Manchester Metropolitan University

e-space
Manchester Metropolitan University's Research Repository

Please cite the Published Version

Dobbin, Nicholas, Highton, Jamie, Moss, Sam and Twist, Craig (2019) Factors affecting the anthropometric and physical characteristics of elite academy rugby league players: a multi-club study. International Journal of Sports Physiology and Performance, 14 (7). pp. 958-965. ISSN 1555-0273

DOI: https://doi.org/10.1123/ijspp.2018-0631

Publisher: Human Kinetics

Version: Accepted Version

Downloaded from: https://e-space.mmu.ac.uk/622006/

Usage rights: © In Copyright

Additional Information: This is an Author Accepted Manuscript of a paper accepted for publication by Human Kinetics in International Journal of Sports Physiology and Performance.

Enquiries:
If you have questions about this document, contact openresearch@mmu.ac.uk. Please include the URL of the record in e-space. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from https://www.mmu.ac.uk/library/using-the-library/policies-and-guidelines)

Manuscript Title: Factors affecting the anthropometric and physical characteristics of elite academy rugby league players: a multi-club study.

Abstract

Purpose: To investigate the factors affecting the anthropometric and physical characteristics of elite academy rugby league players.

Methods: One hundred and ninety-seven elite academy rugby league players (age = 17.3 ± 1.0 years) from five Super League clubs completed measures of anthropometric and physical characteristics during a competitive season. The interaction between, and influence of contextual factors on characteristics was assessed using linear mixed modelling.

Results: Associations were observed between several anthropometric and physical characteristics. All physical characteristics improved during preseason and continued to improve until mid-season where thereafter 10 m sprint (η^2 = 0.20 *cf.* 0.25), CMJ (η^2 = 0.28 *cf.* 0.30) and prone Yo-Yo Intermittent Recovery Test (Yo-Yo IR) (η^2 = 0.22 *cf.* 0.54) performance declined. Second (η^2 = 0.17) and third (η^2 = 0.16) years were heavier than first years, whilst third years had slower 10 m sprint times (η^2 = 0.22). Large positional variability was observed for body mass, 20 m sprint time, medicine ball throw, countermovement jump, and prone Yo-Yo IR1. Compared to bottom-ranked teams, top demonstrated superior 20 m (η^2 = -0.22) and prone Yo-Yo IR1 (η^2 = 0.26) performance whilst middle-ranked teams reported higher CMJ height (η^2 = 0.26) and prone Yo-Yo IR1 distance (η^2 = 0.20), but slower 20 m sprint times (η^2 = 0.20).

Conclusion: These findings offer practitioners designing training programmes for academy rugby league players insight into the relationships between anthropometric and physical characteristics and how they are influenced by playing year, league ranking, position and season phase.

Keywords: collision sport, physical qualities, contextual factors, player monitoring

Introduction

The anthropometric and physical characteristics of rugby league players, including stature, body mass, body composition, speed, strength, power, change of direction speed and intermittent running ability,[1] can influence career progression,[2,3] discriminate between selected and non-selected players,[4,5] differentiate between age categories,[6] influence on-field performance[7,8,9] and have implications for recovery.[7] Furthermore, well-developed physical characteristics might serve to moderate training load and reduce injury risk in team sport athletes.[10,11]

The aforementioned characteristics are potentially influenced by numerous factors, including: playing position,[12] playing age,[6,13] performance standard (i.e. amateur *cf.* professional),[6,14,15] league position[16] and season phase.[16-18] Understanding the role of contextual factors on player characteristics could be informative for coaches, strength and conditioning coaches and sport scientists when monitoring and interpreting player progression. However, the extent to which multiple factors influence a comprehensive range of rugby league players' characteristics have not been explored, likely due to the relatively small samples often used.[14,17,18] Indeed, to our knowledge, the only study of this type in team sports was conducted by Mohr and Krustrup,[16] who investigated changes in distance covered during the Yo-Yo Intermittent Running Test level 2 (Yo-Yo IR2) across an entire league in semi-professional soccer players. This study demonstrated that season phase, playing position, number of appearances and league position all influenced Yo-Yo IR2 performance. For example, the highest ranked five teams covered 8-16% greater distance during the Yo-Yo IR2 compared to the five lowest ranked teams, suggesting that Yo-Yo IR2 might influence team success. The authors also reported that Yo-Yo IR2 distance increased during the pre-season period up to mid-season, before reducing at the end of the season. These findings support the need to consider the independent effects of different factors on player characteristics that are deemed important in team sports.

