DIFFERENCES IN GLENOHUMERAL JOINT ROTATION AND PEAK POWER OUTPUT BETWEEN SUPER LEAGUE AND CHAMPIONSHIP RUGBY LEAGUE PLAYERS

Running Head: Glenohumeral Joint Rotation and Peak Power in Rugby League Players

Matthew R. Haines*

Department of Health Sciences, University of Huddersfield, Queensgate Campus, Huddersfield, HD1 3DH

*Corresponding author: m.haines@hud.ac.uk, 01484 472701

Differences in Glenohumeral Joint Rotation and Peak Power Output between Super League and Championship Rugby League Players

ABSTRACT

Rugby league is a high-intensity sport with large impact forces sustained during play resulting in high prevalence of shoulder injury. Consequently, shoulder strength and player power are important considerations for injury prevention and performance. Additionally, professional teams regularly compete against semi-professional teams, where differences in physical conditioning could be marked. The aim of this study was to test for differences in glenohumeral joint rotation and peak power between a professional Super League (SL) and semi-professional Rugby League Championship (RLC) team. A cross sectional analysis was used to test 25 SL and 24 RLC players during pre-season training. Isokinetic dynamometry, at $240°\cdot s^{-1}$ for concentric and eccentric actions, was used to assess glenohumeral rotation. Peak power was determined using a maximal 30-s cycle ergometer test. Selective muscular development of the internal rotators without concomitant external rotator strength was evident in the SL team but not the RLC team. Internal rotation peak torque was higher for the SL club for concentric (~24%) and eccentric (~16%) muscle actions ($P < 0.05$), and this contributed to a lower ipsilateral reciprocal muscle group ratio (external/internal concentric) for the SL team compared to the RLC team (~47% and ~60% respectively; $P < 0.05$). Peak power output was also higher for the SL team (1409 ± 153 *vs*. 1273 ± 159 W; $P < 0.05$). The results highlight a mismatch in the physical conditioning of SL and RLC players with implications for practitioners to design strength and conditioning programmes that minimise the risk of injury whilst optimising performance.

KEY WORDS isokinetic, injury, shoulder, ergometery, strength

INTRODUCTION

Rugby league is a high-intensity collision sport played predominantly in Australia, England and Pacific Island countries. The game is characterised by frequent physical contact and high impact forces, including a faster style of play with more passing, open field running, and tackling compared to rugby union. Players engage in 20–40 physical confrontations per game (1) with anecdotal reports (2) of regular negative accelerative (deceleration) forces ten times that of acceleration due to gravity (i.e. -980 $m \cdot s^2$). Studies have found the physiological capacities of players, the incidence of injury and the physiological demands of the sport all increase as the playing standard is increased (3). Consequently, the physical conditioning of players for performance and injury prevention is paramount in rugby league, with an emphasis on the development of strength and power (4).

Specifically, the ability to rapidly generate high muscular force is an important performance attribute, and the relative mass and speed of the opponent are important factors for injury risk during tackling. These are timely considerations in English rugby league as a recent re-structuring of the competition means that full-time professional teams from the Super League (SL) regularly compete against teams from the Rugby League Championship (RLC), who are mostly semi-professional. In this regard, it is likely that SL teams can dedicate more time to training, strength and conditioning and recovery compared to RLC teams. Recent research revealed no difference in body mass between SL and RLC players, but lean mass was significantly greater in the SL players (5). An improved ability to accelerate mass results in a high amount of force entering a tackle, whilst improved shoulder strength might allow for better tolerance of associated forces during the acts of tacking and being tackled. These physical characteristics might provide an advantage for SL teams, both of which fall under the remit of strength and conditioning specialists.

