Title: The influence of preseason training phase and training load on body composition and its relationship with physical qualities in professional junior rugby league players.

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Abstract

This study investigated changes in body composition in relation to training load determined using RPE and duration (sRPE), and its relationship with physical qualities over a preseason period. Sixteen professional academy players (age = 17.2 ± 0.7 years; stature = 179.9 ± 4.9 cm; body mass = 88.5 ± 10.1 kg) participated in the study. Body composition was assessed before and after each training phase and physical qualities assessed at the start and end of preseason. Across the whole preseason period, skinfold thickness, body fat percentage and fat mass were *most likely* lower (ES = -0.73 to -1.00), and fat free mass and lean mass were *likely to most likely* higher (ES = 0.31 to 0.40). Results indicated that the magnitude of change appeared phase-dependent (ES = -0.05 to -0.85) and demonstrated large individual variability. Changes in physical qualities ranged from *unclear* to *most likely* (ES = -0.50 to 0.64). Small to moderate correlations were observed between changes in body composition, and TL with changes in physical qualities. This study suggests training phase and TL can influence a player's body composition; that large inter-participant variability exists; and that body composition and TL are related to the change in physical qualities.

Key Words: Collision sport, performance, skinfolds, nutrition.

Introduction

Rugby league is a high-intensity intermittent collision sport, requiring players to possess well-developed speed, strength, power and intermittent running capacity to cope with the demands of training and match-play (Johnston, Gabbett & Jenkins, 2014). Such physical qualities are routinely measured and used to ensure players are conditioned appropriately to perform rugby-specific skills (Gabbett, Jenkins & Abernethy, 2010), evaluate adaptation to training programmes (Morgan & Callister, 2011), talent identification (Johnston et al., 2014) and monitoring the development of players (Waldron, Worsfold, Twist & Lamb, 2014). Whilst we recognise that performance and success in rugby league might be influenced by the complex interaction of an individual's and team's technical and tactical characteristics, much focus has been given to the anthropometric, body composition and physical qualities of players (Johnston et al., 2014).

Body composition is of particular interest for both practitioners and researchers, as changes in criterion (e.g. DXA) or predictive (e.g. skinfolds) measures of body fat percentage (%BF), fat mass (FM), fat free mass (FFM) and lean mass (LM) can be indicative of adaptation to training (Gabbett et al., 2010; Bradley, Cavanagh, Douglas, Morton, & Close, 2015), physical development (Waldron et al., 2014; Jones et al., 2017) and a player's dietary intake (Smith, Jones, Sutton, King, & Duckworth, 2016). Studies examining body composition of rugby league players have reported differences between playing positions (Morehen, Routledge, Twist, Morton, & Close, 2015), performance standards (Jones et al., 2015) and phase of the competitive season (Harley, Hind, & O'Hara, 2011; Georgeson, Weeks, McLellan, & Beck, 2012). Hit-up forwards are heavier, have greater LM, FM and %BF compared to outside backs and adjustable, with small differences between the latter positions (Morehen et al., 2015). Super League players typically have lower %BF and FM, with greater total, leg and trunk LM compared to Championship players (Jones et al., 2015). Seasonal variation also indicates that FM increases and LM decreases during the latter stages of the season (Harley et al., 2011). These findings highlight the importance of body composition in rugby league and support the notion that it should be regularly monitored across the season whilst considering playing position and training status.

To develop anthropometric and physical qualities, strength and conditioning (S&C) practices are a key component in rugby league, particularly during the preseason period, where S&C coaches have 12-13 weeks to prepare players for competition. Once competition commences, the focus is largely placed on recovery, technical performance and tactical awareness, resulting in a decrease in training volume (Gabbett & Domrow, 2007). To date, several studies have explored the preseason changes in anthropometric and physical qualities in rugby league (Comfort, Haigh, & Matthews, 2012; Morgan & Callister, 2011; Gabbett & Domrow, 2007), suggesting this period is effective for reducing fat mass (-0.6 kg) and percentage body fat (-1.0%), and promoting muscle mass (0.7 kg) in rugby league players (Morgan & Callister, 2011). Furthermore, Comfort et al. (2012) observed improvements in sprint times across 5, 10 and 20 m as well as greater relative strength (1.78 ± 0.27 *cf.* 2.05 ± 0.21 $kg \cdot kg^{-1}$). These results concur with those of Argus et al. (2010) who observed reductions in skinfold thickness and FM, and a small increase in FFM after only 6 weeks of rugby union preseason training, which coincided with increases in bench press and box squat. Whilst comparisons between codes should be made with caution, these findings suggest that preseason training ranging from 6 to 13 weeks is effective for promoting changes in body composition.

