Manuscript Title: A reliable testing battery for assessing physical qualities of elite academy rugby league players.

ABSTRACT

This study assessed the inter-day reliability of a testing battery for the assessment of physical qualities of rugby league players. Fifty players (age 17.1 ± 1.1 years; stature 181.3 ± 6.3 cm; body mass 89.0 ± 11.6 kg) from three Super League academies participated in this study. Tests of countermovement jump performance, 10 and 20 m sprint performance, change of direction, medicine ball throw and a modified Yo-Yo Intermittent Recovery Test Level 1 (prone Yo-Yo IR1) were completed on three separate occasions. Between-day intraclass correlation coefficient, typical error (TE), coefficient of variation (CV) and the smallest worthwhile change (SWC) were calculated to determine the reliability and sensitivity of each measure. Individual tests (except medicine ball throw) were not systematically different between trials (*P*>0.05), with an inter-day variability that was <10%. In all instances, the TE was larger than the calculated SWC change although variability was less than that typically observed after a training intervention or specific training period (i.e. preseason). Using a magnitude-based inference approach, we present the required change for all performance tests to be 75% confident the change is beneficial. This simple and time efficient testing battery is sufficiently reliable to detect previously observed changes in a range of physical qualities of rugby league players.

Key Words: measurement, performance, team sport, testing

INTRODUCTION

Rugby league is an intermittent collision sport that requires players to perform frequent high-intensity movements such as high-speed running, sprinting, and tackling interspersed with periods of low-intensity activities such as standing, walking, and jogging (14). As such, players are required to possess highly developed physical qualities including speed, strength, power, agility and endurance as well as skill and tactical awareness (4,15,16). The assessment of these physical qualities can provide objective data that can be used to ensure players can meet the demands of the sport (15), evaluate adaptation to training programmes (14), identify talent (13,14), monitor player development (37) and predict player selection (4).

Acceleration and sprint ability is frequently assessed by rugby league practitioners and used in combination with body mass to determine a player's sprinting momentum, evaluate training adaptation and monitoring development (37). Furthermore, acceleration and sprinting appears to be an integral component for successful performance in rugby league, with players performing on average 35 ± 2 sprints per match (17). These actions often occur during critical passages of play such as scoring or conceding a try (19). Consequently, rugby league players' sprint performance is typically measured over 10, 20, and 40 meter (m) distances; thereby encompassing a measure of acceleration (0-10 m) and maximal speed (10-40 m) (19). Acceleration and sprint ability are reported to improve from off-season to mid-season in junior rugby league players (14) and can differentiate between playing standards (e.g. professional, semi-professional and amateur) (14). Therefore, the ability to assess these qualities in the context of a practically meaningful change in acceleration and maximal speed is essential for rugby league practitioners.

The ability to change direction is also an essential quality in rugby league that differentiates between playing standards (13). Several change of direction tests have been used in rugby league; these include the Illinois agility test (13), 'L'-run (14,20), and 505 agility (20). However, no rugby-league specific test is universally advocated and those used typically focus on change of direction angles above 90° rather than incorporating 'cutting'; a skill often performed during rugby league match-play (20).

Well-developed muscular power in rugby league has been associated with successful skill execution (38) and reduced post-match fatigue (29). Accordingly, practitioners at all standards of the game must be able to assess power using practical methods of assessment. Several methods have been employed to assess upper- and lower-body power in rugby league players, including, but not limited to, the jump squat (5), countermovement jump (CMJ) (38), medicine ball throw (36) and bench press throw (5). While the medicine ball throw and vertical jump do not provide direct measures of muscle power, both tests are valid measures of this physical quality (28) and are easy and quick to administer. Scores obtained using the medicine ball throw and CMJ can differentiate between national and regional youth rugby league players (36).

The Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) and 30-15 Intermittent Field Test are often used to assess intermittent running capacity of rugby league players (1,32). Using the Yo-Yo IR1 to differentiate between low- and high-fitness players, Johnston et al. (29) reported that the high-fitness group covered significantly greater distances and high- and very high-speeds during match-play as well as improved recovery. In contrast, no significant relationship was observed between Yo-Yo IR1 and measures of physical match performance in semi-professional rugby league players (21). It is known that the collision contributes to a greater physiological load (31), which might result in a disassociation between physical match performance and a running-based intermittent field test (3). As such, we have introduced an up-and-down action at the start of each shuttle to assess the players' ability to get up after the tackle and join play. This modified Yo-Yo IR1 test is associated (r = 0.48-0.78) with a player's ability to maintain relative distance, mean speed, high metabolic power, and sprint performance during a simulated match (unpublished data). We therefore believe that the prone Yo-Yo IR1 provides a valid measure of rugby-specific high-intensity running capacity.

The use of a standardised testing battery that is economical, easy to administer, requires the minimum of technical equipment or expertise would be useful for rugby league practitioners to accurately monitor changes in performance due to training adaptations (37). Further, due to the range of tests that have been incorporated into testing batteries, it is difficult to compare players between age-grades, clubs and countries, and as such, a standardised battery that is easily replicable could be useful (37). It is important to ensure that all measurements made as part of a testing battery are reliable (2). The reliability, expressed as a coefficient of variation, for the 10 m (3.05%) and 20 m (1.82%) sprint times (11), CMJ height (5.2%) (9), Yo-Yo IR1 (8.7%) (35) and pre-planned agility (1.9-2.5%) (20) has been reported using team sport athletes. However, few studies have established the reliability using only rugby league players, which is important given the large differences in physical attributes (i.e. body mass) compared to other team sports. Furthermore, previous reliability studies have typically used small sample sizes (< 50) over two repeated trials. Hopkins noted that to achieve reasonable precision for estimates of reliability, approximately 50 participants and at least three trials are required (24). Understanding the reliability of a range of performance tests used in rugby league and the extent to which players require habituation (as determined by a third trial) would therefore be practically meaningful. Accordingly, this study sought to assess the inter-day reliability, in the context of meaningful changes in performance, of a standardised testing battery that can be used to assess the physical qualities of rugby league players.

METHODS

Experimental Approach to the Problem

The repeated measure design required participants to complete the same battery of tests on three separate occasions with 7.9 ± 3.8 (range 5-14) days between visits. All visits took place during each club's pre-season with players performing no work-based or leisure-time physical activity in the 24 h before data collection. On arriving at the club's own training facility, measures of stature (SECA stadiometer, Leicester Height Measure, Hamburg, Germany) and body mass (SECA scales, 813, Hamburg, Germany) were recorded before performing a CMJ, 10 and 20 m sprint test, change of direction test, medicine ball throw and modified Yo-Yo IR1 (prone Yo-Yo IR1). All tests were carried out by the same researcher and were performed on an outdoor synthetic grass pitch (3G all-weather surface) at the same time of day (± 2 h), with a mean temperature during the three trials of 10.8 ± 3.8°C. Participants were asked to refrain from caffeine 12 hours before testing, and although not measured, were advised to attend each session well-hydrated. Participants were required to wear the same clothing and footwear (studded boots) for each visit and completed a standardised warm up before being divided into two groups. Group one completed the CMJ and sprint tests, while group two completed the medicine ball throw and change of direction test. The groups then swapped and came together to complete the prone Yo-Yo IR1. The test order was standardised for all visits and was completed within ~75 min.

Subjects

With institutional ethics approval, 50 academy rugby league players from three professional clubs playing in the Under-19s Super League competition (age 17 ± 1 years; stature 181.3 ± 6.3 cm; body mass 89.0 ± 11.6 kg) participated in the study. Players were informed of the benefits and risk associated with this study before providing written informed consent and completing a pre-test health questionnaire Parental consent also provided for all participants <18 years old. Players were free from injury at each time point of the study, which was confirmed by the respective club's medical team.

