players at the Under 16 age category, training consisted of 1 gym-based and 1 field-based session per week, with players also training and competing with their local amateur club. Players at the Under 17-20 age categories only trained and played at the professional club. Training typically included three gym-based and two field-based sessions in the pre-season period (November – March) and two gym-based and three field-based sessions alongside one game per week during the season (March – September). Players not selected for matches would undertake an additional conditioning training session. All experimental procedures were approved by the institutional ethics committee with assent and parental consent provided along with permission from the rugby league club.

Procedures

All testing was completed across two testing sessions in November each year at the beginning of the pre-season training period. All testing was undertaken by the lead researcher in the same location throughout the 6-year period. A standardised warm up including jogging, dynamic movements and stretches was used prior to testing followed by full instruction and demonstrations of the assessments. The first testing session incorporated field based assessments of speed (10 and 20 m sprint) and endurance (Yo-Yo intermittent recovery test level 1). The second testing session incorporated gym based testing including anthropometric (height, body mass and sum of 4 skinfolds), vertical jump and 1-RM strength (back squat, bench press and prone row) measures.

Anthropometry: Height was measured to the nearest 0.1 cm using a Seca Alpha stand (Seca, Birmingham, UK). Body mass, wearing only shorts, was measured to the nearest 0.1kg using calibrated Seca alpha (model 770) scales. Sum of four site skinfolds (biceps, triceps, subscapular, suprailliac) were determined using calibrated skinfold callipers (Harpenden, British Indicators, West Sussex, UK) in accordance to Hawes and Martin (16) as used in previous research in rugby league (33, 34).

Lower body power: Countermovement jump, with both hands positioned on the hips, was used to assess lower body power via a just jump mat (Probotics, Huntsville, AL, USA). Jump height was measured to the nearest 0.1cm from the highest of three attempts (18) with 60 s rest allowed between each assessment. Intraclass correlation coefficient (ICC) and coefficient of variation (CV) for the vertical jump were r = 0.92 and CV = 2.6% indicating acceptable reliability based on established criteria (i.e., >0.80; 17).

Speed: Sprint speed was assessed over 10 m and 20 m using timing gates (Brower Timing Systems, IR Emit, Draper, UT, USA). Players started 0.5 m behind the initial timing gate and were instructed to set off in their own time and run maximally past the 20 m timing gate. Times were recorded to the nearest 0.01 s with the quickest of the three times used for the sprint score. Intraclass correlation coefficient and CVs for 10 m and 20 m sprint speed were r = 0.85, CV = 4.5% and r = 0.91, CV = 3.0%, respectively.

10 m Momentum ($kg{\cdot}s^{-1}$): Momentum was calculated using estimated velocity ($m{\cdot}s^{-1}$) from 10 m sprint velocity (distance / sprint time) multiplied by body mass (kg^{-1}; 2).

Endurance: Endurance was assessed via the Yo-Yo intermittent recovery test level 1 (Yo-Yo IRTL1; 20), which has recently been used to assess endurance performance in rugby league players (14, 33). Players were required to run 20 m shuttles, keeping to a series of beeps, followed by a 10 s rest interval. Running speed increased progressively throughout until the players reached volitional exhaustion or until players missed two consecutive beeps, resulting in the test being terminated. Total running distance was recorded. Previous research (20) has shown an ICC and CV for the yo-yo intermittent recovery test level 1 of r = 0.98 and CV = 4.6%.

Strength: 1-RM back squat, bench press, and prone row were used as measures of lower-body pushing, upper-body pushing, and upper-body pulling strength, respectively. All players were accustomed to these exercises as they were regularly used as part of their training program, and any player who did not demonstrate competent technique (e.g., ability to squat to parallel) was not assessed on these measures. Participants performed a warm-up protocol of 8, 5, and 3 repetitions of individually selected loads before 3 attempts of their 1-RM with 3-minute rest between attempts. For the 1-RM squat, all players had to squat until the top of the thigh was parallel with the ground, which was visually determined by the lead researcher (2). Players then had to return to a standing position to record a 1RM score (33). For the bench press, athletes lowered the barbell to touch the chest and then pushed the barbell until elbows were locked out (33). For the prone row, also known as a bench pull, the players lay face down on a bench. The bench height was determined so player's arms were locked out at the bottom position and then had to pull the barbell towards the bench. The 1-RM lifts were only included if both sides of the barbell touched the bench (33). After all strength assessments, player's 1-RM scores were divided by body mass to provide a strength score relative to body mass.