Typically, the preseason comprises 3-4 periodised phases of varying length (Morgan & Callister, 2011). Each phase will vary depending on the coach, though typically focus on aerobic and anaerobic conditioning, sprinting mechanics, muscular strength and power, flexibility, and rugby-specific skills (Morgan & Callister, 2011; Weakley et al., 2017). Whilst previous research has reported the pre- to post-preseason change in body composition, to our knowledge no one has reported the change in relation to the training phase and training load within each periodised block. How these changes in body composition and training load relate to changes in physical qualities is of interest to support future programming and enable sports nutritionist and players to periodise energy and macronutrient intake (Close, Hamilton, Philp, Burke, & Morton, 2016). Therefore, the aims of this study were threefold: 1). To determine the effects of training phase and training load on group and individual changes in body composition, 2). To explore the individual variability of the change in body composition, and 3). To assess the relationship between the overall changes in body composition, total training load and measures of physical qualities.

Methods

Participants

With institutional ethics approval, 16 academy rugby league players (forwards = 8; backs = 8) from a single professional club playing in the Under-19s Super League competition (age, 17.2 ± 0.7 years; stature = 179.9 ± 4.9 cm; body mass 88.5 ± 10.1 kg) participated in this study. Players were familiar with all testing procedures and were informed of the benefits and risks associated with this study before providing written informed consent and completing a pre-test health questionnaire. Parental assent was obtained for participants <18 years old. Only players free of injury during the whole preseason period, as confirmed by the club's medical team, were included.

Study design

A repeated measures design was used to investigate the changes in body mass, skinfold thickness, %BF, FM, FFM and LM as well as measures of physical qualities. Training load (TL) was recorded for every session and used to assess the relationship between TL and changes in body composition with the change in physical qualities. The preseason training was prescribed by the club's strength and conditioning coach and was divided into three phases (phase 1 = 5 weeks, phase 2 = 4 weeks, phase 3 = 4 weeks + 1-week taper), with the end of phase 1 and start of phase 2 interspersed by a 10-day rest period. A 'typical' week is presented in Table 1. Assessments of body composition were taken before and after each training phase and physical qualities assessed the week before preseason training started and one week before their first competitive fixture. All physical qualities were measured on the club's own artificial pitch by the same researcher.

**** INSERT TABLE 1 HERE ****

Methodology

Body Composition

An International Society for the Advancement of Kinanthropometry (ISAK) protocol was used and the same assessor conducted all measurements (intra-rater reliability CV = 0.3-1.3%). Stretch stature was measured using a portable stadiometer (Seca, Leicester Height Measure, Hamburg, Germany) to the nearest 0.1 cm, and body mass (Seca, 813, Hamburg, Germany) to the nearest 0.1 kg. Skinfold thickness was assessed using Harpenden calipers (Harpenden, Burgess Hill, UK) on the right side of the body and included seven sites (triceps, subscapular, biceps, supraspinale, abdominal, thigh, calf). All measures were taken in duplicate with the mean value used, unless the differences exceeded 5%, whereby a third measurement was taken and the median value used. Body density was calculated (Withers et al., 1985) before the following equation was applied to covert body density to %BF: %BF = (495/body density)-450 (Siri 1956). Fat free mass (body mass – FM) was then calculated using the equation: FFM = body mass - (body mass * %BF)/100. Lean mass index was also used to quantify proportional changes in LM using the equation M/S^x; where M is the log transformed body mass in kilograms, S is log transformed skinfold thickness in millimetres and x represents an exponent for rugby union backs (0.14) (Slater, Duthie, Pyne & Hopkins, 2006).

