Strength and Conditioning Practices in Adolescent Rugby Players: Relationship with Changes in Physical Qualities

ABSTRACT

Adolescent rugby players benefit from the implementation of resistance training. However resistance training practices and how they influence short-term physical change is unknown. Therefore the purpose of this study was to quantify resistance training practices, evaluate physical development, and relate these changes to resistance training variables across 12-weeks in adolescent rugby union players. Thirty-five male adolescent rugby union players participated in the study with subjects completing an anthropometric and physical testing battery pre- and post- a 12-week in-season mesocycle. Subjects recorded resistance training frequency, exercises, repetitions, load, minutes, and rating of perceived exertion for each session using weekly training diaries during the 12-week period. Paired sample t-tests and Cohen's *d* effect sizes were used to assess change, while Pearson correlation coefficients assessed relationships between variables. Resistance training practices were variable, while significant ($p \leq 0.05$) improvements in body mass, countermovement jump (CMJ) height, front squat, bench press, and chin up strength were observed. Resistance training volume load had moderate to strong relationships with changes in CMJ (r =0.71), chin up (r =0.73) and bench press (r =0.45). Frequency of upper and lower body compound exercises had significant moderate to large relationships with changes in CMJ (r =0.68), chin up (r =0.65), and bench press (r =0.41). Across a 12-week in-season period, adolescent rugby union players have varying resistance training practices, while anthropometric and physical characteristics appear to improve. Given the observed relationships, increased volume loads through the implementation of free-weight compound exercises could be an effective method for improving physical qualities in young rugby players.

Rugby union, resistance training, strength, power

INTRODUCTION

Rugby union is a team sport characterised by high and low-intensity periods of intermittent activity involving running, static exertions, and collisions during match play (7, 29). Due to the physical qualities that underpin the match demands, high levels of strength, power, and speed are favourable, while increased mass can be beneficial for enhanced sporting performance (33). Previously these physical characteristics have been established to be strongly related to playing level and age, with professional and older adolescent players demonstrating greater levels than their non-professional (35) and younger counterparts (12). To develop these physical qualities, strength and conditioning practices are common and have been implemented with positive outcomes in both adult (1, 4, 13) and adolescent (17, 34) rugby athletes.

Despite research providing evidence that strength and conditioning training is an important aspect of an adolescent rugby player's development (17, 34, 39, 41), limited evidence exists exploring the strength and conditioning practices that adolescent rugby athletes currently undertake. To date, Hartwig et al. (18) examined the training loads of adolescent rugby union players using global positioning system (GPS) tracking devices and training diaries, quantifying on-field training (e.g., distances covered and duration) sessions. Individuals who played at the highest representative level were found to undertake larger amounts of rugby training each week, compared to their school boy counterparts, while maintaining similar distances covered in training sessions. Unfortunately, no measure of resistance training or strength and conditioning practices were undertaken, thus practices and responses within this cohort are yet to be thoroughly evaluated. Such information would be useful in helping to understand and design strength and conditioning routines that stimulate and maximise adaptations.

Existing research has investigated the physical characteristics of adolescent rugby players by age (21, 38), position (12, 41) and level (21, 36). Till et al. (38) observed that adolescent rugby players have significant annual improvements in their anthropometric and physical characteristics, which were greatest between 16 and 17 years compared to their older counterparts (18 to 20 year old) and likely demonstrate that greater changes occur in younger individuals upon the commencement of a structured training programme. This has been supported with recent work demonstrating that players who have a younger training age tend to develop at a greater rate than their more experienced counterparts (37). However, although physical changes are evident, the aforementioned studies did not provide information on the training programme and how training programme design considerations (e.g., mode, frequency, and volume of training) may have affected training adaptations. As such, it is difficult to evaluate the impact of strength and conditioning training on the relationship to changes in physical qualities based on the current available evidence. Consequently the purposes of this study were to (1) quantify the resistance training practices and (2) evaluate their relationship with changes in physical qualities across a 12-week period in adolescent rugby union players.