Statistical Analyses

Data are presented as mean ± *SD*s of anthropometric and physical characteristics at each age category and the percentage change in characteristics between annual-age categories (i.e., Under 16-17, 17-18, etc.). To evaluate annual development, paired samples t-tests analysed differences between players anthropometric and physical characteristics at consecutive annual-age categories (i.e., Under 16s and 17s, Under 17s and 18s, etc.) with Cohen's d and 95% confidence limit effect sizes reported (5). A Cohen's d effect size of 0 – 0.2 was considered to be a trivial effect, 0.2 – 0.6 a small effect, 0.6 – 1.2 a moderate effect, 1.2 – 2.0 a large effect, and >2.0 a very large effect (3). In addition, a univariate analysis of variance (ANOVA) was used to examine the differences in the performance change between the consecutive annual age categories with a Tukey post-hoc used. To evaluate long-term development of the 15 players assessed across four years, a repeated measures analysis of variance (MANOVA) was used. Cohen's d effect sizes were calculated as in part 1 between annual age categories and across the four years (Under 16s-19s). The percentage changes in anthropometric and physical characteristics were also calculated for each player on an individual basis and the inter-player variability for each measure was analysed using co-efficient of variation (CV) analysis. SPSS (IBM, Armonk, New York, USA) version 19.0 was used to conduct analysis with all statistical significance set at $p \leq 0.05$.

RESULTS

Table 1 shows the mean and SD of the anthropometric and physical characteristics of the players who were assessed at consecutive age categories (i.e., Under 16s and 17s, 17s and 18s, etc.). Paired samples t-tests identified significant annual differences for height, body mass, 10 m momentum, Yo-Yo IRTL1 distance, vertical jump, 1-RM and relative bench press, squat and prone row across all age categories. Height and body mass significantly increased across age groups with performance improvements identified for the physical characteristics. No significant differences were identified for sum of four skinfolds, 10 m or 20 m sprint demonstrating no change in these measures across an annual period. Cohens d effect sizes generally demonstrated trivial to small effects for height, body mass, 10 m momentum, Yo-Yo IRTL1 distance and vertical jump. However, for strength measures, especially between the Under 16 and 17 age categories, moderate to large effect sizes were evident.

Insert Table 1 near here

Table 2 shows the percentage change in anthropometric and physical characteristics between annual-age groups (i.e., Under 16-17 to Under 19-20). Age category had a significant effect on the annual change in body mass ($p<0.001$; $\eta^2 = 0.26$; $1\text{-}\beta = 1.00$), 10 m momentum ($p<0.001$; $\eta^2 = 0.27$; $1\text{-}\beta = 0.99$), vertical jump ($p=0.013$; $\eta^2 = 0.09$; $1\text{-}\beta = 0.80$), 1-RM squat ($p<0.001$; $\eta^2 = 0.26$; $1\text{-}\beta = 1.00$), 1-RM bench press ($p<0.001$; $\eta^2 = 0.27$; $1\text{-}\beta = 1.00$), 1-RM prone row ($p<0.001$; $\eta^2 = 0.17$; $1\text{-}\beta = 0.99$), relative bench press ($p=0.001$; $\eta^2 = 0.15$; $1\text{-}\beta = 0.96$) and relative squat ($p=0.004$; $\eta^2 = 0.12$; $1\text{-}\beta = 0.89$). Post-hoc analyses demonstrated the greatest gains in body mass, 10 m momentum, 1-RM squat, bench press and prone row and relative bench press occurred between the Under 16-17 age categories, which were significantly greater than all other age categories. For vertical jump and relative squat, the percentage change was only significantly greater between the Under 16-17 age categories than the Under 18s-19s.

Insert Table 2 near here

Table 3 shows the annual changes in anthropometric and physical characteristics for the 15 players that were assessed on 4 consecutive years. A repeated measures MANOVA demonstrated significant overall effects for time ($p<0.001$; $\eta^2 = 0.78$; $1\text{-}\beta = 1.00$) with significant univariate effects demonstrated for height, body mass, 10 m momentum, Yo-Yo IRTL1 distance, vertical jump, 1-RM and relative bench press, squat and prone row. For each of the above measures, performance increased with age (see Table 3). Moderate to large effect sizes were found for 10 m momentum, vertical jump, 1-RM bench press, squat and prone row and relative bench press between the Under 16 and 17 age categories; vertical jump, 1-RM bench press, squat and prone row and relative bench press and prone row between the Under 17 and 18 age categories; with only trivial-small effect sizes evident between the Under 18 and 19 age categories. Effect sizes for the change in anthropometric and physical characteristics between Under 16 and 19 were large to very large for all variables except sum of 4 skinfolds, 10 m and 20 m sprint.