Sprint performance and momentum

Sprint performance was measured using electronic timing gates (Brower, Speedtrap 2, Brower, Utah, USA) positioned at 0, 10 and 20 m. Participants began each sprint from a two-point athletic stance with their driving foot placed 30 cm behind the start line. Participants performed two maximal 20 m sprints recorded to the nearest 0.01 s with two minutes recovery. The best 10 and 20 m sprint times were used for analysis (CV = 4.2 and 3.6%, respectively). Momentum was calculated by multiplying body mass by mean velocity (distance / time) over the best 10 and 20 m times (Darrall-Jones, Jones, & Till, 2015). Sprint performance and momentum over these distances are reported to be reliable (Dobbin, Hunwicks, Highton, & Twist, 2017).

Change of direction

Change of direction (CoD) performance was measured using electronic timing gates (Brower, speedtrap 2, Brower, Utah, USA) placed 150 cm apart and at a height of 90 cm, and required participants to complete two trials (left and right) consisting of different cutting manoeuvres over a 20 x 5 m course with markers position at 0, 5, 15 and 20 m (see Dobbin et al. 2017). Participants started when ready from a two-point athletic stance with their driving foot placed 30 cm behind the start line and the times from the left and right were combined and used for analysis (CV = 2.5%) (Dobbin et al., 2017).

Countermovement Jump

Participants completed two countermovement jumps (CMJ) with their hands placed on the hips and two minutes recovery between jumps. Participants started upright before flexing at the knee to a self-selected depth and then extending into the jump striving for maximal height keeping their legs straight throughout. Jump height was recorded using a jump mat (Just Jump System, Probotics, Huntsville, Alabama, USA) and corrected (Dobbin, Hunwicks, Highton, & Twist, 2016) before peak height was used for analysis (CV = 5.9%) (Dobbin et al., 2017).

Medicine ball throw

To measure whole-body power, participants began standing upright with a medicine ball (dimensions: 4 kg, 21.5 cm diameter) above their head before lowering the ball towards their chest, squatting down to a self-selected depth and extending up onto their toes pushing the ball as far as possible. Feet remained shoulder width apart, stationary and behind a line that determined the start of the measurement. The distance was measured to the nearest centimetre using a tape measure from the start line to the rear of the ball's initial impression on the 3G surface. A trial was not recorded if the participant stepped into the pass, jumped or if the ball landed outside of the measuring area and, in such cases, an additional trial was completed. Participants completed two trials separated by 2-minutes recovery with the furthest distance used for analysis (CV = 9.0%; Dobbin et al., 2017).

Prone Yo-Yo Intermittent Recovery Test Level 1

The prone Yo-Yo IR1 was used to measure rugby-specific high-intensity intermittent running ability and required participants to complete as many 40 m (2 x 20 m) shuttles as possible with a 10 s active recovery (walking) between shuttles. Running speed for the test commenced at

10 km·h^{-1} and increased 0.5 km·h^{-1} approximately every 60 s to the point at which the participants could no longer maintain the required running speed. Unlike the traditional Yo-Yo IR1, participants were required to start each 40 m shuttle in a prone position with their head behind the start line and legs straight, and were allowed two practice shuttles before starting the test. The final distance achieved was recorded after the second failed attempt to meet the start/finish line in the allocated time (CV = 9.9%; Dobbin et al., 2017).

Training Load

Thirty minutes after training, away from teammates and coaches, participants were asked to provide a rating of perceived exertion (RPE) for each activity (i.e. gym, skills, conditioning) using 10-point scale, which was subsequently multiplied by duration in minutes to provide a measure of training load (sRPE; Foster et al., 2001).