METHODS

Experimental approach to the Problem

Adolescent rugby players were assessed for anthropometric (height, and body mass) and physical (countermovement jump [CMJ], speed [20 and 40 metres], and three repetition maximum [3RM] strength [squat, bench press, chin ups]) characteristics pre- and post- a 12-week observational period. Testing weeks occurred when rugby games had not been scheduled, and these weeks were not included in the 12-week observational period. The 12-week period occurred in the second half of the adolescent playing season, taking place from mid-January until mid-April. During the observational period, players completed a weekly training diary for 12 weeks, which included rating of perceived exertion (RPE) of all rugby games and training, resistance training, and extracurricular activities, in addition to the duration of each session. Players also recorded all resistance training exercises, sets, repetitions, and load. The relationships between the changes in anthropometric and physical characteristics and resistance training were then undertaken.

Subjects

Thirty-five adolescent male rugby union players (mean ± SD, age: 16.9 ± 0.4 years, height: 1.78 ± 0.07 m, body mass: 80.1 ± 10.5 kg) were recruited to take part in the study. All subjects were recruited from four school rugby teams in the United Kingdom. Initially, seven rugby playing schools were approached to be involved, with four of these seven confirming that they would be willing to participate. The seven schools approached were selected as they all had access to playing and training fields, resistance training facilities, and were actively partaking in rugby practice and games. Between four to 13 boys were recruited from each school. All subjects were free from injury for the duration of the study and had at least six months resistance training experience prior to recruitment. Experimental procedures were approved by the institutional ethics committee, while assent and parental consent were provided along with permission from schools.

Procedures

Anthropometric and physical testing was completed across two testing sessions within the same week during the rugby playing season. The first testing session included anthropometric, CMJ, and sprints, while 3RM strength measures were recorded in the second. A standardised warm up which included stationary cycling, dynamic movements and stretches was completed at the end of the anthropometric measures and prior to the CMJ and sprints, as well as prior to the 3RM testing on the second day of testing. Upon the completion of the 12-week observation period, testing was repeated in the same order and at the same time of day. Subjects were instructed to rest in the 48 hours before all testing and to maintain normal dietary habits throughout the study.

Anthropometry:

Height was measured using a stadiometer (Secca Alpha, 213, Germany) to the nearest 0.1 cm. Subjects stood barefoot, facing forward with their head placed in the Frankfort plane. Body mass was measured using a Tanita BF-350 bio-impedance analyser (Tanita Corporation, Arlington Heights, IL, USA). This method has previously been validated and deemed reliable in males and females with satisfactory results of inter-day agreement (intraclass correlation =

0.978) (24). Body mass was calculated to the nearest 0.1 kg. All measures were taken post-micturition, between two and four hours post-prandial and prior to the initiation of exercise.

Countermovement Jump

Two CMJs were performed on a calibrated portable 400 Series Force Plate (Fitness Technology, Adelaide, Australia) indoors. Vertical ground reaction forces were measured with the force plate at a sampling rate of 600Hz. The force plate was connected to a laptop via USB and was calibrated with Ballistic Measurement software (BMS) (Innervations Inc., Muncie, IN). Jump variables (peak and mean power, peak and mean force, and jump height) were recorded through the software. All subjects undertook the two CMJs, with hands on hips, instructed to start in a standing position and drop to a self-selected depth before jumping as high as possible. A three-minute rest period was provided between the two attempts. This method is consistent with previous literature concerning adolescent rugby union players and has been reported to have a CV of 4.9% in the same demographic with the same equipment (12, 31). Subjects were familiarised with the movement and allowed to attempt the action prior to the first testing to reduce systematic bias.

Sprint time, velocity, acceleration and momentum

Subjects completed a 40 m straight line sprint, measured using timing gates (Brower Timing Systems, IR Emit, USA) placed at 10, 20, and 40 m on the same designated athletics track pre- and post-study. Subjects completed two maximal sprints with three minutes rest between repetitions. The fastest of the two repetitions was selected for analysis. All times were measured to the nearest 0.01 second.

Subjects commenced each sprint with their foot on a starting point, 50 cm from the light beam of the first timing gate, consistent with Coutts et al. (10) and Darrall-Jones et al (11). While 10, 20, and 40m distances were used as outcome variables, initial (0 to 10 m) and maximal (30 to 40 m) sprint momentum as used by Barr et al. (3), were measured to assess changes in momentum. Momentum was calculated by multiplying body mass by sprint velocity. The distance between two splits, divided by the change in time was used to calculate velocity. Reliability of these tests utilising a similar cohort and the same equipment has been reported to have a CV of 3.05, 1.82, and 1.33% for the 10, 20, and 40 metre sprint, respectively (11).