Insert Table 3 near here

Table 4 shows the mean, SD and range for the percentage change in anthropometric and physical characteristics for players assessed on a long-term basis between the Under 16s and 19s age categories. Large standard deviations, ranges and CVs were identified for each characteristic identifying the large inter-player variability in long-term changes.

Insert Table 4 near here

DISCUSSION

This is the first study to evaluate the annual and long-term (i.e., 4 years) development of anthropometric and physical characteristics in academy rugby league players aged between 16 and 20 years. This study progressed upon recent studies examining anthropometric and physical characteristics in academy rugby league players (33), the seasonal changes in such characteristics (34) and previous longitudinal studies in younger rugby league players (13-15 years; 29, 30, 31). As hypothesized, the majority of anthropometric and physical characteristics improved over an annual and long-term (i.e., 4 year) period with the greatest gains occurring between the younger annual-age categories (i.e., between Under 16s and 17s). These findings suggest that rugby league players involved in an academy programme will develop anthropometric and physical characteristics over time but the longitudinal development of these characteristics are dynamic with large inter-player variability.

As hypothesized, height, body mass, 10 m momentum, vertical jump, 1-RM and relative strength measures developed across an annual period consistent with previous cross-sectional analyses (9, 33) within academy aged players. Although significant changes were identified, the annual changes for height, body mass, 10 m momentum and vertical jump were trivial to small compared to strength measures that were moderate to large. Such findings provide evidence of the annual changes that may occur in physical performance characteristics within academy rugby league players. In addition, these findings suggest that strength characteristics will demonstrate the largest gains. These annual changes may be related to the normal adaptations related to growth and maturation (21) or may reflect the training programme undertaken during this period. In terms of growth and maturation, although height velocity plateaus in late adolescence, lean mass and BMC continues to increase into the early 20s (24) resulting in increases in muscular and skeletal development alongside performance improvements (4). Training related changes have been evident in adolescent athletes following a range of training modalities (e.g., strength, small sided games, sport specific training; 15) and therefore a combination of the processes of growth and maturation alongside training interventions would result in annual improvements in anthropometric and physical characteristics.

Although most characteristics improved across time, there was no significant annual change in sum of four skinfolds or 10 m or 20 m sprint performance, which is also, consistent with previous research (9, 33). This suggests to practitioners that sum of four skinfolds and speed performance would not improve on an annual basis between pre-season periods within a group of youth rugby league players. However, such changes may not be evident as some players increase sum of skinfolds and speed performance while other players decrease performance. This suggests that sum of four skinfolds and speed should be monitored closely by practitioners. However, the annual development of 10 m momentum (sprint velocity x body mass) will most likely develop within academy rugby players, due to increases in body mass, and may be a more important physical characteristic to monitor for rugby league performance (2, 34).

Interestingly, the current findings demonstrate that Yo-Yo endurance performance, measured by distance run, increased on an annual basis, which contradicts previous cross-sectional research (33) that demonstrated no significant difference between the Under 16 to Under 20 annual-age categories. Till and colleagues (33) suggested that age had no effect on Yo-Yo endurance performance between 16 and 20 years and that performance changes may not occur due to increases in body mass potentially affecting running performance. Current results counter this point, even though effect sizes are small, as when the same players are measured on consecutive years an increase in endurance performance is observed. This would be expected to occur to meet the increasing intensity of match play (10) with advancing age. Such findings support the use of longitudinal data over cross-sectional methods in tracking player development. A possible explanation of this finding is due to the sample measured at each age category as cross-sectional studies can include a range of players, thereby making changes across annual periods inaccurate. Such findings suggest that cross-sectional data may not be appropriate to calculate longitudinal changes in performance that occur in academy rugby league players and other respective sports. This may be important when evaluating player performance as developmental trajectories may be undetectable using cross-sectional assessment (29).