Statistical Analysis

Data are presented as mean ± standard deviation (SD). Magnitude-based inferences (MBI) and effect sizes with 90% confidence limits were used, with effect sizes calculated as the difference between trials divided by the pooled SD for all assessments. This approach was applied to the body composition data to assess the pre-to-post change within each training phase and overall changes (pre-phase 1 to post-phase 3) in body composition measures and physical qualities. Threshold values for effect sizes were: 0.0-0.2, *trivial*; 0.2-0.6, *small*; 0.6-1.2, *moderate*; 1.2-2.0, *large*; >2.0, *very large*. Threshold probabilities for a mechanistic effect based on the 90% confidence limits were: 25-75% *possibly*, 75-95% *likely*, 95-99% *very likely* and > 99.5 *most likely* (Batterham & Hopkins, 2006). Effects with confidence limits spanning a likely small positive or negative change were classified as *unclear*. To determine if a change in body composition was practically meaningful when considering the researcher's reliability, the smallest worthwhile changes (0.2 * pooled SD) was added to the coefficient of variations [(TE / grand mean) x 100] to give 75% confidence likely change. To ascertain the relationship between the overall (i.e. pre-phase 1 to post-phase 3) change in body composition measures, TL and changes in physical qualities, Pearson's correlation (*r*) was used with the following criteria applied: < 0.1, *trivial*; >0.1-0.3, *small*; >0.3-0.5, *moderate*; >0.5-0.7, *large*; >0.7-0.9, *very large*; and >0.9-1.0, *almost perfect* and the coefficient of determination included. Statistical analysis was conducted using a predesigned spreadsheet for comparing means (Hopkins, 2006) and correlations coefficient and coefficient of determination (Hopkins 2015).

Results

Players' completed 90 ± 7% of total sessions during the preseason period. Phase 1 consisted of 37 ± 1 sessions (14 ± 1 resistance, 12 ± 2 conditioning and 11 ± 1 rugby) and an accumulated TL of 11018 ± 1130 AU (4288 ± 517 resistance, 4206 ± 513 conditioning and 2525 ± 490 AU rugby). Phase 2 included 26 ± 6 sessions (11 ± 2 resistance, 7 ± 2 conditioning and 8 ± 2 rugby) and resulted in a total TL of 7493 ± 1322 AU (3126 ± 658 resistance, 1926 ± 332 conditioning, 2441 ± 521 AU rugby). The final phase consisted of 25 ± 2 sessions (10 ± 2 resistance, 4 ± 1 conditioning and 11 ± 2 rugby) and an accumulated TL of 4159 ± 839 AU (1788 ± 373 resistance, 331 ± 111 conditioning, 2051 ± 482 AU rugby).

INSERT TABLE 2 ABOUT HERE

Mean body composition before and after each training phase as well as the whole period are presented in Table 2. Individual changes in body mass, skinfold thickness, %BF, FM, FFM and LM are presented for each training phase in Figure 1 and 2.

INSERT FIGURE 1 ABOUT HERE

*** INSERT FIGURE 2 ABOUT HERE***

Changes in 10- and 20 m sprint time over the preseason period were *unclear.* Ten and twenty-metre momentum were *possibly* lower and of trivial and small magnitude, respectively. A small to moderate effect was observed for countermovement jump, power pass and prone Yo-Yo IR1 scores, which were considered *very* to *most likely* higher after the preseason period. Change of direction time was *very likely* lower and of a small magnitude after the preseason period (Table 3).

INSERT TABLE 3 ABOUT HERE

The correlation coefficient and coefficient of determinations between changes in body composition and TL with changes in physical qualities are presented in Table 4.

INSERT TABLE 4 ABOUT HERE

Discussion

This study sought to determine the changes in body composition in relation to training phase and TL, and establish if a relationship existed between body composition and TL with changes in physical qualities over the preseason period. The principle findings were that preseason training phase influenced the change in body composition, with greater changes observed during phase 1 when training load was highest. Results also indicated large individual variability in changes of body composition and that these changes were correlated with the change in physical qualities.