Three Repetition Maximum (3RM) and Relative Strength:

3RM back squat, bench press and neutral grip chin ups were completed to measure the lower and upper body strength of all subjects. The exercise choice was based on similar exercises used within resistance training programmes (10, 33). The subjects were informed of the order of testing and completed a standardised warm up, which consisted of stationary cycling, dynamic movements and stretches prior to the initiation of any external resistance. Upon the completion of the warm up, an exercise specific warm up was completed that included 8 repetitions with an empty bar (or body weight for the chin up exercise), followed by two sets of 5 repetitions, and then 3 repetitions all at submaximal self-selected loads as previously completed in adolescent resistance training literature (12). Each subject had three attempts to achieve a 3RM load, with minimum incremental increases in load being 2.5 kg, and were required to have three minutes rest between maximal attempts (12, 39).

For the back squat, subjects were required to lower themselves to a position in which the top of the thigh was at least parallel to the floor, determined by the lead researcher (12). When completing the bench press, subjects chose a self-selected hand width, lowered the bar to the chest and returned to the starting position with the arms locked without assistance. The neutral grip chin up began with subjects hanging, with arms fully extended and was completed with a 0.75kg weighted belt (Harbinger, Leather Dip Belt, USA) with external weight attached to the subject if additional load was required. They were then instructed to lift their body to a point with their chin above the chin up bar (10). 3RM strength for the chin up was recorded as the subject’s body mass plus external load.

Relative strength for all movements was calculated as total load divided by body mass. The CV of the three movements utilising the same equipment and the same subjects was reported to be 2.5, 3.7 and 3.7% for the squat, bench press and chin up (42).

Training Diaries

Training diaries were used to record all resistance training, rugby related game and training, and extracurricular exercise that took place during the 12-week observation period. Subjects were asked to record the RPE of each exercise session along with the duration of that session according to the method outlined by Foster et al. (14). As well as the session RPE and duration, subjects were required to detail all resistance training undertaken including resistance exercise, the weight used, the number of repetitions completed, and the number of sets. Total-, upper-, and lower-body volume load, weekly-training load, gym frequency, gym and non-gym (i.e. exercise that took place outside of resistance training) training duration, and upper- and lower-body exercise training frequency were all calculated using the training diaries. Diaries were checked each week for consistency and were recorded on a weekly basis.

Training load: Training load was calculated according to the method of Foster et al. (14). Throughout the 12-week observation period, the duration (in minutes) and intensity (rated on a modified Borg category ratio scale (14) that was supplied at the front of each training diary, noted 10 to 30 minutes after the cessation of exercise) were recorded by each subject after each training session (gym, rugby, and extracurricular) and match. The multiplication of the duration and intensity is known as sessional rating of perceived exertion (s-RPE). Average weekly training load was calculated as the summation of total training load across the 12 weeks, this was then averaged for the 12 weeks of the study for each subject, and provided as a mean of the cohort.

Volume load: Volume load has been used in the literature as a means to calculate total workload that is completed in a resistance training programme (16, 25). It is calculated through multiplying the weight (kg), total repetitions, and sets completed (i.e. repetitions x sets x weight (kg)). For standardisation purposes and to avoid miscalculation of work completed, only free-weight compound exercises (as explained by Baechle et al. (2)) were included in the calculation of volume load. Exercises that included pulley systems, counter balancing, and isolation exercises can be easily miscalculated due to machine differences and lack of standardisation amongst differing brands of equipment and were therefore omitted from the analysis.

Upper and lower body volume load utilised the same calculation as total volume load, however upper body volume load only incorporated exercises that used predominantly upper body musculature (e.g. bench press, chin up), while the lower body utilised exercises that predominantly exercised the lower peripheries (e.g. squat, lunge).

Frequency: Mean weekly frequency of lower/upper body lifts was calculated as the number of times that an individual completed a free weight compound exercise (i.e., those included in volume load equation) over the 12-week period and then divided by the number of weeks (i.e. 12) in the observational period.