The use of multi-level mixed modelling has recently been applied to account for the influence of multiple factors on total and relative distance, high-speed distance and metabolic power in rugby league.[19] Such an approach might also be used to explore the independent effects of contextual factors on the anthropometric and physical characteristics of rugby league players, whilst concurrently controlling for other variables. Furthermore, the introduction of each anthropometric and physical characteristic into the model can highlight any interaction between characteristics.[20]

The purpose of this study was therefore to examine the influence of contextual factors on anthropometric and physical characteristics, and their interaction, in elite academy rugby league players from multiple clubs.

Methods

Participants and Design

With institutional ethics approval, 214 male elite academy rugby league players from five Super League clubs were recruited during the 2016 (n = 98/327; 30% of league cohort) and 2017 (n = 132/356; 37% of league cohort) season. Of these, 197 players were included in the final analyses, with some individuals competing in both seasons, resulting in a total of 230 'player-seasons' (age 17.3 ± 1.0 years; stature 180.7 ± 6.4 cm; body mass 87.0 ± 10.6 kg) (Supplement 1). Skinfold thickness was recorded for 67 'player-seasons' from three clubs.

A longitudinal observational design was used with anthropometric and physical characteristics assessed at 'early preseason', 'end of preseason', 'mid-season' and 'end of season'. Early preseason testing took place within the first week of preseason; end of preseason after 12 weeks of training; mid-season after 10/11 competitive league matches (out of 20/22); and the end of season after another 10/11 matches. Players represented all playing positions (hooker, halfback, wingers, centre, second row, prop, loose forward, scrum half and stand-off), playing years (1st, 2nd and 3rd years) and were categorised as those playing within top- (top 4), middle- (middle 5) and bottom-ranked (bottom 4) teams based on this final league position in the academy Super League competition (Supplement 1). All players completed at least two assessments (mean ± SD = 3.3 ± 0.8) during the season and did not experience any illness or injuries that resulted in 4 weeks or more of missed matches.

Each session was completed at the clubs' training facilities (artificial turf, n = 179; running track, n = 51) after at least 48 hours of rest and at the same time of day. Participants were instructed to arrive in a fed and hydrated state, and were habituated to the testing procedures, which were conducted by the same researcher. During each session, players were divided into two groups, with group 1 performing the sprint tests and countermovement jump first and group 2 completing the change of direction test and medicine ball throw. The groups then swapped and came together for the prone Yo-Yo IR1. The order of tests and groups were standardised for all sessions and a period of 5 minutes was given between each test. Temperature and humidity were typical of the seasonal climate during each session (9.6 ± 1.5 to 17.7 ± 2.6ºC and 72.2 ± 6.2 to 84.8 ± 8.3%).

Procedures

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 in accordance with International Society for the Advancement of Kinanthropometry with skinfold thickness measured using Harpenden callipers (Harpenden, Burgess Hill, UK) on the right side of the body and the sum of eight sites (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, thigh, calf) used for analysis. 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. The same researcher conducted all measurements (intra-rater coefficient of variation (CV) = 1.3%).

Sprint performance was measured using electronic timing gates (Brower, Speedtrap 2, Brower, Utah, USA) positioned at 0, 10 and 20 m, 150 cm apart and at a height of 90 cm. Participants began each sprint from a two-point athletic stance 30 cm behind the start line. Two maximal 20 m sprints were recorded to the nearest 0.01 s with two minutes between each attempt and the best 10 and 20 m sprint times used for analysis possessing a CV of 4.2 and 3.6%, respectively.[21]

Participants completed two countermovement jumps with 2-minutes passive recovery between each attempt. Participants placed their hands on their hips and started upright before flexing at the knee to a self-selected depth and extending up for maximal height, keeping their legs straight throughout. Jumps that did not meet the criteria were not recorded, and participants were asked to complete an additional jump. Jump height was recorded using a jump mat (Just Jump System, Probotics, Huntsville, Alabama, USA) and corrected before peak height was used for analysis, with a CV of 5.9%.[21]

Change of direction performance was measured using electronic timing gates (Brower, Speedtrap 2, Brower, Utah, USA) placed at the start/finish line 150 cm apart and at a height of 90 cm. The test consisted of different cutting manoeuvres over a 20 x 5 m course (see Ref 21) with each effort interspersed by 2-minutes passive recovery. Participants started in a two-point athletic stance 30 cm behind the start line and completed one trial on the left; the timing gates were then moved, and a second trial was performed on the right in a standardised order before the times were combined (CV = 2.5%).[21] Failure to place both feet around each cone resulted in disqualification and the trial being repeated.