Procedures

Countermovement Jump

Participants completed four countermovement jumps (CMJ) comprising two using their arms (with) to determine the influence of the arm swing on measures of reliability and two with hands placed on the hips (without) in an attempt to standardise the jump. A period of 2-minutes recovery was permitted between jumps. Participants started upright in their playing boots before flexing at the knee to a self-selected depth and then extending into the jump 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 (12) before peak height was used for analysis.

Sprint performance and momentum

Sprint performance was measured using single beam electronic timing gates (Brower, Speedtrap 2, Brower, Utah, USA) positioned at 0, 10 and 20 m. The timing gates were placed 150 cm apart and at a height of 90 cm for all trials. 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 2-minutes recovery between each. The best 10 and 20 m sprint times were used for analysis. Momentum was calculated by multiplying body mass by mean velocity (distance / time) over the best 10 and 20 m time recorded (11).

Change of direction

Change of direction performance was measured using single beam 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 (Figure 1). Participants started when ready from a two-point athletic stance with their driving foot placed 30 cm behind the start line. One trial was performed on the left, the timing gates were then moved, and a second trial was performed on the right in a standardised order before times were combined. Failure to place both feet around each cone resulted in disqualification and participants were required to repeat the trial.

Medicine ball throw

Whole-body muscle function was assessed by having participants throw a medicine ball (dimensions: 4 kg, 21.5 cm diameter) striving for maximum distance. Participants began standing upright with the ball above their head. They then lowered the ball towards their chest whilst squatting down to a self-selected depth before extending up onto their toes and 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 line on the floor to the rear of the ball's initial landing position. 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.

****Insert Figure 1 about here****

Prone Yo-Yo Intermittent Recovery Test Level 1

The prone Yo-Yo IR1 was used to measure high-intensity intermittent running capacity and required participants to complete as many 40 m shuttles as possible with a 10 s active recovery (walking) between shuttles (6). Running speed for the test commenced at 10 $km \cdot h^{-1}$ and increased 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. Participants were required to start each shuttle in a prone position 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.

Statistical Analysis

Data are presented as mean ± SD. The distribution of each variable was examined using the Shapiro-Wilk normality test and homogeneity of variance was verified with the Levene test. To determine if there was a systematic difference between trials, separate repeated measure ANOVA were performed with alpha set at 0.05 and a *non-significance* interpreted as a lack of systematic performance improvement or decrement rather than no difference between trials. In the presence of a statistically significant difference, *post-hoc* paired samples *t*-tests were performed with Bonferroni adjustment. To determine the reliability of each measure, intraclass correlation coefficient (ICC) with 95% confidence limits (CL), and typical error (TE) and coefficient of variation (CV%) with 90% CL were used. TE was calculated as the standard deviation of the differences between trials divided by the √2 and the CV% as (TE / grand mean) x 100. Standardised changes of different magnitudes were calculated to provide context for the observed inter-day variation in measurements. A smallest worthwhile change (SWC) in performance was considered as 0.2 x the pooled standard deviation for each variable (7,27). To ascertain the performance improvement required to be 75% confident the change was beneficial (22), a magnitude-based inferences approach was used using the SWC and TE for each variable (25) and reported as the "required change". These required performance improvements are presented in the results and are later used as an 'analytical goal' (i.e. the observed reliability must be sufficient to allow confident detection of feasible or previously observed changes in performance). Statistical analyses were conducted using SPSS for Windows (Version 22.0, 2013) and a pre-designed spreadsheet (26).

RESULTS

There were no systematic changes in stature or body mass across the three trials. Inter-day reliability of the performance tests across the three trials is presented in Table 1. While none of the variables had a TE less than the SWC all variables had a TE less than that typically observed after a preseason season training period or intervention. All tests had a CV of less than 10% with the agility test (2.4%) and 20 m sprint tests (3.6%) demonstrating the lowest and prone Yo-Yo IRT1 (9.9%) the highest variability. Intraclass correlation coefficient ranged from 0.74 and 0.98. The required change for all performance tests with 75% confidence are presented in Table 1.