Time: Mean weekly training time was calculated as the summation of all the minutes spent exercising throughout the week (incorporating field based training time, resistance exercise training time, personal training time, playing time, and extracurricular activities). This number was then averaged across the 12 weeks of the study for each individual and provided as a mean of the cohort.

Statistical analyses:

Data were assessed for normality and were presented as means, standard deviations (SD), and range (lowest-highest). Non-gym time, mean weekly training time, and weekly load data were all non-parametric, while all other data were normally distributed. Paired samples t-tests were used to assess the change in characteristics during the 12 week period. Significance was set at an alpha level of $P < 0.05$. Cohen's *d* effect size (8) was calculated with thresholds being set at: <0.2 (*trivial*), 0.2-0.6 (*small*), 0.61-1.2 (*moderate*), 1.21-2.0 (*large*), and >2.0 (*very large*) with corresponding 90% confidence intervals (CI). Pearson product moment correlation coefficient was used to evaluate the relationships between the change in physical qualities and training load, with descriptor thresholds set at; 0.0-0.1 (*trivial*) 0.11-0.3 (*small*), 0.31-0.5 (*moderate*), 0.51-0.7 (*large*), 0.71-0.9 (*very large*), and 0.91-1 (*nearly perfect*) (8).

RESULTS

Description of Training Loads

Table 1 shows the mean weekly training loads (i.e., frequencies, duration, volumes), and median and interquartile range (IR) of non-gym and combined training times, weekly load, and weekly strain during the 12-week observational period for adolescent rugby players.

Table 1 here

Change in Anthropometric and Physiological Characteristics

Tables 2 and 3 show the changes pre and post the 12-week observational period for anthropometric and physical characteristics in adolescent rugby union players. Significant, *small* improvements were found for body mass and while significant, yet *trivial* differences were found for CMJ mean force. All strength measures, CMJ height and maximal sprint momentum significantly improved, with *small* to *moderate* effects. All other characteristics were deemed to be non-significant with *trivial* effects, apart from CMJ mean power and peak force which recorded *small* positive effects.

Tables 2 and 3 here

Relationship between Training Volume, Frequency and Anthropometric and Physical Characteristics

Table 4 presents the relationships between training habits (i.e., training volume and frequency), and changes in anthropometric and physical characteristics. Total volume load, lower body volume load and the number of lower body exercises completed had significant *large* to *very large* relationships with CMJ height change (r = 0.68 – 0.74). Gym frequency only showed a significant *moderate* relationship with CMJ height improvement (r = 0.39).

Chin up performance improvements had significant *large* to *very large* relationships with total volume load, upper body volume load and the number of upper body exercises completed (r = 0.65 – 0.73). Bench press strength change had a significant *moderate* relationship to upper body volume load and the number of upper body exercises completed (r = 0.41 – 45). Minutes spent resistance training did not show any significant relationships with any dependent variables.

Initial sprint momentum, maximum sprint momentum, 20m sprint, and squat performance did not show significant relationships to any of the independent variables.

Table 4 here

DISCUSSION

This study aimed to establish the training practices, and anthropometric and physiological changes that occur in adolescent rugby union players over a 12 week period. Furthermore, the relationships between resistance training practices and changes in physical qualities were investigated to assist in the understanding of the complex association between training and adaptation in adolescent rugby players. Findings demonstrate highly variable training practices in adolescent rugby union players, and overall improvements in anthropometric and physical characteristics across a 12-week in-season period. Moreover, resistance training volume load and the number of compound exercises were strongly related to the change in physical characteristics. This study demonstrates the importance of resistance training practices for improving anthropometric and physical performance qualities in adolescent rugby union players.

Training Loads and Frequencies

Weekly training loads, in almost all recorded aspects of training, were highly variable which could have been suboptimal to excessive for adaptation (31). While subjects undertook 1.4 ± 0.6 gym sessions per week on average over the 12 week observational period, this is below the suggested 2-3 sessions that is thought to be optimal for the development of muscular strength in children and adolescents (5). When this is coupled alongside the relatively low weekly frequencies of upper (3.0 ± 1.7) and lower (1.5 ± 0.8) body exercises completed, and total volume loads (5443 ± 3423 AU), it is clear that adolescent rugby union players may not be participating in strength and conditioning practices that are optimal for physical adaptation.