Mean data revealed that changes in total body mass across each phase and the entire preseason were *most likely trivial,* which might be explained by the contrasting changes in FM and FFM and the inclusion of forward and backs. For example, Morgan & Callister (2011) observed a 0.9 kg increase in body mass for rugby league backs, whereas forwards reported a reduction of 0.3 kg during a 14-week preseason period. However, it is important to acknowledge the 'individual' when interpreting such data as demonstrated in phase one where the percentage change in body mass ranged from -3.8% to 4.1%. Interestingly, the results show that the direction of change for body mass was, for the most part, consistent for each participant (i.e. if they increased in body mass during phase 1, they did for all phases). This possibly indicates that the participants' nutritional intake remained stable across the preseason period regardless of TL and has important implications for those players who need to adjust their energy intake to increase/decrease body mass to optimize performance and reduce injury risk (Smith et al., 2016).

A reduction in skinfold thickness was observed after phase 1 and 2 but not phase 3. Over the entire preseason, a moderate change was observed in skinfold thickness reaffirming work of Bradley et al. (2015) and Morgan and Callister (2011) in rugby union and rugby league, respectively. At the individual level, our results indicate that phase 1 and 2, both of which had the highest TL, elicited *most likely* reductions in skinfold thickness, though during phase 3 the changes was somewhat more variable with some individuals increasing their skinfold thickness by 1.3 to 18.3%. Furthermore, the mean absolute and relative body fat were comparable to that reported for Super League players (Morehen et al., 2015; Jones et al., 2015), though it is important to recognise the methodological differences between studies. The overall change in %BF (-3.4%) and FM (-3.3 kg) were larger than that previously observed in rugby union

(Bradley et al., 2015; Argus et al., 2010; Smart & Gill, 2013) and rugby league (Morgan & Callister, 2011) players, and might reflect the longer preseason period and large emphasis on conditioning during phase 1. This finding might also be explained by the training age of the participants as it is known that chronological age, biological maturity and training experience can influence the magnitude of adaptation observed in youth rugby league players (Till, Darrall-Jones, Weakley, Roe & Jones, 2017). Almost all players continued to reduce their body fat during phase 2 potentially owing to the higher TL, though changes during phase 3 were considered trivial. Over a competitive season it has been reported that %BF and FM increases towards the end of the season due to a reduced TL (Harley et al., 2011; Georgeson et al., 2012). Our results suggest that some individuals increased body fat when TL was reduced towards the end of preseason. In these situations, it is essential players and staff are aware of the energy requirements for each individual to ensure optimum performance during different stages of the preseason period as an increase in %BF and FM is likely to be detrimental to rugby performance (Jones et al., 2017; Harley et al., 2011; Georgeson et al., 2012).

Given the physicality of rugby league and the requirements to dominate an opponent during a tackle, increasing lean mass is a key focus during the preseason period (Harley et al., 2011). The assessment of whole body or regional LM is impractical given it requires access to expensive and sophisticated equipment (i.e. DXA) that is not readily available in the applied setting. As such, the use of skinfold measurements and predictive equations for fat free mass and lean mass index has been used and relate (r = 0.97 and r = 0.97, respectively) to criterion measures of FFM (Delaney et al., 2016). Our results indicate a greater FFM compared to adolescent rugby union players (Smart & Gill, 2013) and semi-professional rugby league players (Morgan & Callister, 2011) but lower than professional rugby union players (Bradley et al., 2015; Argus et al., 2010). Over the preseason period, FFM increased by 2.3 kg on average, with *most likely* increases occurring during phase 1. However, assessing the individual responses, one participant decreased FFM by approximately 2%, suggesting further training or nutritional support (i.e. protein consumption) might be required. This is particularly pertinent in light of the poor nutritional knowledge amongst rugby players (Walsh, Cartwright, Corish, Sugrue, & Wood-Martin, 2011). Responses during phase 2 and 3 were considered *most likely trivial* and demonstrated large inter-participant variability. Lean mass index represents the changes in body mass adjusted for changes in skinfold thickness and provides some insight into an individual's LM status. Our results indicate that mean LM increased by 0.8 kg over the preseason period, reaffirming existing observations of 0.8 and 0.7 kg increases in lean mass in rugby league forwards and backs, respectively, over a similar period (Morgan and Callister, 2011). Furthermore, the percentage change observed in this study (~2.4%) is consistent with that recommended by Jones et al. (2017) to stay in positive balance after consideration for the 1-2% loss over a competitive season (Harley et al., 2011; Georgeson et al., 2012). However, our results suggest that some players might be approaching the season sub-optimally given the association LM has with several physical qualities; and therefore, nutrition, TL and the contents of each training phase requires consideration in order to maximise performance and reduce injury risk.