Based on pooled data analysis, the incidence of injury in rugby league is high with 40.3 injuries sustained per 1000 player hours (6). A recent systematic review (7) reported that shoulder injuries represent 28% of all injuries in rugby players, and that shoulder lesions are more likely in the ball carrier during a tackle when the adducted arm is placed on the front-side of contact as a shield-mechanism, exposing the joint to excessive collision force. In a retrospective analysis of rugby specific intra-articular shoulder pathology, Horsley et al. (8) reported the primary mechanism of injury was direct tackling in 56% of cases. At arthroscopy, superior labrum anterior to posterior (SLAP) lesions (83%), rotator cuff tears (43%), inferior or posterior labrum lesions (34%), and Bankart lesions (33%) were reported. Furthermore, most players exhibited multiple shoulder pathologies (75% of cases). The increased forces and subsequent risk of shoulder pathology are likely a result of the increased aggression and intensity with which the game is played, as it has changed from a largely amateur sport to one that is now played professionally (9).

Furthermore, it has been suggested that the frequency and severity of shoulder injuries has increased in recent years (9). Several mechanisms during game play have been identified to explain this trend, including both defensive tackling and offensive players being tackled (10). In both instances impact directed to the anterior-superior surface of the shoulder and humerus results in posteriorly directed force and horizontal abduction of the arms and subsequent leveraging forces over the glenohumeral joint. The strength of rotator cuff and scapular skeletal muscles which provide stability to the joint, could have an important protective role in injury risk during the large deceleration forces inherent during physical contact in rugby league. This could also enhance defensive play through an improved ability to tackle an offensive player with an abducted arm, and during a smothering tackle when the tackler attempts to hold up the ball carrier to prevent passing (or off-loading) of the ball during the tackle.

These are important considerations for strength and conditioning professionals who are concerned with developing practices that develop robust players which optimise performance whilst minimising the risk of injury during game play. Significant time within strength and conditioning programmes is dedicated to prehab with the aim of preventing common injuries. Therefore, considering that strength of muscle around the shoulder and player power are important considerations for both injury prevention and optimal performance, the aim of this study was to compare glenohumeral joint function and peak power output between SL and RLC teams. This was deemed particularly relevant since the professional status of a club likely effects the time available for training and strength and conditioning support, which disadvantages semi-professional teams. The experimental hypothesis was that SL teams would have superior strength and power compared to the RLC team.

METHODS

Experimental Approach to the Problem

With institutional ethics approval and permission from the respective rugby clubs, a cross-sectional analysis was used to compare glenohumeral joint rotation and peak power (dependent variables) between a professional SL team and a semi-professional RLC team (independent variable). Isokinetic dynamometry and cycle ergometery were used to assess glenohumeral joint rotation and peak power output, respectively. Testing these physiological parameters enabled comparison between the teams to consider the experimental hypothesis. Muscle performance parameters have been measured in several sports using isokinetic dynamometry and can be measured reliably during shoulder rotation, although greater variability may be expected during eccentric testing (11). Cycle sprints rely on a player's capacity to generate high levels of lower body muscular impulse and power and as such, are effective methods of evaluating maximal intensity exercise relevant to rugby league (12). The players from each team attended the laboratory for testing on separate occasions during the latter stages of pre-season, prior to their first competitive league games. Each team attended the laboratory at the same time of day (morning) and undertook isokinetic dynamometry before cycle ergometery following a short rest. Player nutrition prior to testing was not monitored and blinding of assessors who measured outcome measures was not possible.

Subjects

Forty-nine players provided informed consent to undertake testing, consisting 25 SL players (stature, 1.83 m ± 0.04 m; mass, 96.7 ± 11.3 kg; age, 26.6 ± 3.9 years) (mean ± SD) and 24 RLC players (stature, 1.84 m ± 0.05 m; mass, 94.1 ± 8.0 kg; 25.9 ± 3.2 years). Players were informed of the benefits and risks of the investigation prior to signing an informed consent form to participate, and the study was approved by the University of Huddersfield ethics panel. There were no players under the age of 18 years in this study. The players included were representative of the teams' first grade squads, and therefore included both forwards (props, hookers, second rowers and loose forwards) and backs (half-backs, centres, wingers and full-backs), and had varying rugby league experience. Players were excluded from either isokinetic dynamometry or cycle ergometery if they had an existing injury. Furthermore, players were excluded from isokinetic dynamometry if they had neck or shoulder surgery within the previous 16 weeks.