In addition to gym training, time spent completing other activities (e.g. rugby and extracurricular training) was thought to be excessive for some individuals (range; 30 – 637 minutes). While the median of the non-gym training time was 120 minutes (IR: 151), which is much lower than previous adolescent rugby union research (19), the range illustrated the highly varying amounts of exercise that adolescents undertake. Over the 12-weeks an average for some subjects was recorded as up to 637.0 minutes (>10.5 hours) each week. When this is compared to the maximum mean time spent resistance training each week (177.0 minutes per week) it is clear that subjects' favoured non-gym related training over resistance training. While no exact optimal ratio between exercise modalities exist, prior adolescent rugby union interventions have utilised 2-3 resistance training sessions per week (17, 34) which may be superior in promoting physical adaptation.

Anthropometric and Physical change

Over the 12-week period, this study demonstrated positive changes in a range of physical characteristics. Body mass changes were consistent with seasonal changes in adolescent rugby league players (34), with changes of 2.7 ± 3.6% in the current cohort compared to 2.5 ± 4.7%. Therefore, coaches of players within this age group should expect to see increases in a player's body mass during the season. This may be due to maturation (39), with systematic increases in weight slowing as players' progress towards adulthood. It would be prudent for coaches of young players to therefore monitor changes in body mass throughout a season to assist in athletic programming, as well as aid in long term development due to the need for increasing body mass at higher playing levels due to the physical demands of the sport (12, 33). Previous research in rugby league players of a similar age from both the United

Kingdom (39) and Australia (15), have suggested that these increases in mass are related to improvements in lean body mass and fat mass content. This could also be the same for the current study. However, in stating that general improvements in body composition occur, it should be noted that due to the considerable deviation around the mean change in body mass, individual responses may widely vary (range; -3.7 – 13.9%). Therefore, coaches and conditioning staff may need to monitor changes in these characteristics to understand if players are progressing at an appropriate trajectory.

Current findings showed absolute strength improvements, were lower than previous adolescent rugby resistance training studies (17, 34). Harries et al. (33.9 - 44.5%; 17) and Smart et al. (72.5%; 34) both reported squat improvements of a larger magnitude when adolescents completed supervised, periodized resistance training. However when adolescents weren't supervised but provided the same periodized resistance training programme, strength improvements in the squat were of a lower amount (16.8%; 34). Due to the relatively similar improvements in strength in non-supervised subjects in the study by Smart et al. (34) and subjects in the current study (24.0 ± 16.9%), supervision rather than programme design may be important for adolescent athletes to maximise development, which corroborates work from Coutts et al. (10) in adolescent rugby league players. These findings suggest that the adolescent strength and conditioning coach is not only important for helping teach technique and supervise resistance exercise, but also provides improved adherence and motivation (10, 34), which results in superior physical adaptation compared to unstructured, unsupervised resistance training.

Measures of power in this study showed varying responses, with CMJ height and maximal sprint momentum showing significant, yet *small* improvements. Changes in CMJ height, which have previously been shown to occur during an "off-season" conditioning programme in under 18 rugby union players (34), corresponds well with lower body strength improvements. These improvements were not however reflected in positive sprint performance at any distance. This may be related to the "force-vector theory" (9) which proposes that squat strength more readily crosses over to CMJ than sprint performance due to loading being in the axial vector. Due to the *trivial* changes in speed, it can confidently be stated that improvements in maximal sprint momentum were most likely attributed to improvements in body mass. These changes have occurred in other rugby union and rugby league athletes of a similar age, with changes thought to be due to maturation and increased body mass of the player rather than large improvements in velocity (3, 39).

Relationships between Training Loads & Frequency and Physical Characteristic Changes

There were strong relationships between resistance training variables (i.e., volume load and number of exercises completed) and changes in physical characteristics. Strong significant relationships were found between exercise frequency (quantified as the number of compound, free weight exercises completed) and resistance training volume load, and improvements in lower body power and force, and upper body strength (Table 4). While this study is not the first to demonstrate the relationship between volume load and strength (22, 23), or the benefits of including free weight compound exercises in resistance training programmes (42), it does provide evidence that resistance training variables can affect the development of physical characteristics in adolescent rugby players.