Changes in 10- and 20 m sprint times were considered *unclear* between the two assessments and agree with Weakley et al. (2017), who observed trivial changes in rugby union players sprint time after a 12-week preseason period. That body mass was lower after preseason likely explains the *possibly* lower 10- and 20 m momentum scores, though the magnitude of change was considered trivial and small, respectively. Trivial to small correlations existed between changes in body composition and sprint time whereas, small to large correlations were observed with TL and changes in sprint time. Countermovement jump height was *very likely* higher after the preseason period, which is agreement with previous research (Weakley et al., 2017; Smart & Gill, 2013). Further, moderate correlations were observed between resistance, skills and total TL with changes in CMJ height. Similarly, Weakley et al. (2017) reported *very large* correlations between the percentage change in CMJ height and total TL, supporting the notion that practitioners should ensure sufficient TL is provided through resistance training and rugby-specific skills (i.e. wrestling) to develop lower-body power. Medicine ball throw performance was *most likely* higher after preseason and was positively correlated with resistance TL, which agrees with Weakley et al. (2017). Change of direction times were *very likely* lower after the preseason period with small to moderate positive correlations between changes in some measures of body composition. A *most likely* improvement in prone Yo-Yo IR1 performance was elicited over the preseason period and was higher than the required change for 75% confidence previously reported (Dobbin et al., 2017). Small negative correlations were observed for changes in body mass, skinfold thickness, FM and %BF with the change in prone Yo-Yo IR1 distance, indicating that body mass and excessive body fat might be detrimental for high-intensity intermittent running. These results concur previous work in soccer where a relationship between sRPE-TL and time to exhaustion during the Montreal Track test, lower-body power and sprint performance was observed in junior soccer players (Gill-Rey, Leaun, Los Arcos, 2015). In all, the result indicated that changes in body composition over the entire preseason period as well as training load accumulated can influence the anthropometric and physical qualities of youth rugby league players.

Our results support the notion that TL and the change in body composition can influence physical qualities in rugby league players, though there are some limitations. Dietary intake was not monitored in this study and a single club was used. Therefore, future research might determine the nutritional intake of rugby league players across the preseason period using multiple clubs and explore how this influences measures of body composition. Whilst we have provided the coefficient of determination between variables, future analysis might use a larger sample size and consider step-wise regression to understand the extent to which the change in measures of physical qualities can be explained by changes in body composition and TL. Finally, this study used sRPE to determine training load, which might not fully reflect the psychophysiological construct associated with certain activities and therefore more detailed analyses combining microtechnology and differential RPE to quantify training load (McLaren, Smith, Spears & Weston, 2017) might be considered in the future.

Conclusion

For the first time, we provide evidence that training phase and TL is important to consider when assessing body composition during the preseason period in rugby league players. These findings have practical implications for strength and conditioning staff working to develop the physical attributes of rugby league players, and suggest that coaches should provide sufficient TL to optimise body composition and monitor player's dietary intake during the preseason period, particularly during the latter stages. These results support previous work and show large inter-participant variability and therefore suggest that practitioners within rugby league should consider the 'individual' rather than group means. Finally, given the influence changes in body composition and TL can have on improvements in physical qualities over a specified training phase, optimising body composition and providing sufficient TL should be a priority for practitioners.