****Insert Table 1 about here****

Between day comparisons indicated that medicine ball throw distance was greater on trial 2 ($P<0.05$) compared to trials 1 and 3. Performance during all other tests did not systematically change across trials ($P>0.05$). Specific comparisons of variability between days indicated that reliability was, for the most part, best when comparing trials 1 and 2 (Table 2).

****Insert Table 2 about here****

DISCUSSION

The purpose of this study was to determine in inter-day reliability of a testing battery for the assessment of physical qualities. Overall, the variability exceeded the statistically determined ‘smallest worthwhile change’ in performance, but was less than that typically observed after a preseason training period or intervention. This suggests the testing battery used can detect a meaningful change with 75% confidence comparable that typically observed or that is considered feasible. The testing battery was quick and simple to administer, and required minimal equipment and expertise, thus enables rugby league practitioners to use our results when interpreting differences between players and for assessing the effectiveness of training programmes.

The reliability of 10 and 20 m sprint times was similar to that previously reported (4.2% cf. 3.1% and 3.6% cf. 1.8%, respectively) (11). However, it is important to note that the study by Darrall-Jones et al. (11) used a combination of rugby league and rugby union players who likely present different anthropometric characteristics and running mechanics (10). The TE for 10 and 20 m sprint times was greater than the SWC for both distances; however, when considering the reliability of sprint performance against previously reported improvements, both distances appear sensitive enough to detect the observed change (TE 0.08 cf. 0.13 s; CV 4.2% cf. 7.3%) after an 8-week preseason training period in professional rugby league players (8). Indeed, using a magnitude-based inferences approach our analysis revealed that an individual change was lower than the improvement observed over 10 (0.11 cf. 0.13 s) and 20 m (0.15 cf. 0.18 s) after a 8-week strength and power preseason training block (8). Inter-day comparisons for 10 and 20 m sprint performance were best between trials 1 and 2, suggesting that habituation to sprint tests is not required with academy rugby league players.

To the authors' knowledge, this is the first report of between-session reliability for momentum in professional rugby league players. The TE for 10 and 20 m momentum was greater than the SWC. Nonetheless, based on the mean body mass (96.2 ± 11.11 cf. 97.7 ± 11.13 kg), 10 m sprint times (1.78 ± 0.07 cf. 1.65 ± 0.08 s) and 20 m sprint times (3.03 ± 0.09 cf. 2.85 ± 0.11) reported by Comfort et al. (8) before and after 8 weeks of preseason strength and power training, changes in momentum would be of greater magnitude than the TE (52 and 51 cf. 25 $kg·m·s^{-1}$, respectively) and CV% (9.6 and 8.0 cf. 5.5%, respectively) reported in this study. Our results revealed that a 34 and 19 $kg·m·s^{-1}$ improvement over 10 and 20 m, respectively, is required to be 75% confident the change is meaningful (22), which could feasibly be achieved through a reduction in sprint times or an increase in body mass. These results, combined with the inter-day comparisons, suggest that momentum could be a useful measure for practitioners in rugby league to assess the combined effect of an individual's body mass and sprint capability over 10 m and 20 m.

Our data indicate that the CMJ is a reliable measure of lower-body muscle function and is improved when a participant's hands remain on their hips (CV% = 5.9% cf. 6.2%). The use of an arm swing during jumping can improve jump height due to an increased release velocity and centre of mass (30). The use of arms allows the athlete to use energy in the elbow, shoulder and hip to increase the kinetic energy at take-off and increase the vertical 'pull' on the trunk (30). However, with the added movement complexity, the arm swing increases the within-participant variability between jumps. Our results also indicate that reliability was best for CMJ with arms between trials 2 and 3 suggesting that habituation is required. Overall, the CV% for CMJ without arms are similar to that reported by Cormack et al. (9) and reliability is smaller than typical improvements in jump performance observed in young (7.2%) but not senior (4.5%) team sport players after preseason training (16). Furthermore, our data revealed that the TE is sufficient to confidently detect a change (3.4 cm) which is less than that previously observed in junior rugby players after a 14-week preseason training programme (~4.2 cm) (16). Inter-day reliability for CMJ with arms was best between trials 1-2 suggesting that habituation is not required when using academy rugby league players.