To assess whole-body muscle function, 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 whilst squatting down to a self-selected depth. With their feet shoulder width apart, in contact with the ground and behind a line that determined the start of the measurement, they were then instructed to extend up pushing the ball forwards striving for maximum distance. Distance was measured to the nearest centimetre using a tape measure from the back of the start line to the rear of the ball's initial landing imprint on the artificial surface. Participants completed two trials interspersed by 2-minutes recovery, with the maximum distance used (CV = 9.0%).[21]

The prone Yo-Yo IR1 required participants to start each 40 m shuttle in a prone position with their head behind the start line, legs straight and chest in contact with the ground. Shuttle speed was dictated by an audio signal commencing at 10 $km \cdot h^{-1}$ and increasing 0.5 $km \cdot h^{-1}$ approximately every 60 s to the point at which the participants could no longer maintain the required running speed. The final distance achieved was recorded after the second failed attempt to meet the start/finish line in the allocated time. The reliability (CV% = 9.9%)[21] and concurrent validity of this test have been reported.[7]

Statistics analysis

Linear mixed modelling was used to determine the independent effects of season phase, playing year, playing position, league ranking, and anthropometric and physical characteristics on each dependent variable (Supplement 2). Data was checked for normality through visual inspection of normal plots of residuals (Q-Q plot). Once checked, individual players and teams were included as random factors. A "step-up" model was employed beginning with an "unconditional" null-model containing only random factors before fixed factors were introduced and retained upon significantly ($P < 0.05$) altering the model as determined by the maximal likelihood test and χ^2 statistic. The intercept, which represents a modelled value that corresponds to the convergence of all random slopes (i.e. slope for players and teams) once all fixed factors are entered in each model, were derived for each individual's slope as the height at $x = 0$. However, as none of the continuous fixed factors were measured at 0 (i.e. 0 kg body mass), the origin was shifted using mean centering. The t-statistic was converted to effect size correlations (η^2) and associated 90% confidence intervals (90% CI).[22] Effect size correlations were interpreted as < 0.1, *trivial*; 0.1-0.3, *small*;

0.3-0.5, *moderate*; 0.5-0.7, *large*; 0.7-0.9, *very large*; 0.90-0.99, *almost perfect*; 1.0, *perfect*.[23] The likelihood of the effect was established using magnitude-based inferences, where quantitative chances of the true effect were assessed qualitatively, as <1%, *almost certainly not*; 1-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possibly*; 75-97.5%, *likely*; 97.5-99%, *very likely*; >99%, *almost certainly*.[23] For clarity, only effects that were considered clear (not necessarily significant) were included. Linear mixed models were constructed using SPSS (Version 24) and interpreted using a pre-deigned spreadsheet.[24]

Results

Exploring the interaction between characteristics revealed that body mass was negatively associated with countermovement jump height (η^2 = -0.26) and prone Yo-Yo IR1 distance (η^2 = -0.16), and positively associated with greater change of direction (η^2 = -0.21) and 20 m sprint (η^2 = 0.08) times (Figure 1A). Skinfold thickness was positively associated with body mass (Figure 1B). Change of direction time was positively associated with 20 m sprint (η^2 = 0.23) and negatively associated with countermovement jump (η^2 = -0.16) and prone Yo-Yo IR1 performance (η^2 = -0.15) (Figure 2A). Twenty-meter sprint time was positively associated with 10 m sprint performance (η^2 = 0.85) and negatively associated with countermovement jump (η^2 = -0.31) (Figure 2B). Ten-meter sprint time was positively associated with prone Yo-Yo IR1 distance (η^2 = 0.20) (Figure 2C). Medicine ball throw was negatively associated with 20 m sprint time (η^2 = -0.06) and positively associated with countermovement jump performance (η^2 = 0.27) (Figure 3A). Body mass, change of direction and 20 m sprint time were negatively associated with prone Yo-Yo IR1 distance. Full model outputs can be found in Supplement 3.