There were no significant relationships between changes in physical characteristics with gym frequency and the amount of time spent resistance training. While minutes spent resistance training did border on moderate improvements in chin up strength ($r = 0.33$), the lack of significance and the relatively weak relationships suggests that other resistance training variables may have a greater role in the improvement of physical traits than frequency and time alone. In this study volume load was calculated using free weight compound exercises, which suggests that when aiming to efficiently increase resistance training volume load, these types of exercises should be used. When the back squat (a free weight, compound exercise) and leg press (a machine based compound exercise) have previously been compared (32), total work (total work = volume load x displacement) has been significantly ($p < 0.05$) greater in the squat at the same relative intensities of repetition maximum, while producing larger testosterone, growth hormone, and lactate responses. Interestingly however, RPE between the two exercises was not significantly different, which suggests that when completing free weight compound exercises total work diverges from the internal perception of intensity when compared to machine based exercises (32). Previous literature assessing the role of time and efficiency within resistance training programmes proposes that volume load and exercise intensity can be maintained in time constrained periods when appropriately structured protocols are employed (26-28). The strength and conditioning coach should therefore be aware of the relationship between physical improvement, time and volume, and implement resistance training programmes which are being monitored through means of efficiency (i.e. volume load per unit of time) (26). These methods can then be progressed through either increasing the total volume load while maintaining time, or decreasing the time allotted to the session.

While this study is the first of its kind, it is not without its limitations that might reduce transferability of current findings to real life practice. Firstly, due to the relatively small sample size used, the findings may not be applicable to all individuals due to differing positional demands and maturation. Till et al. (39) showed that adolescent rugby league players develop at differing rates and therefore it would be imprudent to suggest that changes in the current study can be extrapolated to all adolescent rugby union players of a similar age. Furthermore, training age and experience has been related to differing rates of physical change in adolescent rugby league players (37) which could further confound potential relationships. Secondly, due to the lack of mid-study measures, it is not possible to identify when in the 12-week period that changes in physical performance occurred. Finally, this study utilised training diaries to assist with the recording of training and game data. It is acknowledged and accepted that there are limitations of this method with regards to compliance (20) and burden on the players (6), yet it was decided that due to other commitments and reliability, this would be the most time efficient and practical method of attaining data.

In conclusion, this study presents the training practices, anthropometric and physical characteristics, and changes in traits related to resistance training across 12 weeks in adolescent rugby union players. The findings have demonstrated that large variance occurs in the frequency, time and load of exercise that is undertaken by under 18-year-old rugby players. Physical characteristics were shown to have positive trends that imply that body mass, lower body power, strength and momentum improve within a season, while sprint ability did not appear to improve to the same extent. Resistance training, the type of exercise selected, and the volume load completed with these exercises showed strong to very strong relationships with improved physical characteristics, while on the other hand gym frequency and the amount of time spent resistance training demonstrated relatively weak relationships. This study suggests that adolescent rugby union players should undertake appropriate amounts of resistance training to support their physical development, however practitioners should be aware of the large amount of inter-individual variation that can occur due to individual response, training age, and maturation status.

PRACTICAL APPLICATION

An adolescent rugby players' time is often split between school, social demands, and sport. For this reason it is important that training is time efficient and effective with current findings showing that these young athletes complete varying quantities of training and playing which can differ due to the player, week, and stage of the season. For this reason it could be suggested that appropriate monitoring of training loads could benefit players so that optimal adaptation can occur. As well as this, structured planning of training loads throughout the season, which take into account specific goals may assist in the adaptation of preferential anthropometric and physiological characteristics. Furthermore, it has been shown that a number of resistance training variables can greatly enhance physical adaptation. The frequency with which compound exercises are completed, and with what volume is used has been strongly linked to improvements in desirable traits and should be of emphasis for the strength and conditioning coach. Meanwhile frequency of attending the gym and the number of minutes spent resistance training had weak relationships with change. This indicates that training efficiency is of importance and that manipulating resistance training methods so that sufficient volume loads and number of exercises can be completed in time constrained periods could be of benefit to the young player.