The medicine ball throw has been used as a measure of whole-body muscle function in rugby players that is valid and reliable (34). However, it is important to note that several techniques have been adopted. The present study required participants to throw a medicinal ball from the chest in a standing position to better replicate the upper-body actions of rugby league, e.g. a ‘hand-off’. The variability was greater than the SWC in medicine ball throw performance, whilst an increase of 0.7 m in distance would be required to ensure an improvement is beneficial with a certainty of 75% (22). As the TE was greater than the SWC, practitioners who want to use the medicine ball throw should consider incorporating this into training to regularly assess whole-body power (23). The reliability of the medicine ball throw was likely influenced by use of the lower-body as well as the lack of control over the release angle. Notwithstanding this, using the results of Speranza et al. (33) who reported an increase in plyometric push-up performance of 11.9% after an 8-week preseason training period in semi-professional rugby league players, the medicine ball throw could detect large changes (>0.7 m) in whole-body muscle function, albeit further research is required to confirm this.

Our results indicated good reliability for the change of direction test, albeit the variability exceeded what is considered the SWC in left, right and total time. Nonetheless, the variability is less than the typical change (junior = 17.7% and senior 16.3%) in 'L run' times after a 14-week preseason period using rugby league players (16). To achieve 75% confidence, an improvement of -0.31, -0.35 and -0.67 s for left, right and total change of direction times is required. However, directly comparing the absolute change required against that previously observed is difficult given the novelty of the test used and further research might reaffirm this. Inter-day comparisons revealed that the reliability was similar between all trials but was lowest between days 1 and 3 for left, right and total time, suggesting habituation to this test might be required. The change of direction test used in this study assesses a player's ability to change direction over several angles that better replicates the movement characteristics during intermittent team sport.

The variability associated with the prone Yo-Yo IR1 was greater than that considered to be the SWC in performance. The required change in individual performances when accounting for the TE corresponded with a 120 m (or 3 shuttles) increase in performance to be considering meaningful (22). To date, no research has reported the change in Yo-Yo IR1 performance after a training intervention or preseason training period using rugby league players. However, Bangsbo et al. (6) reported changes of between 12.7-31.1% after 6- to 12-weeks of soccer-specific, interval and repeated sprint training, a change that could confidently be detected with our reported TE. Whilst practitioners might use the reliable Yo-Yo IR1 for assessment of running alone, the modified Yo-Yo presented here offers an opportunity to assess high-intensity intermittent running incorporating a match specific-task with sufficient reliability.

While every effort was made to reduce the contribution of fatigue by conducting tests on the day after a scheduled rest day, collecting data during pre-season means players were likely to be subject to higher training volumes than other times of the year (18). Therefore, it is possible that some residual fatigue from training several days beforehand each test might have contributed to a larger variability between trials. Future research might consider using perceptual measures of fatigue to quantify recovery status when establishing the inter-day reliability of this testing battery. This notwithstanding, our data are taken from a large sample size within a professional training environment that reflects the real-world variability in performance. It also noteworthy that the test order was different for the two groups although results (not reported) revealed minimal difference in reliability (for example, 10 m sprint time: group 1; TE = 0.08 and CV = 4.5%, and group 2; TE = 0.08 and CV = 3.9%).We would, however, recommend that practitioners perform the testing in the following order to minimise any influence of residual fatigue on test performance: warm up, 10 and 20 m sprint, change of direction test, CMJ, medicine ball throw, and prone Yo-Yo IR1.