Body mass was positively associated with season phase as indicated by the *very* to *most likely* higher scores at the end of preseason, mid-season and end of the season periods (η^2 = 0.15 to 0.30) compared to early preseason. Skinfold thickness was negatively associated (i.e. lower) with season phase at the end of preseason through to the end of season when compared to early preseason (η^2 = -0.31 to -0.68) (Figure 1). Ten-meter sprint (η^2 = -0.20 to -0.29), change of direction (η^2 = -0.17 to -0.39) and 20 m sprint (η^2 = 0.18 to 0.23) performance were positively associated with season phase as indicated by the *most likely* quicker times at end of preseason through to end of season. Prone Yo-Yo IR1 distance was positively associated with season phase and was greater at end of preseason, mid-season and end of season (η^2 = 0.22 to 0.54) compared to early preseason (Figures 2-3). Medicine ball throw was positively associated with the mid-season and end of season phases (η^2 = 0.31 and

0.52, respectively). Whilst early preseason was included as a dummy variable, changes between end of preseason and mid-season, and mid-season and end of season can be inferred by the effect size correlation. Results indicate that body mass ($\eta^2 = 0.23$ *cf.* 0.30), countermovement jump height ($\eta^2 = 0.28$ *cf.* 0.30) and prone Yo-Yo IR1 ($\eta^2 = 0.22$ *cf.* 0.54) distance increased and skinfold thickness and 10 m sprint times decreased from the end of preseason to mid-season. Performance during the 10 ($\eta^2 = -0.29$ *cf.* -0.25) and 20 ($\eta^2 = 0.18$ *cf.* 0.23) m sprint tests, countermovement jump ($\eta^2 = 0.30$ *cf.* 0.20) and prone Yo-Yo IR1 ($\eta^2 = 0.54$ *cf.* 0.45) decreased from mid-season to the end of season whilst skinfold thickness increased ($\eta^2 = -0.68$ *cf.* -0.60) and body mass decreased ($\eta^2 = 0.30$ *cf.* 0.15).

****INSERT FIGURE 1 ABOUT HERE****

Body mass was positively associated with playing year with second and third years heavier ($\eta^2 = 0.16$ to 0.17) than first years. Ten-meter sprint time was positively (i.e. slower time) associated with being a third year ($\eta^2 = 0.01$).

****INSERT FIGURE 2 ABOUT HERE****

Large positional variability was observed for measures of body mass and 20 m sprint, countermovement jump, medicine ball throw and prone Yo-Yo IR1 performance (Figure 1, 2 and 3). In contrast, less variability was observed between playing positions for skinfold thickness, 10 m sprint time, and change of direction time (Figure 1 and 2).

****INSERT FIGURE 3 ABOUT HERE****

Positive associations were observed between middle-ranked teams and countermovement jump height ($\eta^2 = 0.26$) whilst prone Yo-Yo IR1 distance was positively associated with top- and middle-ranked teams ($\eta^2 = 0.20$ to 0.26; Figure 3C) when compared to bottom-ranked teams.

Discussion

This is the first study to assess the influence of multiple factors on the anthropometric and physical characteristics of rugby league players, whilst controlling for confounding variables using linear mixed modelling. Our results indicated an interaction between several physical characteristics that are influenced by contextual factors including playing position, league ranking, playing age and season phase.

Understanding the interaction between anthropometric and physical characteristics is important for practitioners when developing optimal strength and conditioning practices. For example, Delaney et al.[20] reported a positive relationship between body mass and change of direction time, suggesting a greater body mass can negatively influence change of direction speed. However, they noted that lower-body strength and power training could improve change of direction time without compromising a high body mass. Our results indicate that body mass was positively associated with and medicine ball throw and negatively associated with change of direction time countermovement jump height and prone Yo-Yo IR1 distance. This suggests a focus on increasing body mass in academy players can have both positive and negative effects on certain characteristics and requires consideration with respect to long-term athlete development. Furthermore, countermovement jump height was positively associated with medicine ball throw and prone Yo-Yo IR1 distance, reaffirming associations between power and intermittent running.[8] Indeed, based on our model, an increase in body mass of 1 kg would increase change of direction time by 0.46 s. Therefore, increasing academy players' body mass given its positive association with running momentum[12,15] and ball carrying success in match play[25] would potentially impair change of direction ability, countermovement jump and intermittent running. Such findings might suggest that increases in body mass should occur at a similar rate to the development of physical characteristics, particularly in youth and academy players who are required to develop holistically as they progress to senior rugby. Understanding the potential impact of developing a specific characteristic on a range of other important determinants of rugby league performance enables practitioners to make more informed training decisions based on individual player objectives.