The present study provides comparative data for the annual percentage changes in anthropometric (e.g., body mass, Under 16-17 = 7.2 ± 4.1 %) and physical (e.g., Vertical jump, Under 17-18 = 5.5 ± 5.3 %; 1-RM prone row, Under 18-19 = 7.9 ± 4.6 %)

characteristics, which could be used by strength and conditioning coaches for monitoring player development and progression on an annual basis rather than using cross-sectional data. When the changes in anthropometric and physical characteristics were evaluated between annual-age categories (i.e., Under 16-17, Under 17-18, etc.), age category had a significant effect on body mass, 10 m momentum, vertical jump, 1-RM squat, bench press and prone row. Post-hoc analyses demonstrated the greatest annual improvements occurred between the Under 16-17 age categories. These findings are consistent with seasonal changes in body mass, 10 m momentum, vertical jump and strength measures, which were significantly greater during younger (i.e., Under 16s) compared to older (i.e., Under 18s and 20s) academy players (33). An explanation for these findings are that the Under 16 players are closer to the period of maturation, where significant increases in body size and growth androgens (e.g., testosterone) occur (20) affecting the development of strength related measures (28). In addition, for the players involved in this study, the U16 – U17 period was the first exposure to a structured strength and conditioning programme and therefore players were more likely to have a lower training age / history (33) resulting in increased neuromuscular adaptations to training and enhancing the training response (6). However, it is not clear if the large improvements between the U16-17 age categories were because of their age (maturation status) or because it was their first exposure to a structured strength and conditioning programme. Future studies should look to investigate this, as findings may provide an insight as to when strength and conditioning programmes should commence for optimal development. Coaches should also be aware that junior players will not continue to improve performance at the rate experienced during younger ages (i.e., 16 years) or upon the commencement of a structured training programme.

The long-term (i.e., 4 year) tracking of characteristics for a subset (n=15) of players triangulated with the annual changes previously discussed in that height, body mass, 10 m momentum, Yo-Yo distance, vertical jump and strength measures differed significantly across the annual-age categories with performance improving with age. Cohen's d effect sizes were also consistent with the annual change but when Cohen's d were conducted between Under 16s and 19s over a 4 year period this demonstrated large to very large changes for all variables except sum of four skinfolds, 10 m and 20 m speed. Such findings suggest that coaches should approach the development of physical characteristics within an academy programme from a long-term perspective and allow appropriate time for players to develop physical characteristics, through a combination of mechanisms related to growth and maturation and training adaptation.

The individual monitoring of players, demonstrated via range and CV data, allowed an evaluation of the variability in player development within academy rugby league players to be explored. The potential percentage increases (based on maximal values) in size (e.g., body mass = 26.1%), fitness (e.g., Yo-Yo distance = 172.3%) and strength (e.g., 1-RM squat = 88.9%) demonstrate the large improvements in performance that can occur between 16 and 19 years of age. Individual changes showed sum of four skinfolds, speed and endurance performance can increase or decrease across four years whilst body mass, momentum, strength and power consistently improved throughout the four-year period. The findings demonstrated large ranges and CVs for all variables (i.e., ranging from 27.8% for prone row to 2700.2% for sum of four skinfolds) demonstrating the large inter-player variability that exists in the development of academy rugby league players over a four-year period. These findings emphasize the inter-player and dynamic nature of the development of anthropometric and fitness characteristics (24, 30) and how players may be perceived at certain time point's dependent upon their development. Practitioners should therefore be cautious when evaluating player performance on a cross-sectional basis at one-off time points due to the potential improvements that can occur in academy rugby league players between 16 and 19 years.

Although this study progresses on previous cross-sectional (9, 32) and longitudinal seasonal changes (33) and has implications to inform practitioners of the long-term development of academy rugby players, it is not without limitations. Firstly, the lack of a control group means it is difficult to ascertain whether the development of anthropometric and physical characteristics is a result of processes related to growth and maturation or adaptation to training. Secondly, the lack of maturational assessment within the players limits the evaluation of the influence of maturation on the longitudinal development of anthropometric and physical characteristics. Finally, the lack of quantification of training volume and load results in a poor understanding of the training stimuli required to optimally develop physical characteristics in the long-term. Future research should aim to progress on this study and the recent research (32, 33) within academy rugby league players to understand the relationship between training and performance development (14) whilst evaluating optimal interventions to aid the long-term development of anthropometric and physical characteristics in academy rugby league players.