Procedures

Isokinetic dynamometry

Isokinetic dynamometry was used to assess glenohumeral joint rotation using a Cybex HUMAC (HUMan Assessment Computer) NORM Testing & Rehabilitation System and data were analysed using HUMAC2009 software version 9.8.4 (CSMI, Stoughton, MA, USA). The dynamometer calibration was checked prior to each testing session and gravity correction was applied to torque data by weighing the limb in a relaxed position with the arm at anatomical zero (see below for definition). The fastest manufacturer cushion setting of 5 was used to decelerate the dynamometer arm to $0°·s^{-1}$ at the ends of the range of motion (ROM).

A modified base position was used with the player standing. With the dynamometer tilted at 30° from the transverse plane, the glenohumeral joint was placed in 30° of abduction and 30° of forward flexion into the scapular plane (scaption). Using the elbow stabiliser pad, the olecranon was aligned with the dynamometer's mechanical axis of rotation with the dynamometer height adjusted to ensure the shoulder was in a neutral position (i.e. not elevated or depressed). This position permits enhanced bony congruity and a neutral glenohumeral position, resulting in a mid-range position for the anterior capsular ligaments and an enhanced length-tension relationship of the rotator cuff muscles (13). This protocol also minimises the risk of supra-humeral impingement and is deemed safe for most pathologies and postoperatively (14). Anecdotally, strength and conditioning coaches and physiotherapists typically test shoulder rotation in rugby league players at 0° and 90° of abduction. However, functional activity rarely occurs in the frontal or sagittal plane but rather in a mid-position of flexion and abduction. The protocol used in this study was considered a compromise between these two positions, and was considered to more closely mimic sporting positions during rugby league game play. Furthermore, it has been recommended that tolerance of this test is a required precursor to use of the 90° glenohumeral joint abduction position (15). Relative and absolute reliability of common strength imbalance ratios and isokinetic peak torque muscle strength is considered acceptable for use in sports medicine using the Cybex NORM (16). Relative technical error of measurement values ranging from 3.2% to 4.9% (dependant on dynamometer speed) have been recorded for shoulder rotation in the scapular plane test position in our laboratory, which is in-line with other research which has shown this can be measured reliably (11).

Concentric and eccentric muscle actions for shoulder internal and external rotation were evaluated at $240°\cdot s^{-1}$. Within manufacturer recommended ROM limits, of 80° internal rotation and 60° external rotation relative to anatomical zero (defined as 0° with the forearm placed in the sagittal plane), players self-selected a 'comfortable' full range of motion. To familiarise, players performed three submaximal repetitions for each movement, followed by a warm-up set at $120°\cdot s^{-1}$. Players then performed four maximal repetitions for each action in a standardised order, before repeating on the contralateral limb (Table 1). Standardised verbal encouragement and visual feedback in the form of peak torque bars for each repetition were used throughout to ensure maximal torque was generated in all actions. It was not possible to secure players with pelvic and diagonal straps for trunk stabilisation due to the standing position, although players were encouraged to maintain a strict technique only moving at the shoulder. Torque *vs*. position curves were inspected for each repetition, to check for spurious data, with peak torque across all reps recorded for each action.

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

Cycle ergometery

A Wattbike cycle ergometer (Wattbike Pro, Nottingham, UK) was used to assess anaerobic capacity with absolute and relative peak power output recorded. Saddle height was adjusted for each player to ensure close to full knee-joint extension (~170°) when the pedal was at the bottom of the cycle. After a

3-min warm-up pedalling at a comfortable intensity, players performed a single ‘all-out’ 30 s cycling sprint using the air and magnetic settings to create a flywheel braking force appropriate for peak power generation, as recommended by Wattbike (17). This is like the Wingate test (18) protocol designed for the Monark cycle ergometer which relies on loading weights relative to body mass to create flywheel resistance. However, the Wattbike calculates power output by measuring real time chain tension over a load cell (sampled at 100 Hz) based on known crank length, the average force per crank revolution, and the time taken to complete a crank revolution. The 30-s sprint test on the Wattbike has been shown to be highly reproducible for absolute and relative peak power (19).