Playing age influenced body mass with second and third year players being heavier than first year players. This finding has been observed elsewhere,[26] and is likely a consequence of both increased training exposure and maturation.[26] Our results also indicated a positive association between playing age and 10 m sprint times, suggesting that third year players recorded slower sprint times compared to first years. Slower sprint performance in older academy players has been reported previously[26] and suggests that, despite greater training experience, coaches might place more emphasis on increasing body mass and lean mass in a position-specific manner (i.e. greater focus in forwards) to minimise the discrepancy between academy and senior Super League players.[27] However, such an approach might have a detrimental effect on sprint speed in third year academy players and requires consideration when programming given the importance of sprinting ability to discriminate between playing standards[28] and its influence on performance of ball-carrying success.[25] Whilst our observations suggest increases in body mass might have a detrimental effect on sprint speed, it is important to recognise that body mass continues to increase as players move into senior rugby league,[27] yet the average sprint times are also lower (i.e. faster).[6] It is possible that rather than body mass *per se*, it is the rapid increase in body mass required in a short time period (3 years) that negatively impacts on sprinting performance, and that practitioners should look to increase body mass and factors that influence sprinting ability (i.e. force, velocity, power) concurrently.

Dated studies on the physical qualities of senior players[29,30] and the recent practice of grouping players (e.g. outside backs, adjustable and hit-up forwards)[5] has limited our current understanding of the positional variability within rugby league. Given the large sample size across multiple clubs, this study offered insight into the influence of playing positions on the anthropometric and physical characteristics of academy rugby league players. Large between-position variability was observed for body mass, 20 m sprint, medicine ball throw, countermovement jump and prone Yo-Yo IR1 performance, while low positional variability was observed for skinfold thickness, 10 m sprint time and change of direction time. Variability between positions is likely influenced by the selection of academy players to playing roles based on physical qualities. For example, larger players are selected into roles that require greater body mass to facilitate greater running momentum and impact forces.[25] Similarly, players with superior intermittent running capacity (e.g. hookers) are best suited to roles that require numerous offensive and defensive involvements.[31] Homogeneity between positions for 10 m sprints and change of direction possibly reflect shared training practices that emphasise speed and agility over short distances because of the limited distance (~10 m) between attacking and defending players during match play and is similar to that observed for 15 and 40 m sprint times across majority of playing positions in senior rugby league.[29] The lack of variability in skinfold thickness between positions probably reflects the generic nutritional advice provided to academy rugby league players and the regular monitoring of body composition.

To the authors' knowledge, no study has explored the differences in anthropometric and physical qualities based on league ranking in rugby league. Our findings concur with those reporting *small* to *large* differences between elite and sub-elite players in rugby league[4] and the results of Mohr and Krustrup[16] who reported an 18-20% greater Yo-Yo IR2 distance in top- and middle-ranked teams compared to bottom-ranked teams in semi-professional soccer. Whilst it is likely that numerous factors influence a team's league ranking, our results suggest that well-developed sprinting ability and rugby-specific intermittent running might be important for success.

In agreement with other team sports,[16-18] season phase influenced the anthropometric and physical characteristics of rugby league players. All measures (except medicine ball throw) improved during the preseason period and continued to improve until mid-season. Between the mid- and late-season phases, change of direction time and medicine ball throw distance continued to improve, whereas body mass, 10 m sprint, countermovement jump and prone Yo-Yo IR1 performance decreased, and skinfold thickness increased. These results might be indicative of a decrease in training load over the course of the season,[17] which might negatively impact on some physical characteristics. Given the influence some anthropometric and physical characteristics have on fatigue[7] and their potential moderating effects on the workload-injury relationship,[10,11] these findings have important implications for optimal performance capabilities of players (and teams) at the end of the season. With this in mind, future research might explore methods of maintaining the anthropometric and physical characteristics of players during the latter stages of the competitive season that do not simultaneously compromise match performance capability.

Despite the novel approach employed, this study is not without limitations. While this study uses a large data set from several clubs, our data still only represent approximately a third of players in the entire league and is susceptible to the individual selected clubs' approach to talent identification and development. Furthermore, we were unable to document to ethnicity and maturation status of players. Due to the difficulties standardising measures of training and match load across multiple clubs, we were also unable to confirm the proposed reductions in training load that have been reported previously and whether these were responsible for the changes in physical qualties.[17] We also did not include any measures of skill-based performance or muscle strength despite these being important in rugby league.[26] Future research should look to explore these limitations by incorporating a league-wide testing battery, including measures of rugby skills, alongside practical measures of training and match load.