In conclusion, this study presents the annual and long-term (i.e., 4 years) changes in anthropometric and physical characteristics of academy rugby league players aged between 16 and 20 years. The findings identify that height, body mass, 10 m momentum, Yo-Yo distance, vertical jump and strength measures improve on an annual and long-term basis within academy rugby players but improvements in sum of four skinfolds and 10 m and 20 m are inconsistent. Greater percentage changes in anthropometric and physical characteristics occur at younger (i.e., Under 16-17) annual-age categories due to players being closer to maturation alongside a likely lower training age. This suggests that coaches should understand the development of anthropometric and physical characteristics and that players will not continue to develop at such an accelerated rate as age and training experience increases. In addition, improvements in Yo-Yo endurance performance improve with age, which contradicts previous cross-sectional data, highlighting potential inaccuracies in using cross-sectional data. Therefore, longitudinal data should be used where possible to evaluate the developmental process of academy rugby players. Finally, the large standard deviations of the annual and long-term percentage change and the large CVs support the inter-player variation in the development of anthropometric and physical characteristics between 16 and 20 years. Therefore, the use of an individual and longitudinal approach to monitoring and evaluating player development should be considered most effective.

PRACTICAL APPLICATIONS

Annual and long-term changes in height, body mass, momentum, endurance, lower body power and strength are expected within academy rugby league players aged between 16 and 20 years. Rugby practitioners and strength and conditioning coaches should utilize a longitudinal approach to data measurement and evaluation to answer several questions in relation to player development (e.g., how much did a player improve his body mass over the last year? How much stronger has this player become over a 4-year period? How does this compare with the team / comparative data?). This longitudinal approach develops upon cross-sectional assessments, which may not be the most appropriate method for monitoring and evaluating player performance, only providing coaches with a snapshot of current performance. However, it is important that coaches understand the large inter-player variability in the development of anthropometric and physical characteristics, further emphasizing the need to track performance changes on an individual and longitudinal basis (30). Such an approach should inform practitioners in the prescription of training, conditioning and nutritional interventions whilst considering long-term objectives rather than short-term outcomes within adolescent athletes.

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Table 1. Anthropometric and physical characteristics between annual-age categories for players with consecutive annual data