PRACTICAL APPLICATIONS

Our results support the interpretation of tests of physical qualities and provide a novel approach using magnitude-based inferences. All performance tests demonstrate acceptable reliability in the context of detecting a typical change after a training intervention and/or preseason training period using rugby league players. However, the variability associated with each performance measure, when tested in the ‘field’, was greater than that required to detect the smallest worthwhile change in performance. Between-trial comparisons revealed that, for the most part, habituation was not required when using rugby league players. Due to the large between-trial variation during the medicine ball throw, researchers might wish to investigate the reliability and sensitivity of the medicine ball throw when controlling variables such as release angle. Our results also revealed that the reliability of the CMJ was improved when participants placed their hands on their hips and that the between-trial reliability of momentum was acceptable and can be used to assess the relationship between body mass and 10 and 20 m sprint capacity. Future research should establish the usefulness of this testing battery to monitor changes in players’ physical qualities over a season or during specific training periods (e.g. preseason). Where time and resources are scarce, this testing battery can be conducted in a relatively short time frame (<75 min), does not impact on other training and requires minimum specialist equipment.

ACKNOWLEDGEMENTS

The authors wish to thank all participants and Super League clubs who took part in the study.

REFERENCES

1. Atkins, SJ. Performance of the Yo-Yo intermittent recovery test by elite professional and semiprofessional rugby league players. *J strength Cond Res* 20(1): 222-225, 2006.

2. Atkinson, G, and Nevill, AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 24(4): 217-238, 1998.

3. Austin, DJ, Gabbett, TJ, and Jenkins, DG. Reliability and sensitivity of a repeated high-intensity exercise performance test for rugby league and rugby union. *J Strength Cond Res* 27(4): 1128-1135.

4. Baker, DG, and 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* 22(1): 153-158, 2008.

5. Baker, DG, and Newton, RU. Discriminative analyses of various upper body tests in professional rugby league. *Int J Sports Physiol Perform* 1(4): 347-360, 2006.

6. Bangsbo, J, Iaia, FM, and Krustrup, P. The Yo-Yo intermittent recovery test: a useful tool for evaluation of physical performance in intermittent sports. *Sports Med* 38(1): 37-51, 2008.

7. Batterham, AM, and Atkinson, G. How bid does my sample need to be? A primer on the murky world of sample size estimation. *Phys Ther Sport* 6: 153-163, 2005.

8. Comfort, P, Haigh, A, and Matthews, MJ. Are changes in maximal squat strength during preseason training reflected in changes in sprint performance in rugby league players? *J Strength Cond Res* 26(3): 772-776, 2012.

9. Cormack, SJ, Newton, RU, McGuigan, MR, and Doyle, TLA. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform* 3(2): 131-144, 2008.

10. Cross, MR, Brughelli, M, Brown, SR, Samozino, O, Gill, ND., Cronin, JB, and Morin, JB. Mechanical properties of sprint in elite rugby union and rugby league. *Int J Sports Physiol Perform* 10(6): 695-702, 2015.

11. Darrall-Jones, JD, Jones, B, and Till, K. Anthropometric and physical profiles of English academy rugby union players. *J Strength Cond Res* 29(8): 2086-2096, 2015.

12. Dobbin, N, Hunwicks, R, Highton, J, and Twist, C. Validity of a jump mat for assessing countermovement jump performance in elite rugby players. *Int J Sprots Med* 38(2): 99-104, 2017.

13. Gabbett, TJ. Physiological characteristics of junior and senior rugby league players. *Br J Sports Med* 36(5): 334-339, 2002.

14. Gabbett, TJ. Science of rugby league: a review. *J Sports Sci* 23(9): 961-976, 2005a.

15. Gabbett, TJ. A comparison of physiological and anthropometric characteristics among playing positions inn junior rugby league players. *Br J Sports Med* 39(9), 675-680: 2005b.

16. Gabbett, TJ. Performance changes following a field conditioning program in junior and senior rugby league players. *J Strength Cond Res* 20(1): 215-221, 2006.

17. Gabbett, TJ. Sprinting patterns of national rugby league competition. *J Strength Cond Res* 26(1): 121-130, 2012.

18. Gabbett, TJ, and Domrow, N. Relationship between training load, injury, and fitness is sub-elite collision sport athletes. *J Sport Sci* 25(13): 1507-1519, 2007.