Practical Application

The findings of this study highlight the importance of considering multiple factors when interpreting a players anthropometric and physical characteristic. Furthermore, we show the interaction between physical characteristics and suggests that practitioners need to consider both the positive and negative consequences of developing particular characteristics and align this with the player's developmental stage. For example, strength and conditioning coaches working with youth and academy players should look to manage the increase in a player's body mass and improve physical characteristics concurrently. Furthermore, our results underline the importance of considering contextual factors such as playing year and position when assessing or comparing players to national performance standards or selected groups (i.e. first team). We also demonstrated how league ranking and season phase influence several anthropometric and physical characteristics, suggesting practitioners should look to maximise the development of body mass, linear sprint speed, CMJ and intermittent running during the preseason period and strive to maintain these over the course of the competitive season using appropriate training and training loads.

Conclusion

Using a large sample from multiple clubs, we report on several factors that influence anthropometric and physical characteristics of academy rugby league players. Firstly, practitioners should note the covariance between several anthropometric and physical characteristics when planning strength and conditioning programmes. Our results also indicate that playing position, league ranking, playing age and season phase influence the anthropometric and physical characteristics of rugby league players. Such insight can be used by practitioners to develop individual players based on their playing position and playing age. Practitioners should also consider the in-season training loads in order to negate any negative changes in anthropometric and physical characteristics, particularly towards the latter stages where teams might be looking to succeed in competitions.

References

1. Chiwaridzo M, Ferguson GD, Smits-Engelsman BCM. A systematic review protocol investigating tests for physical or physiological qualities and game-specific skills commonly used in rugby and related sports and their psychometric properties. *Syst Rev* 2016; 5: doi: 10.1186/s13643-016-0298-1.
2. Till K, Cobley S, O'Hara J, *et al*. Retrospective analysis of anthropometric and fitness characteristics associated with long-term career progression in rugby league. *J Sci Med Sport* 2015; 18(3):310-314.
3. Till K, Jones BL, Cobley S, *et al.* Identifying talent in youth sport: a novel methodology using higher-dimensional analysis. *PLoS One* 2016; 11(5):e0155047.
4. Tredrea M, Dascombe B, Sanctuary CE, *et al.* The role of anthropometric, performance and psychological attributes in predicting selection into an elite development programme in older adolescents rugby league players. *J Sports Sci* 2017; 35(19):1897-1903.
5. Gabbett T, Kelly J, Ralph S, *et al*. Physiological and anthropometric characteristics of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. *J Sci Med Sport* 2009; 12(1):215-222.
6. Gabbett TJ. Physiological characteristics of junior and senior rugby league players. *Br J Sports Med* 2002; 36(5):334-339.
7. Johnston RD, Gabbett TJ, Jenkins DG, *et al.* Influence of physical qualities on post-match fatigue in rugby league players. *J Sci Med Sport* 2015; 18(2):209-213.
8. Dobbin N, Highton J, Moss SL, *et al.* The concurrent validity of a rugby-specific Yo-Yo Intermittent Recovery Test (Level 1) for assessing match-related running performance. *J Strength Cond Res* 2018; doi: 10.1519/JSC.0000000000002621
9. Gabbett TJ, Seibold AJ. Relationship between tests of physical qualities, team selection, and physical match performance in semiprofessional rugby league players. *J Strength Cond Res* 2013; 27(12):3259-3265.
10. Windt J, Zumbo BD, Sporer B, *et al.* Why do workload spikes cause injuries, and which athletes are at higher risk? Mediators and moderators in workload-injury investigations. *Br J Sports Med* 2017; 51(13):993-994.
11. Malone S, Hughes B, Doran DA, *et al.* Can the workload-injury relationship be moderated by improved strength, speed and repeated sprint qualities? *J Sci Med Sport* 2018; https://doi.org/10.1016/j.jsams.2018.01.010
12. Morehen JC, Routledge HE, Twist C, *et al*. Position specific differences in anthropometric characteristics of elite European super league rugby players. *Eur J Sport Sci* 2015; 15(6): 523-529.