	U16 (n=35)	U17 (n=35)	Cohens d (95% CI)	U17 (n=44)	U18 (n=44)	Cohens d (95% CI)	U18 (n=34)	U19 (n=34)	Cohens d (95% CI)	U19 (n=16)	U20 (n=16)	Cohens d (95% CI)
Age (years)	15.72 ± 0.24	16.72 ± 0.24		16.74 ± 0.23	17.74 ± 0.23		17.69 ± 0.26	18.69 ± 0.26		18.72 ± 0.20	19.72 ± 0.20	
Height (cm)	176.7 ± 5.5	178.0 ± 5.5***	0.24 (0.10-0.30)	178.7 ± 5.5	179.9 ± 5.5***	0.22 (0.15-0.29)	180.9 ± 5.18	181.7 ± 5.31***	0.15 (0.09-0.22)	180.8 ± 4.78	181.3 ± 4.72**	0.11 (0.04-0.16)
Body Mass (kg)	76.4 ± 8.4	81.3 ± 8.3***	0.59 (0.37-0.78)	81.8 ± 9.3	84.7 ± 9.5***	0.31 (0.17-0.45)	87.3 ± 10.4	89.0 ± 10.38***	0.16 (0.09-0.24)	88.4 ± 9.14	89.0 ± 8.30	0.07 (-0.06-0.21)
Sum of 4 skinfolds (mm)	35.0 ± 10.9	35.5 ± 11.2	0.05 (-0.10-0.20)	37.0 ± 13.2	36.2 ± 11.1	-0.07 (-0.27-0.13)	38.1 ± 13.0	38.1 ± 13.2	0.00 (-0.14-0.05)	37.6 ± 10.3	34.6 ± 9.2	-0.31 (-0.62-0.01)
10 m (s)	1.81 ± 0.07	1.81 ± 0.06	0.00 (-0.23-0.22)	1.80 ± 0.06	1.79 ± 0.08*	-0.14 (-0.35-0.01)	1.80 ± 0.06	1.80 ± 0.07	0.00 (-0.23-0.19)	1.81 ± 0.08	1.79 ± 0.06	-0.28 (-0.57- 0.08)
20 m (s)	3.12 ± 0.11	3.12 ± 0.10	0.00 (-0.18-0.29)	3.11 ± 0.09	3.09 ± 0.10	-0.18 (-0.35- -0.01)	3.09 ± 0.11	3.09 ± 0.13	0.00 (-0.26-0.30)	3.09 ± 0.13	3.07± 0.10	-0.17 (-0.61-0.16)
10m Mom ($kg.s^{-1}$)	419 ± 40	448 ± 43***	0.69 (0.40-0.94)	456 ± 48	476 ± 48***	0.42 (0.24-0.57)	486 ± 54	497 ± 54***	0.19 (0.09-0.29)	488 ± 47	496 ± 46*	0.19 (0.02-0.36)
Yo-Yo IRTL1 (m)	1372 ± 443	1479 ± 362	0.26 (-0.08-0.48)	1475 ± 327	1547 ± 335*	0.22 (0.06-0.51)	1408 ± 281	1548 ± 379*	0.42 (0.06-0.77)	1353 ± 352	1499 ± 282	0.46 (-0.11-1.02)
Vertical Jump (cm)	45.8 ± 5.5	50.1 ± 5.7***	0.78 (0.51-1.04)	48.7 ± 2.8	51.6 ± 5.9*	0.45 (0.29-0.60)	51.2 ± 5.5	53.1 ± 5.2**	0.35 (0.14-0.57)	50.3 ± 4.1	53.2 ± 5.5**	0.60 (0.20-0.99)
Bench Press (kg)	74.8 ± 12.5	92.0 ± 10.0***	1.52 (1.01-2.03)	93.9 ± 13.4	105.1 ± 15.6***	0.76 (0.53-0.99)	110.3 ± 15.9	117.6 ± 15.5*	0.46 (0.27-0.66)	110.0 ± 15.3	118.0 ± 14.9***	0.53 (0.23-0.83)
Relative Bench Press (kg/kg)	0.99 ± 0.14	1.13 ± 0.13***	1.04 (0.66-1.50)	1.14 ± 0.14	1.24 ± 0.14***	0.71 (0.44-0.91)	1.25± 0.14	1.31 ± 0.15*	0.41 (0.19-0.60)	1.24± 0.15	1.31 ± 0.15**	0.49 (0.19-0.87)
Squat (kg)	101.8 ± 18.8	122.6 ± 18.0***	1.13 (0.66-1.59)	123.6 ± 17.1	135.2 ± 14.9***	0.72 (0.44-0.99)	138.2 ± 16.3	143.3 ± 14.2**	0.33 (0.12-0.54)	134.0 ± 19.5	142.6 ± 24.7**	0.39 (0.14-0.64)
Relative Squat (kg)	1.34 ± 0.20	1.51 ± 0.23***	0.79 (0.35-1.22)	1.51 ± 0.21	1.60 ± 0.18***	0.46 (0.21-0.72)	1.57 ± 0.16	1.60 ± 0.16	0.19 (-0.02-0.38)	1.50 ± 0.21	1.59 ± 0.26**	0.38 (0.08-0.62)
Prone Row (kg)	72.2 ± 9.7	83.0 ± 9.3***	1.42 (0.79-1.49)	84.0 ± 10.6	92.6 ± 9.9***	0.84 (0.61-1.06)	93.9 ± 11.0	101.1 ± 11.4***	0.64 (0.43-0.84)	94.3 ± 11.8	103.2 ± 11.6***	0.76 (0.43-1.09)
Relative Prone Row (kg/kg)	0.95 ± 0.12	1.02 ± 0.10***	0.63 (0.33-0.88)	1.02 ± 0.10	1.09 ± 0.09***	0.77 (0.49-0.96)	1.07 ± 0.10	1.13 ± 0.11***	0.60 (0.38-0.75)	1.06 ± 0.11	1.15 ± 0.08***	0.94 (0.47-1.40)

Significant differences between annual-age categories; *$p<0.05$; **$p<0.01$; ***$p<0.001$

Table 2. Mean and SD of the percentage change of anthropometric and physical characteristics between annual-age categories