Statistical Analyses

Statistical analyses were carried out using IBM SPSS Statistics version 22 (IBM, Armonk, NY, USA) with the alpha level for significance set at 0.05. Before analyses, data were explored to check assumptions. Normality of data was assessed via visual inspection using histograms, stem-and-leaf-plots and Q-Q plots in addition to a Shapiro-Wilk normality test, which is considered the preferable method for a sample size < 50 (20). One-way analysis of variance (ANOVA) was used to compare all parameters between SL and RLC teams. The assumption of homogeneity of variance was checked using Levene’s test and with this satisfied, Bonferroni *post-hoc* analyses were used to determine where significant differences occurred. Bonferroni correction was used to control for familywise error rate. The magnitude of differences was calculated using Cohen’s *d*, interpreted using a modified scale proposed to better define the thresholds for moderate and large effects: 0.0–0.19 ‘trivial’, 0.2–0.59 ‘small’, 0.6–1.19 ‘moderate’, 1.2–1.99 ‘large’ and > 2.0 ‘very large’ (21).

RESULTS

Glenohumeral internal rotation peak torque was significantly higher for the SL club with a moderate effect size for concentric (right arm: 24%, ES = 0.72; left arm: 23%, ES = 0.67) and eccentric (right arm: 17%, ES = 0.66; left arm: 16%, ES = 0.71) muscle actions ($P < 0.05$) (Table 2). Concentric external rotation was also higher for the SL club with a small effect size, although this was not statistically significant. However, there was no difference in eccentric external rotation between the clubs. These values contributed to a lower ipsilateral reciprocal muscle group ratio (concentric external/concentric internal) for the SL club compared to the RLC club (~47% and ~60% respectively; $P < 0.05$). There was no difference between left and right shoulder rotation within each club.

Cycle ergometery peak power was also higher for the SL club compared to the RLC club, in both absolute (1409 ± 153 *vs*. 1273 ± 159 W, ES = 0.89; $P = 0.01$) and relative terms (9.0 ± 0.7 *vs*. 8.4 ± 0.6 $W \cdot kg^{-1}$, ES = 0.99; $P = 0.01$). The mean mass and stature of players in the two teams were not different.

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

DISCUSSION

The main finding of this study was that SL players demonstrated greater strength during glenohumeral internal rotation compared to RLC players. Both concentric (~24%) and eccentric (~16%) peak torque was significantly higher ($P < 0.05$; see Table 2). This could be an important consideration for both injury prevention and optimal performance, especially since RLC players regularly compete against SL players under the new competition structure in England. Forces placed upon the shoulder during a rugby tackle have been measured at over 1600 N and are normally tolerated by the tissues of the shoulder (22). However, repeated stressful positions that cause leveraging force across the shoulder, during the acts of tackling and being tackled, are likely to contribute to injury. Increased strength of internal rotator muscles, especially during eccentric muscle actions (deceleration), might improve tolerance of posteriorly directed forces and rapid limb deceleration in horizontal abduction in SL players, which may in-turn reduce the incidence of injury. An increased rate of shoulder injury has been reported in forwards compared to backs in rugby union (23) due to the higher rate of tackles per match, although others (24) have reported an increased rate of tackle-derived shoulder injuries for backs. Therefore, it is likely that strength increases in the rotator cuff and scapular muscles could be protective in all playing positions. Furthermore, it is possible that the greater strength observed in SL players enhances defensive play though an improved ability to tackle with an abducted arm, and to hold up an offensive player to prevent off-loading of the ball during a tackle.