13. Till K, Scantlebury S, Jones B. Anthropometric and physical qualities of elite male youth rugby league players. *Sports Med* 2017; 47(11):2171-2186.
14. Baker DG, Newton RU. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J Strength Cond Res* 2008; 22(1):153-158.
15. Atkins SJ. Performance of the yo-yo intermittent recovery test by elite professional and semiprofessional rugby league players. *J Strength Cond Res* 2006; 20(1):222-225.
16. Mohr M, Krustrup P. Yo-Yo intermittent recovery test performances within an entire football league during a full season. *J Sports Sci* 2014; 32(4):315-327.
17. Gabbett TJ. Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *J Strength Cond Res* 2005; 19(2):400-408.
18. Waldron M, Gray A, Worsfold P, *et al.* The reliability of functional movement screening and in-season changes in physical function among elite rugby league players. *J Strength Cond Res* 2016; 30(4):910-918.
19. Delaney JA, Thornton HR, Duthie GM, *et al.* Factors that influence running intensity of interchange players in professional rugby league. *Int J Sports Physiol Perform* 2016; 11(8):1047-1052.
20. Delaney JA, Scott TJ, Ballard DA, *et al.* 2015. Contributing factors to change-of-direction ability in professional rugby league players. *J Strength Cond Res* 2015; 29(10):2688-2696.
21. Dobbin N, Highton J, Hunwicks R, *et al*. Reliable testing battery for assessing physical qualities of elite academy rugby league players. *J Strength Cond Res* 2017; doi: 10.1519/JSC.0000000000002280.
22. Rosnow RL, Rosenthal R, Rubin DB. Contrasts and correlations in effect-size estimation. *Pschol Sci* 2000; 11(6):446-453.
23. Hopkins WG, Marshall SQ, Batterham AM, *et al.* Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sport Exerc* 2009; 41:3-12.
24. Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. *Sportscience* 2007; 11:16-20.
25. Waldron M, Worsfold PR, Twist C, *et al*. The relationship between physical abilities, ball-carrying and tackling among elite youth rugby league players. *J Sport Sci* 2014; 32:542-549.
26. Till K, Darrall-Jones J, Weakley JJ, *et al.* The influence of training age on the annual development of physical qualities within academy rugby league players. *J Strength Cond Res* 2017; 31(8):2110-2118.

27. Till K, Jones B, O'Hara J, *et al*. Three-compartment body composition in academy and senior rugby league players. *Int J Sports Physiol Perform* 2016; 11(2):191-196.
28. Gabbett TJ, Kelly JN, Sheppard JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res* 2008; 22(1):174-181.
29. Meir R, Newton R, Curtis E, *et al.* Physical fitness qualities of professional rugby league football players: determination of positional differences. *J Strength Cond Res* 2001; 15(4):450-458.
30. Gabbett TJ. A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. *J Sports Sci* 2006; 24(12),1273-1280.
31. Austin DJ, Kelly SJ. Professional rugby league positional match-play analysis through the use of global positioning system. *J Strength Cond Res* 2014; 28(1):187-193.

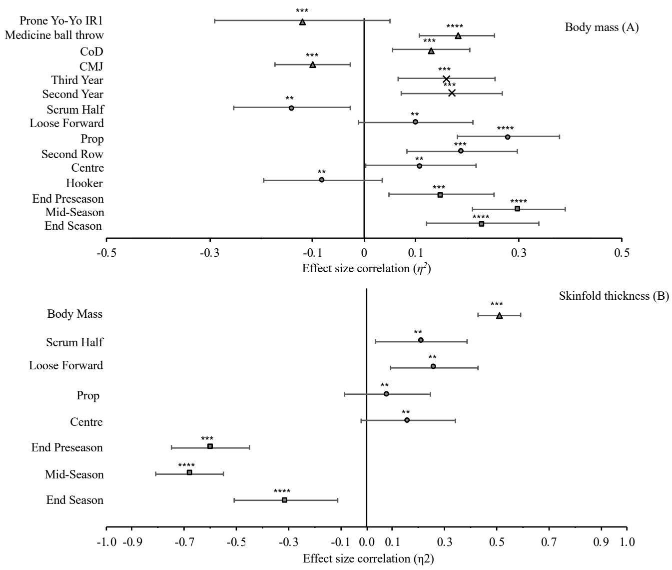
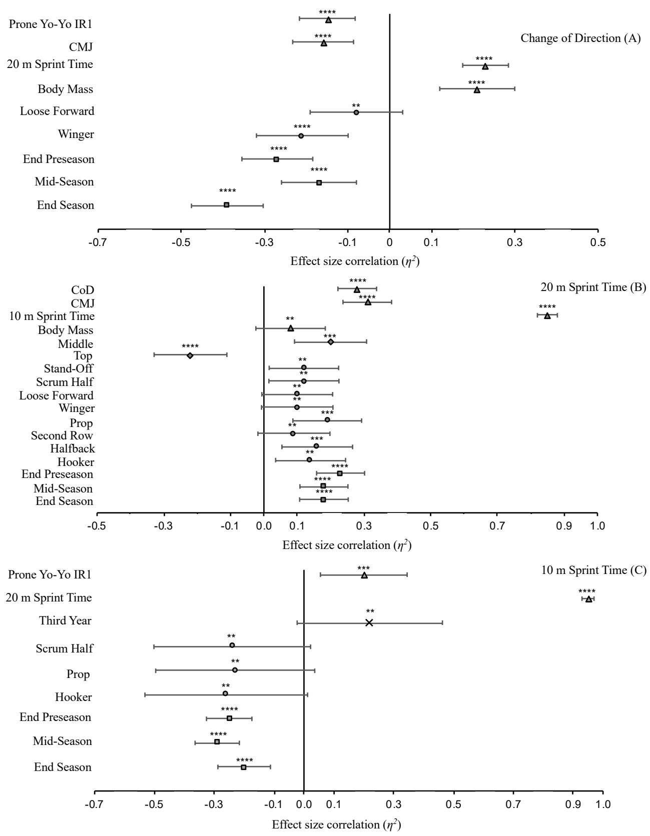