19. Gabbett, TJ, and Gahan, CW. Repeated high-intensity effort activity in relation to tries scored and conceded during rugby league match-play. *Int J Sports Physiol Perform* 11(4): 530-534, 2015.

20. Gabbett, TJ, Kelly, JN, and Sheppard, JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res* 22(1): 174-181, 2008.

21. Gabbett, TJ, and Seibold, AJ. Relationship between tests of physical qualities, team selection, and physical match performance in semiprofessional rugby league players. *J Strength Cond Res* 27(12): 3259-3265.

22. Haugen, T, and Buchheit, M. Sprint running performance monitoring: methodological and practical considerations. *Sports Med* 46(5), 641-656, 2016.

23. Hopkins, WG. How to interpret changes in an athletic performance test. *Sportscience* 8: 1-7.

24. Hopkins, WG. Measures of reliability in sports medicine and science. *Sports Med* 30(1): 1-15, 2000a.

25. Hopkins, WG. Precision of the estimate of a subject's true value (Excel spreadsheet). *Sportscience.* Retrieved from htpp://www.sportsci.org/resource/stats/xprecisionsubject.xls, 2000b.

26. Hopkins, W. Spreadsheets for analysis of controlled trials, with adjustment for a subject characteristic. *Sportscience,* 10: 46–50, 2006.

27. Hopkins, WG, Marhsall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sport medicine and exercise science. *Med Sci Sport Exerc* 41(3): 3-13(2009).

28. Johnson, DL, and Bahamonde, R. Power output estimate in university athletes. *J Strength Cond Res* 10(3): 161-166, 1996.

29. Johnston, RD, Gabbett, TJ, Jenkins, DG, and Hulin, BT. Influence of physical qualities on post-match fatigue in rugby league. *J Sci Med Sport* 18(2): 209-213, 2015.

30. Lees, A, Vanrenterghem, J, and De Clercq, D. Understanding how an arm swing enhances performance in the vertical jump. *J Biomech* 37(12): 1929-1940, 2004.

31. Mullen, T, Highton, J, and Twist, C. The internal and external responses to a forward-specific rugby league simulation protocol performed with and without physical contact. *Int J Sport Physiol Perform* 10(6): 746-753, 2015.

32. Scott, TJ, Delaney, JA, Duthie, GM., Sanctuary, CE, Ballard, DA., Hickmans, JA, Dascombe, B.J. Reliability and usefulness of the 30-15 intermittent fitness test in rugby league. *J Strength Cond Res* 29(7): 1985-1990, 2015.

33. Speranza, MJA, Gabbett, TJ, Johnston, RD, and Sheppard, JM. Effect of strength and power training on tackling ability in semiprofessional rugby league players. *J Strength Cond Res* 30(2): 336-343, 2016.

34. Stockbrugger, BA, and Haennel, RG. Validity and reliability of a medicine ball explosive power test. *J Strength Cond Res* 15(4): 431-438, 2001.

35. Thomas, A, Dawson, B, and Goodman, C. The yo-yo test: reliability and association with a 20-m shuttle run and VO(2max). *Int J Sport Physiol Perform* 1(2): 137-149, 2006.

36. Till, K, Cobley, S, O'Hara, J, Brightmore, A, Cooke, C, and Chapman, C. Using anthropometric and performance characteristics to predict selection in junior UK rugby league players. *J Sci Med Sport* 14(3): 264-269, 2011.

37. Till, K, Scantlebury, S, and Jones, B. Anthropometric and physical qualities of elite male youth rugby league players. *Sports Med.* doi: 10.1007/s40279-017-0745-8, 2017.

38. Waldron, M, Worsfold, PR, Twist, C, and Lamb, K. The relationship between physical abilities, ball-carrying and tackling among elite youth rugby league players. *J Sport Sci* 32(6): 542-549, 2014.

Figure 1. Schematic representation of the pre-planned agility test.