References

1. Argus, C. K., Gill, N., Keogh, J., Hopkins, W. G., & Beaven, C. M. (2010). Effects of a short-term pre-season training programmes on the body composition and anaerobic performance of professional rugby union players. *Journal of Sport Science, 28*(6), 679-686.
2. Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inference about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1): 50-57.
3. Bradley, W. J., Cavanagh, B. P., Douglas, T. F., Morton. J. P., & Close G. L. (2015). Quantification of training load, energy intake, and physiological adaptation during a rugby preseason: a case study from an elite European rugby union squad. *Journal of Strength Conditioning Research, 29*(2), 534-544.
4. Close, G. L., Hamilton, D. L., Phil, A., Burke, L. M., Morton, J. P. (2016). New strategies in sport nutrition to increase exercise performance. *Free Radical Biology and Medicine, 98*, 144-158.
5. Comfort, P., Haigh, A., & Matthews, M. J. (2012). Are changes in maximal squad strength during preseason training reflected in changes in sprint performance in rugby league players? *Journal of Strength Conditioning Research, 26*(3), 772-776.
6. Darrall-Jones, J. D., Jones, B., (2015). Till, K. Anthropometric and physical profiles of English academy ruby union players. *Journal of Strength and Conditioning Research, 29*(8), 2086-2096.
7. Delaney, J. A., Thornton, H. R., Scott, T. J., Ballard, D. A, Duthie, G. M., Wood, L. G., Dascombe, B. J. (2016). Validity of skinfold-based measures for tracking changes in body composition in professional rugby league players. *International Journal of Sports Physiology and Performance*, *11*, 261-266.
8. Dobbin, N., Hunwicks, R., Highton, J., & Twist C. (2017). Reliable testing battery for assessing physical qualities of elite academy rugby league players. *Journal of Strength Conditioning Research.* Advanced online publication. doi: 10.1519/JSC.0000000000002280.
9. Dobbin, N., Hunwicks, R., Highton, J., & Twist, C. (2016). Validity of a jump mat for assessing countermovement jump performance in elite rugby players. *International Journal of Sport Medicine, 38*(2), 99-104.
10. Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doeshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength Conditioning Research, 15*(1): 109-115.
11. Gabbett, T. J., & Domrow, N. (2007). Relationship between training load, injury, and fitness in sub-elite collision sports athletes. *Journal of Sport Sciences, 23*(13), 1507-1519.
12. Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2010). Physiological and anthropometric correlates of tackling ability in junior elite and subelite rugby league players. *Journal of Strength and Conditioning Research, 24*(11), 2989-2995.
13. Georgeson, E. C., Weeks, B. K., McLellan, C., Beck, B. R. (2012). Seasonal change in body, muscle and fat in professional rugby league players and its relationship to injury: a cohort study. *British Medical Journal Open*, *2*(6): e001400.
14. Gill-Rey, E., Lezaun, A., & Los Arcos, A. (2015). Quantification of the perceived training load and its relationship with changes in physical fitness performance in junior soccer players. *Journal of Sport Science*, *33*(20), 2125-2132.
15. Harley, J. A., Hind, K., & O'Hara, J. P. (2011). Three-compartment body composition changes in elite rugby league players during a super league season, measured by dual-

energy X-ray absorptiometry. *Journal of Strength and Conditioning Research, 25*(4), 1024-1029.