Despite the increased strength in internal rotation for SL players, there was no difference in external rotation. Therefore, this study provides preliminary evidence that professional SL players have selective strength development of the internal rotators of the shoulder (i.e. subscapularis, pectoralis, latissimus dorsi), comparable to sports that include repetitive overhead movements (e.g. tennis [25]). This contributed to a lower ipsilateral reciprocal muscle group ratio (external concentric/internal concentric) for the SL club compared to the RLC club. The external rotators could generate ~47% of the force of the internal rotators, compared to ~60% for the RLC players. Although sport specific norms for optimal shoulder stability and performance are not available, muscular deficiency or imbalance of the internal and external shoulder rotators are considered probable mechanisms of shoulder injuries. Alterations in this ratio have also been reported in patients with glenohumeral joint instability and impingement (26, 27). A ratio of ~66% is considered normal in the absence of pathology (28). This imbalance was not evident for the semi-professional RLC players and might be explained by the greater amount of time that professional teams can dedicate to strength and conditioning. Modern SL players complete considerable strength training and can develop imbalances typical of weightlifters which may increase susceptibility to shoulder injuries due to practices that create postural imbalances from muscle strength and flexibility (10). McDonough and Funk (29) demonstrated limited shoulder active ROM in professional rugby players further compounding this problem.

In contrast, Edouard et al. (30) compared external/internal rotation strength ratios for rugby players with non-athletic controls and reported no significant differences, suggesting muscle imbalance was not a significant risk factor for glenohumeral injury. Furthermore, the use of peak torque ratios to describe optimal joint function is problematic. Despite convention of reporting concentric ratios (e.g. external concentric/internal concentric), this is not how muscles operate during functional movement. Rather, eccentric antagonist co-activation and serial elastic tension resists concentric agonist action, or vice versa (31). Furthermore, ratios are dependent on angular velocity, test position and gravity compensations (32), although glenohumeral joint rotation is one of few ipsilateral strength ratios that remains consistent across the velocity spectrum (15). As such, although optimal reciprocal strength across the shoulder musculature is likely important to promote control of scapular humeral motions, inferences regarding injury risk remain speculative.

Another finding of this study was that peak power output was moderately higher for the SL club compared to the RLC club, in both absolute (1409 ± 153 *vs*. 1273 ± 159 W, ES = 0.89; $P = 0.01$) and relative terms (9.0 ± 0.7 *vs*. 8.4 ± 0.6 $W \cdot kg^{-1}$, ES = 0.99; $P = 0.01$). Increased power is likely to result in an improved ability to sprint and break through defensive tackles, yet previous research has seldom considered power output of rugby league players using cycle ergometery; instead there is a predilection to record one-repetition maximum strength and rate of force development during vertical jump tasks (for e.g. see 3, 33). Nevertheless, a recent study in semi-professional rugby league players demonstrated that enhancement of lower-body muscular strength and power are associated with improvements in tackling ability (34). Therefore, lower body muscular power is an important attribute in rugby league for defensive and offensive play and when combined with the findings in the present study regarding glenohumeral joint rotation strength, there is a potential mismatch in the physical conditioning of players between professional and semi-professional clubs. The SL player can generate more force entering a tackle, whilst concurrently the RLC player is less able to tolerate the high impact forces directed to the anterior-superior surface of the shoulder sustained during tackling. This has clear implications for the risk of injury and performance.

This study also supports the findings of Jones et al. (5) in that stature and body mass are similar between SL and RLC players, but differences in body composition exist. Although body composition was not measured in this study, the finding that relative power output (W·kg) was significantly higher for the SL players suggests that RLC players might be at a disadvantage due to less lean tissue. These differences are likely to be explained by the amount of time that SL players can dedicate to training, strength and conditioning, prehab and recovery, in addition to more extensive sports science support in terms of nutrition and rehabilitation from injuries.