References:

1. Argus CK, Gill ND, Keogh JW, McGuigan MR, and Hopkins WG. Effects of two contrast training programs on jump performance in rugby union players during a competition phase. *Int J Sports Physiol Perform* 7: 68-75, 2012.
2. Baechle TR, Earle RW. Essentials of Strength Training and Conditioning. Human Kinetics, 2008.
3. Barr MJ, Sheppard JM, Gabbett TJ, and Newton RU. Long-term training-induced changes in sprinting speed and sprint momentum in elite rugby union players. *J Strength Cond Res* 28: 2724-2731, 2014.
4. Beaven CM, Gill ND, Ingram JR, and Hopkins WG. Acute salivary hormone responses to complex exercise bouts. *J Strength Cond Res* 25: 1072-1078, 2011.
5. Behringer M, vom Heede A, Yue Z, and Mester J. Effects of resistance training in children and adolescents: a meta-analysis. *Pediatrics* 126: 1199-1210, 2010.
6. Bratteby L, Sandhagen B, Fan H, and Samuelson G. A 7-day activity diary for assessment of daily energy expenditure validated by the doubly labelled water method in adolescents. *Eur J Clin Nutr* 51: 585-591, 1997.
7. Cahill N, Lamb K, Worsfold P, Headey R, and Murray S. The movement characteristics of English Premiership rugby union players. *J Sport Sci* 31: 229-237, 2013.
8. Cohen J. Statistical Power Analysis for the Behavioral Sciences. L. Erlbaum Associates, 1988.
9. Contreras B, Vigotsky AD, Schoenfeld BJ, Beardsley C, McMaster DT, Reyneke J, and Cronin J. Effects of a six-week hip thrust versus front squat resistance training program on performance in adolescent males: A randomized-controlled trial. *J Strength Cond Res* (ahead of press) DOI: 10.1519/JSC.0000000000001510.
10. Coutts AJ, Murphy AJ, and Dascombe BJ. Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players. *J Strength Cond Res* 18: 316-323, 2004.
11. Darrall-Jones JD, Jones B, Roe G, and Till K. Reliability and Usefulness of Linear sprint testing in adolescent Rugby Union and League players. *J Strength Cond Res* 30:1359-1364, 2016.
12. Darrall-Jones JD, Jones B, and Till K. Anthropometric and Physical Profiles of English Academy Rugby Union Players. *J Strength Cond Res* 29: 2086-2096, 2015.
13. Dobbs CW, Gill ND, Smart DJ, and McGuigan MR. The training effect of short term enhancement from complex pairing on horizontal and vertical countermovement and drop jump performance. *J Strength Cond Res* (ahead of press) DOI: 10.1519/JSC.0000000000000874.
14. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, and Dodge C. A new approach to monitoring exercise training. *J Strength Cond Res* 15: 109-115, 2001.
15. Gabbett TJ. Physiological and anthropometric characteristics of starters and non-starters in junior rugby league players, aged 13-17 years. *J Sports Med Phys Fitness* 49: 233-239, 2009.
16. Haff GG. Quantifying Work Loads in Resistance Training: a Brief Review. *UKSCA J* 19: 31-40, 2010.