	U16-U17 (n=35)	**U17-U18 (n=44)**	**U18-U19 (n=34)**	**U19-U20 (n=16)**
Height (%)	0.7 ± 0.3	0.6 ± 0.4	0.5 ± 0.6	0.3 ± 0.3
Body Mass (%)	7.2 ± 4.1	3.9 ± 4.8[a]	2.1 ± 2.4[a]	0.9 ± 2.5[a,b]
Sum of four Skinfolds (%)	2.7 ± 12.7	-0.1 ± 15.5	0.0 ± 3.2	-6.8 ± 13.7
10 m (%)	-0.1 ± 2.7	-0.7 ± 1.9	0.0 ± 2.3	-0.5 ± 2.1
20 m (%)	0.2 ± 2.2	-0.7 ± 1.8	1.1 ± 4.3	-0.8 ± 2.7
10 m Mom (%)	7.5 ± 4.8	4.5 ± 5.0[a]	2.2 ± 3.0[a]	1.3 ± 2.7[a]
Yo-Yo IRTL1 (%)	13.0 ± 31.2	6.5 ± 17.3	11.6 ± 25.2	15.4 ± 27.5
Vertical Jump (%)	9.5 ± 7.8	5.5 ± 5.3	4.3 ± 6.3[a]	5.6 ± 6.7
1-RM Bench Press (%)	24.0 ± 17.0	11.9 ± 8.8[a]	7.0 ± 6.5[a]	7.8 ± 7.8[a]
Relative Bench Press (%)	15.1 ± 13.9	8.7 ± 7.7[a]	4.8 ± 5.8[a]	7.0 ± 8.2[a]
1-RM Squat (%)	22.5 ± 19.5	10.7 ± 10.8[a]	4.8 ± 6.4[a]	6.2 ± 6.8[a]
Relative Squat (%)	14.0 ± 17.9	7.7 ± 11.1	2.8 ± 5.8[a]	5.4 ± 7.6
1-RM Prone Row (%)	15.4 ± 7.2	10.8 ± 6.3[a]	7.9 ± 4.6[a]	9.8 ± 5.3[a]
Relative Prone Row (%)	7.4 ± 7.5	7.7 ± 6.6	5.7 ± 3.2	9.0 ± 6.6

Post-Hoc – [a] Significantly different from U16-17 ($p<0.05$); [b] Significantly different from U17-U18 ($p<0.05$)

Table 3. Anthropometric and physical characteristics between annual-age categories for players with 4 years of consecutive data