Several limitations should be considered alongside the findings of this study. Differences in glenohumeral joint rotation function and peak power output were examined between one SL and one

RLC team. As such this is a confined cohort of rugby players which may not be representative of the wider Super League or Rugby League Championship competitions. It is therefore difficult to generalise these findings to other teams in either competition. However, it was possible to collect data from a representative sample of players from each squad (i.e. most of the player roster). Furthermore, player position, limb dominance, preferred tackling arm and previous injury are co-variables that were not considered. Finally, the mechanical rationale for isokinetic dynamometry is predicated on the resistance of the device being equal to the applied muscular torque which is dependent on the velocity of movement being controlled and maintained constant (35). This does not mimic the rapid accelerations inherent during game play; nor does the angular velocity used in this study which, although considered somewhat fast for isokinetic dynamometry, is slow compared with the velocities that occur during rugby league tackling.

PRACTICAL APPLICATIONS

Strength and conditioning practitioners should be aware that semi-professional rugby league players could benefit from selective conditioning to improve the stability and strength of scapular muscles to better tolerate the repeated physical confrontations inherent in the game. This applies to both offensive and defensive situations where increased strength could protect the shoulder from the high impact forces sustained when tackling and being tackled. Practitioners should develop creative programmes for players that are consistent with the mechanics, energy system requirements and injury profiles of the sport. Exercises that recruit individual rotator cuff muscles are not necessarily optimal (36) because muscle co-contraction and coordination are important for good scapula mechanics. This can be facilitated using whole kinetic chain exercises, and functional postures and activities combined with a shoulder exercise to offer greater kinetic chain input to further improve shoulder proprioception (29). Furthermore, the predominant energy pathways during rugby league are the aerobic and anaerobic alactic (ATP-PC) energy systems, and there is a requirement for players to engage in physical confrontations in a fatigued state. As such graduated falls and contact could be simulated in a controlled environment whilst fatigued to improve joint position sense (29).

A further consideration for practitioners and researchers alike is the optimal reciprocal muscle group strength ratio of the shoulder. The findings of this study suggest that selective muscular development of the internal rotators without concomitant external rotation strength is evident in professional rugby league players. Biasing strength training programmes in favour of the external rotators is recommended for the prevention of injury is some sports, as well as after insult or surgery to the glenohumeral joint (37). Thus, infraspinatus strengthening may reinforce the posterior capsule and aid posterior joint stability (38). For strength and conditioning coaches, dynamic stabilisation of the glenohumeral joint is key to shoulder stability in rugby league; however, there is a possible trade-off between the ideal strength ratio which might be protective against injury on the one hand, and the requirement for strong internal rotators to tolerate the forces involved in physical contact on the other. This might present a conflict in the aims of strength training for strength and conditioning specialists working in rugby league and should to be considered on an individual player basis. Finally, considering that RLC players are mainly employed part-time, practitioners must consider training practices designed to elicit performance gains in a time limited environment. The differences between professional and semi-professional players in this study suggests that RLC players might benefit from a focus on enhancing the strength of rotator cuff and scapular skeletal muscles, in addition to increasing whole body power relative to body mass.

REFERENCES

1. Gissane, C, White, J, Kerr, K and Jennings, D. Physical collisions of professional Super League rugby, the demands on different player positions. Cleveland Medical Journal. 4: 137–146, 2001.

2. Funk, L. Rugby shoulder injuries: Prevention and screening. https://www.shoulderdoc.co.uk/article/1551. Accessed 04 Aug 2016.

3. Gabbett, TJ. Science of rugby league football: A review. J Sports Sc. 23(9): 961–976, 2005.

4. Meir, R, Colla, P, and Milligan, C. Impact of the 10-meter rule change on professional rugby league: Implications for training. Strength Cond J. 23: 42–46, 2001.

5. Jones, B, Till, K, Barlow, M, Lees, M, O'Hara, JP, and Hind, K. 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. doi: 10.1371/journal.pone.0133188

6. Gissane, C, Jennings, D, Kerr, K, and White, J. Injury rates in rugby league football: impact of change in playing season. The Am J Sports Med. 31(6): 954 – 958, 2003.

7. Papalia, R, Tecame, A, Torre, G, Narbona, P, Maffulli, N, and Denaro, V. Rugby and shoulder trauma: A systematic review. Transl Med UniSa. 12(3): 5–13, 2015.