Figure 1. Effect of fixed factors on body mass (A) and skinfold thickness (B)

Note: data expressed as effect size correlation with 90% CI. Effects that cross 0 were non-significant but demonstrated a clear likelihood effect: ** *likely*, *** *very likely*, **** *most likely.*



Change of Direction (A)
Prone Yo-Yo IR1
CMJ
20 m Sprint Time
Body Mass
Loose Forward
Winger
End Preseason
Mid-Season
End Season
Effect size correlation (η^2)
20 m Sprint Time (B)
CoD
CMJ
10 m Sprint Time
Body Mass
Middle
Top
Stand-Off
Scrum Half
Loose Forward
Winger
Prop
Second Row
Halfback
Hooker
End Preseason
Mid-Season
End Season
Effect size correlation (η^2)
10 m Sprint Time (C)
Prone Yo-Yo IR1
20 m Sprint Time
Third Year
Scrum Half
Prop
Hooker
End Preseason
Mid-Season
End Season
Effect size correlation (η^2)

Figure 2. Effect of fixed factors on change of direction time (A), 20 m sprint time (B) and 10 m sprint time (C).
Note: data expressed as effect size correlation with 90% CI. Effects that cross 0 were non-significant but demonstrated a clear likelihood effect: ** *likely,* *** *very likely*, **** *most likely.*

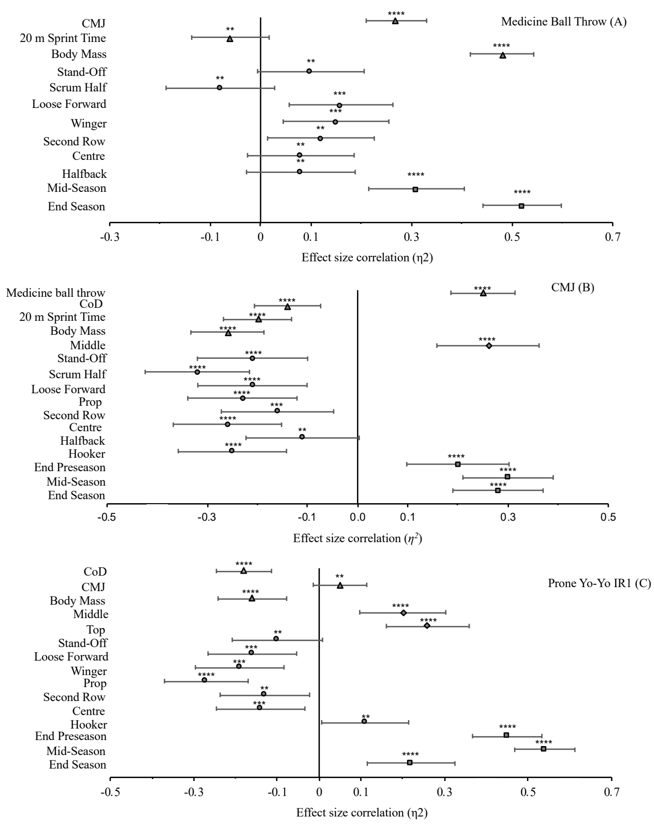


Figure 3. Effects of fixed factors on medicine ball throw (A), countermovement jump (B) and prone Yo-Yo IR1 (C)
Note: data expressed as effect size correlation with 90% CI. Effects that cross 0 were non-significant but demonstrated a clear likelihood effect: ** *likely,* *** *very likely*, **** *most likely*