	U16 (1)	**U17 (2)**	**U18 (3)**	**U19 (4)**	**F**	**P**	**Pairwise**	**Cohens d (95% CI) U16-17**	**Cohens d (95% CI) U17-18**	**Cohens d (95% CI) U18-19**	**Cohens d (95% CI) U16-19**
Height (cm)	177.4 ± 2.7	178.8 ± 2.9	179.7 ± 2.7	180.2 ± 2.7	35.5	<0.001	1<2<3<4	0.33 (0.15-0.50)	0.24 (0.13-0.34)	0.12 (0.05-0.20)	0.67 (0.38-0.96)
Body Mass (kg)	77.9 ± 9.8	84.8 ± 10.1	86.6 ± 9.1	88.0 ± 9.4	28.9	<0.001	1<2,3<4	0.68 (0.37-1.00)	0.23 (-0.02-0.47)	0.13 (0.03-0.23)	1.04 (0.57-1.54)
Sum of 4 skinfolds (mm)	37.9 ± 12.9	41.4 ± 14.0	38.3 ± 11.2	36.4 ± 10.4	1.6	0.226		0.26 (0.01-0.39)	-0.16 (-0.47-0.15)	-0.17 (-0.30- -0.03)	-0.13 (-0.52-0.29)
10 m (s)	1.82 ± 0.07	1.81 ± 0.05	1.81 ± 0.05	1.80 ± 0.05	1.3	0.289		0.02 (-0.23-0.22)	0.00 (-0.31-0.26)	-0.20 (-0.49-0.07)	-0.42 (-0.84-0.02)
20 m (s)	3.12 ± 0.12	3.11 ± 0.09	3.10 ± 0.11	3.08 ± 0.09	1.7	0.209		-0.24 (-0.61-0.14)	-0.10 (-0.39-0.15)	-0.20 (-0.42-0.04)	-0.55 (-1.04 -0.33)
10 m Momentum ($kg.s^{-1}$)	428 ± 49	469 ± 53	480 ± 52	490 ± 52	43.4	<0.001	1<2,3<4	0.80 (0.45-1.17)	0.21 (0.00-0.48)	0.19 (0.07-0.31)	1.22 (0.72-1.86)
Yo-Yo IRTL1 (m)	1286 ± 493	1308 ± 347	1502 ± 301	1667 ± 406	7.2	0.005	2<3,4	0.05 (-0.38-0.48)	0.60 (0.23-0.95)	0.46 (-0.18-1.04)	0.84 (-0.08– 1.50)
Vertical Jump (cm)	44.1 ± 3.8	47.8 ± 5.6	51.3 ± 6.0	52.1 ± 5.3	34.8	<0.001	1<2<3,4	0.82 (0.37-1.26)	0.53 (0.29-0.76)	0.16 (-0.13-0.35)	1.74 (0.89-2.42)
Bench Press (kg)	76.5 ± 15.9	92.7 ± 10.7	106.6 ± 11.4	114.6 ± 17.1	82.7	<0.001	1<2<3<4	1.24 (0.62-1.85)	1.26 (0.67-1.76)	0.55 (0.19-0.94)	2.30 (1.70-2.90)
Relative Bench Press (kg/kg)	0.98 ± 0.16	1.10 ± 0.13	1.24 ± 0.14	1.31 ± 0.19	46.9	<0.001	1<2<3,4	0.82 (0.30-1.28)	1.04 (0.49-1.43)	0.42 (0.13-0.79)	1.88 (1.02-2.59)
Squat (kg)	109.0 ± 23.4	124.8 ± 16.5	137.2 ± 15.7	144.9 ± 15.7	35.4	<0.001	1<2<3<4	0.88 (0.31-1.43)	0.83 (0.34-1.30)	0.49 (0.16-0.79)	1.98 (1.11-2.84)
Relative Squat (kg)	1.40 ± 0.26	1.48 ± 0.21	1.60 ± 0.20	1.66 ± 0.17	9.4	<0.001	1,2<4	0.50 (-0.03-1.03)	0.59 (0.15-1.18)	0.32 (0.06-0.61)	1.45 (0.65-2.23)
Prone Row (kg)	73.8 ± 12.2	86.3 ± 11.9	94.5 ± 10.8	100.8 ± 12.4	153.4	<0.001	1<2<3<4	1.03 (0.55-1.45)	0.80 (0.43-1.18)	0.54 (0.29-0.82)	2.19 (1.60-2.78)
Relative Prone Row (kg/kg)	0.95 ± 0.14	1.02 ± 0.10	1.09 ± 0.10*	1.15 ± 0.11	33.8	<0.001	1,2<3<4	0.57 (0.13-0.96)	0.79 (0.39-1.26)	0.57 (0.28-0.80)	1.66 (0.92-2.39)

Note: Data are presented as mean ± SD. The numbers in parentheses in the column headings relate to the numbers used for illustrating significant (p<0.05) differences in the post-hoc analysis between age categories.

Table 4. Mean, SD, Range and CV of the percentage change of anthropometric and physical characteristics between Under 16 and Under 19 annual-age categories

	U16-U19 % Change	CV
Height (%)	1.6 ± 0.7 (0.5 - 3.4)	45.0%
Body Mass (%)	12.8 ± 7.2 (1.3 - 26.1)	56.2%
Sum of four Skinfolds (%)	-0.9 ± 23.2 (-34.6 - 48.0)	2700.2%
10 m (%)	-1.4 ± 2.7 (-6.3 - 2.4)	189.4%
20 m (%)	-1.7 ± 2.9 (-6.8 - 3.2)	164.5%
10 m Mom (%)	14.7 ± 6.7 (5.3 - 24.3)	45.7%
Yo-Yo IRTL1 (%)	46.8 ± 66.7 (-27.0 - 172.3)	142.5%
Vertical Jump (%)	19.9 ± 10.4 (5.1 - 46.0)	52.2%
1-RM Bench Press (%)	50.0 ± 21.4 (27.3 - 98.2)	42.9%
Relative Bench Press (%)	32.2 ± 16.1 (7.2 - 66.6)	49.9%
1-RM Squat (%)	41.2 ± 22.2 (9.8 - 88.9)	53.9%
Relative Squat (%)	24.8 ± 18.9 (8.9 - 59.1)	56.2%
1-RM Prone Row (%)	40.0 ± 10.6 (23.9 - 66.7)	27.8%
Relative Prone Row (%)	22.2 ± 11.5(1.1 - 45.1)	52.0%