8. Horsley, IG, Fowler, EM, and Rolf, CG. Shoulder injuries in professional rugby: a retrospective analysis. J Orthop Surg Res. 8: 9, 2013.

9. De Beer, J, and Bhatia, DN. Shoulder injuries in rugby players. Int J Shoulder Surg. 3(1): 1–3, 2009.

10. Helgeson, K, and Stoneman, P. Shoulder injuries in rugby players: Mechanisms, examination and rehabilitation. Phys Ther Sport. 15(4): 218–27, 2014.

11. Malerba, JL, Adam, ML, Harris, BA, and Krebs, DE. Reliability of dynamic and isometric testing of shoulder external and internal rotators. J Orthop Sports Phys Ther. 18(4):543–552, 1993.

12. Breivik, SL. Rugby league. In: Sport and Exercise Physiology Testing Guidelines. EM. Winter, AM. Jones, RCR. Davison, PD. Bromley and TH, Mercer, eds. Oxon: Routledge, 2007. pp. 256–61.

13. Saha, AK. Dynamic stability of the glenohumeral joint. Acta Orthop Scand. 42: 491–505, 1971.

14. Ellenbecker, TS, and Derscheid, GL. Rehabilitation of overuse injuries of the shoulder. Clin Sports Med. 8: 583–604., 1989.

15. Ellenbecker, TS, and Davies, GJ. The application of isokinetics in testing and rehabilitation of the shoulder complex. J Ath Training. 35(3): 338–50, 2000.

16. Impellizzeri, FM, Bizzini, M, Rampinni, E, Cereda, F, and Maffiuletti, NA. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. Clin Physiol Funct Imaging. 28(2):113–119, 2008.

17. Wattbike Full Test Guide. https://cdn.wattbike.com/uploads/uk/docs/wattbike-full-test-guide.pdf. Accessed 04 Aug 2016.

18. Bar-Or, O. The Wingate anaerobic test: an update on methodology, reliability and validity. Sports Med. 4: 381–94, 1987.

19. Driller, MW, Argus, CK, and Shing, CM. The Reliability of a 30-s Sprint Test on the Wattbike Cycle Ergometer. Int J Sports Physiol Perf. 8: 379–383, 2013.

20. Ghasemi, A, and Zahediasl, S. Normality Tests for Statistical Analysis: A Guide for Non-Statisticians. J Physiol. 10(2): 486–489, 2012.

21. Hopkins, W. A new view of statistics. http://sportsci.org/resource/stats/effectmag.html. Accessed 04 Aug 2016.

22. Usman, J, McIntosh, AS, and Fréchède, B. An investigation of shoulder forces in active shoulder tackles in rugby union football. J Sci Med Sport. 14(6): 547–552, 2011.

23. Usman, J, and McIntosh, AS. Upper limb injury in rugby union football: Results of a cohort study. Br J Sports Med. 47: 374–379, 2013.

24. Headey, J, Brooks, JH and Kemp, SP. The epidemiology of shoulder injuries in English professional rugby union. Am J Sports Med. 35: 1537–43, 2007.

25. Roetert, EP, Ellenbecker, TS, Chu, DA, and Bugg, BS. Tennis-specific shoulder and trunk strength training. Strength and Conditioning. 19(3): 31–43, 1997.

26. Warner, JP, Micheli, LJ, Arslanian, LE, Kennedy, J, and Kennedy, R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. Am J Sports Med. 18: 366–375, 1990.

27. Leroux, JL, Codine, P, Thomas, E, Pocholle, M, Mailhe, D, and Blotman, F. Isokinetic evaluation of rotational strength in normal shoulders and shoulders with impingement syndrome. Clin Orthop. 304: 108–115, 1994.

28. Ivey, FM Jr, Calhoun, JH, Rusche, K, and Bierhenk, J. Isokinetic testing of shoulder strength: normal values. Arch Phys Med Rehabil. 66: 384–386, 1985.