17. Harries SK, Lubans DR, and Callister R. Comparison of resistance training progression models on maximal strength in sub-elite adolescent rugby union players. *J Sci Med Sport* 19: 163-169, 2016.
18. Hartwig TB, Naughton G, and Searl J. Defining the volume and intensity of sport participation in adolescent rugby union players. *Int J Sports Physiol Perform* 3: 94-106, 2008.
19. Hartwig TB, Naughton G, and Searl J. Motion analyses of adolescent rugby union players: a comparison of training and game demands. *J Strength Cond Res* 25: 966-972, 2011.
20. Hopkins WG. Quantification of training in competitive sports. *Sports Med* 12: 161-183, 1991.
21. Kobal R, Nakamura FY, Moraes JE, Coelho M, Kitamura K, Cal Abad CC, Pereira LA, and Loturco I. Physical performance of brazilian rugby players from different age-categories and competitive levels. *J Strength Cond Res* 30: 2433-2439, 2016.
22. Krieger JW. Single versus multiple sets of resistance exercise: a meta-regression. *J Strength Cond Res* 23: 1890-1901, 2009.
23. Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. *J Strength Cond Res* 24: 1150-1159, 2010.
24. Loenneke JP, Barnes JT, Wilson JM, Lowery RP, Isaacs MN, and Pujol TJ. Reliability of field methods for estimating body fat. *Clin Physiol Funct Imaging* 33: 405-408, 2013.
25. Peterson MD, Pistilli E, Haff GG, Hoffman EP, and Gordon PM. Progression of volume load and muscular adaptation during resistance exercise. *Eur J Appl Physiol* 111: 1063-1071, 2011.
26. Robbins DW, Young WB, and Behm DG. The effect of an upper-body agonist-antagonist resistance training protocol on volume load and efficiency. *J Strength Cond Res* 24: 2632-2640, 2010.
27. Robbins DW, Young WB, Behm DG, and Payne WR. The effect of a complex agonist and antagonist resistance training protocol on volume load, power output, electromyographic responses, and efficiency. *J Strength Cond Res* 24: 1782-1789, 2010.
28. Robbins DW, Young WB, Behm DG, Payne WR, and Klimstra MD. Physical performance and electromyographic responses to an acute bout of paired set strength training versus traditional strength training. *J Strength Cond Res* 24: 1237-1245, 2010.
29. Roberts SP, Trewartha G, Higgitt RJ, El-Abd J, and Stokes KA. The physical demands of elite English rugby union. *J Sports Sci* 26: 825-833, 2008.
30. Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, and Jones B. Between-Day Reliability and Sensitivity of Common Fatigue Measures in Rugby Players. *Int J Sports Physiol Perform* 11: 581-586, 2016.
31. Rogalski B, Dawson B, Heasman J, and Gabbett TJ. Training and game loads and injury risk in elite Australian footballers. *J Sci Med Sport* 16: 499-503, 2013.
32. Shaner AA, Vingren JL, Hatfield DL, Budnar RG, Jr., Duplanty AA, and Hill DW. The acute hormonal response to free weight and machine weight resistance exercise. *J Strength Cond Res* 28: 1032-1040, 2014.

33. Smart D, Hopkins WG, Quarrie KL, and Gill N. The relationship between physical fitness and game behaviours in rugby union players. *Euro J Sport Sci* 14 Suppl 1: 8-17, 2014.
34. Smart DJ and Gill ND. Effects of an off-season conditioning program on the physical characteristics of adolescent rugby union players. *J Strength Cond Res* 27: 708-717, 2013.
35. Smart DJ, Hopkins WG, and Gill ND. Differences and changes in the physical characteristics of professional and amateur rugby union players. *J Strength Cond Res* 27: 3033-3044, 2013.
36. Till K, Cobley S, O'Hara J, Morley D, Chapman C, and Cooke C. Retrospective analysis of anthropometric and fitness characteristics associated with long-term career progression in Rugby League. *J Sci Med Sport* 18: 310-314, 2015.
37. Till K, Darrall-Jones J, Roe G, Weakley J, and Jones B. The influence of training age on the annual development of physical qualities within academy rugby league players. *J Strength Cond Res* (ahead of press) DOI: 10.1519/JSC.0000000000001546.
38. Till K, Jones B, Darrall-Jones J, Emmonds S, and Cooke C. Longitudinal development of anthropometric and physical characteristics within academy rugby league players. *J Strength Cond Res* 29: 1713-1722, 2015.
39. Till K, Jones B, Emmonds S, Tester E, Fahey J, and Cooke C. Seasonal changes in anthropometric and physical characteristics within English academy rugby league players. *J Strength Cond Res* 28: 2689-2696, 2014.
40. Till K, Jones B, and Geeson-Brown T. Do physical qualities influence the attainment of professional status within elite 16-19 year old rugby league players? *J Sci Med Sport* 19: 585-589, 2015.
41. Till K, Tester E, Jones B, Emmonds S, Fahey J, and Cooke C. Anthropometric and physical characteristics of english academy rugby league players. *J Strength Cond Res* 28: 319-327, 2014.
42. Wirth K, Hartmann H, Sander A, Mickel C, Szilvas E, and Keiner M. The Impact of Back Squat and Leg-Press Exercises on Maximal Strength and Speed-Strength Parameters. *J Strength Cond Res* 30: 1205-1212, 2016.