16. Hopkins, W. G. (2006). Spreadsheets for analysis of controlled trials with adjustment for a subject characteristic. *Sportscience, 10*, 46-50.
17. Hopkins, W. G. (2015). Spreadsheets for analysis of validity and reliability. *Sportscience, 19*, 36-42.
18. Johnston, R. D., Gabbett, T. J., & Jenkins, D. G. (2014). Applied sport science of rugby league. *Sports Medicine, 44*(8), 1087-1100.
19. Jones, B., Till, K., Barlow, M., Lees, M., O'Hara, J. P., & Hind, K. (2015). Anthropometric and three-compartment body composition differences between super league and championship rugby league players: considerations for the 2015 season and beyond. *PLoS One, 10*(7): e0133188.
20. Jones, B., Till, K., Roe, G., O'Hara, J., Lees, M., Barlow, M. J, & Hind, K. (2017). Six-year body composition change in male elite senior rugby league players. *Journal of Sport Science*. Advanced online publication. doi: 10.1080/02640414.2017.
21. Jones, T. W., Smith. A., Macnaughton, L. S., & French, D. N. (2017). Strength and conditioning and concurrent training practices in elite rugby union. *Journal of Strength and Conditioning Research, 30*(12), 3354-3366.
22. McLaren, S. J., Smith, A., Spears, I. R., & Weston, M. (2017). A detailed quantification of differential rating of perceived exertion during team-sport training. *Journal of Science and Medicine in Sport, 20*(3), 290-295.
23. Morehen, J. C., Routledge, H. E., Twist, C., Morton, J. P., & Close, G. L. (2015). Position specific difference in the anthropometric characteristics of elite European super league rugby players. *European Journal of Sport Science, 15*(6), 523-529.
24. Morgan, P. J., & Callister, R. (2011). Effects of a preseason intervention on anthropometric characteristics of semiprofessional rugby league players. *Journal of Strength and Conditioning Research, 25*(2), 432-440.
25. Siri, W. E. (1956). Body composition from fluid spaces and density: analysis of methods. *University of California Radiation Laboratory Report,* UCRL no. 3349.
26. Slater, G. J., Duthie, G. M., Pyne, D. B., Hopkins, W. G. (2006). Validation of a skinfold based index for tracking proportional changes in lean mass. *British Journal of Sports Medicine, 40*(3), 208-213.
27. Smart, D. J., & Gill, N. D. (2013). Effect of an off-season conditioning program on the physical characteristics of adolescent rugby union players. *Journal of Strength and Conditioning Research, 27*(3), 708-717.
28. Smith, D. R., Jones, B., Sutton, L., King, R. F., & Duckworth, L. C. (2016). Dietary intakes of elite 14- to 19-year-old academy rugby league players during a pre-season training period. *International Journal of Sport Nutrition and Exercise Metabolism, 26*(6), 506-515.
29. Till, K., Darrall-Jones, J., Weakley, J. J., Roe, G. A., & Jones, B. L. (2017). The influence of training age on the annual development of physical qualities within academy rugby league players. *Journal of Strength and Conditioning Research, 31*(8), 2110-2118.
30. Waldron, M., Worsfold, P., Twist, C., & Lamb, K. (2014). Changes in anthropometry and performance, and their interrelationships, across three seasons in elite youth rugby league players. *Journal of Strength and Conditioning Research, 28*(11), 3128-3136.
31. Walsh, M., Cartwright, L., Corish, C., Sugrue, S., & Wood-Martin, R. (2011). The body composition, nutritional knowledge, attitudes, behaviours, and future education needs

of senior schoolboy rugby players in Ireland. *International Journal of Sport Nutrition and Exercise Metabolism, 21*(5): 365-376.

32. Weakley, J. J., Till, K., Darrall-Jones, J., Roe, G. A., Phibbs, P. J., Read, D., & Jones, B. L. (2017). Strength and conditioning practices in adolescent rugby players: relationship with changes in physical qualities. *Journal of Strength Conditioning Research.* Advanced online publication. doi: 10.1519/JCS.0000000000001828.
33. Withers, R. T., LaForgia, J., Phillans, R. K., Shipp, N. J., Chatterton, B. E., Schultz, C. G., & Leaney, F. (1985). Comparisons of two-, three-, and four-compartment models of body composition analysis in men and women. *Journal of Applied Physiology, 85*(1), 238-245.

Figure 1. Individual percentage change during training phase 1 (dark grey), 2 (grey) and 3 (light grey) body mass (A), skinfold thickness (B) and body fat percentage (C). The shaded area represents the SWC combined with TE (%) to provide a meaningful change with 75% confidence. Scores inside the shaded area are consider unclear.

Figure 2. Individual percentage change during training phase 1 (dark grey), 2 (grey) and 3 (light grey) fat mass (A), fat free mass (B) and lean mass index (C). The shaded area represents the SWC combined with TE (%) to provide a meaningful change with 75% confidence. Scores inside the shaded area are consider unclear.