29. McDonough, A, and Funk, L. Critical reflection of the advanced rehabilitation of an elite rugby league player sustaining a posterior Bankart lesion. Phys Ther Sport. 14: 60–67, 2013.

30. Edouard, P, Frize, N, Calmels, P, Samozino, P, Garet, M, and Degache, F. Influence of rugby practice on shoulder internal and external rotators strength. Int J Sports Med. 30(12): 863–7, 2009.

31. Ostenig, LN, Hamil, J, Lander, JE, and Robertson, R. Co-activation of sprinter and distance runner muscles in isokinetic exercise. Med Sci Sports Exerc. 18: 431–435, 1986.

32. Coombs, R, and Garbutt, G. Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. J Sports Sci Med. 1: 56–62, 2002.

33. McMaster, DT, McGuigan, MR, and Gill, ND. Strength and power training for rugby. In: The Science of Rugby. C. Twist and P. Worsfold, eds. Oxon: Routledge, 2015. pp. 19–35.

34. Speranza, MJA, Gabbett, TJ, Johnston, RD, and Sheppard, JM. Effect of strength and power training on tackling ability in semi-professional rugby league players. J Strength Cond Res. 30(2): 336–342, 2016.

35. Baltzopoulos, V, and Brodie, DA. Isokinetic dynamometry: Applications and limitations. Sports Med. 8(2): 101–116, 1989.

36. Wilk, KE, Meister, K, and Andrews, R. Current concepts in the rehabilitation of the overhead throwing athlete. Am J Sports Med. 30(1): 136–151, 2002.

37. Wilk, KE, and Arrigo, CA. Current concepts in the rehabilitation of the athletic shoulder. J Orthop Sports Phys Ther. 18: 365–378, 1993.

38. Eckenrode, BJ, Logerstedt, DS, and Sennett, BJ. Rehabilitation and functional outcomes in collegiate wrestlers following a posterior shoulder stabilisation procedure. J Orthop Sports Phys Ther. 39(7): 550–559, 2009.

Table 1. Standardised order of isokinetic dynamometry muscle actions.

Set 1: IR CON
Set 2: IR ECC
Set 3: ER CON
Set 4: ER ECC
Repeat on contralateral limb

Abbreviations: IR = internal rotation, ER = external rotation, CON = concentric, ECC = eccentric.

Table 2. Isokinetic dynamometry and cycle ergometery results for Super League (SL) and Rugby League Championship (RLC) teams.

	SL (n = 25)	RLC (n = 24)	SL *vs*. RLC Difference	P =	Cohens d =
Right GHJ (Nm)					
IR CON	60.2 ± 20.3	45.6 ± 15.5	+ 24.2%	0.01*	0.72
IR ECC	87.9 ± 22.1	73.3 ± 17.4	+ 16.6%	0.02*	0.66
ER CON	33.9 ± 13.6	27.6 ± 10.5	+ 18.4%	0.12	0.46
ER ECC	49.6 ± 13.1	49.6 ± 8.2	0%	0.99	0.00
Left GHJ (Nm)					
IR CON	61.9 ± 21.7	47.4 ± 17.3	+ 23.4%	0.02*	0.67
IR ECC	86.2 ± 18.9	72.7 ± 15.4	+ 15.7%	0.02*	0.71
ER CON	32.8 ± 11.1	27 ± 9.2	+ 17.8%	0.07	0.52
ER ECC	50.1 ± 14.3	48.8 ± 1.2	+ 2.5%	0.76	0.09
Cycle ergometery					
PP (W)	1408.6 ± 153.3	1272.6 ± 159.1	+ 9.7%	0.01*	0.89
PP (W·kg)	9.0 ± 0.7	8.4 ± 0.6	+7.3%	0.01*	0.99

* SL and RLC values between groups are significantly different ($P \leq 0.05$) Abbreviations: GHJ = glenohumeral joint, IR = internal rotation, ER = external rotation, CON = concentric, ECC = eccentric, PP = peak power.