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Positional running capacities and in-game demands of South African university level rugby players

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Abstract

Rugby is a complex contact sport consisting of varying intensities of locomotion, interspersed with stationary and contact periods. An increasing professionalisation of the sport even at university and school level has engendered a growing need to collect objective data regarding the physical attributes of rugby players. The aim of the study was to assess the positional running capacities and demands of university rugby players. Twenty-nine male rugby players (age: 22.5 ± 1.2 years; body mass: 96.1 ± 13.26 kg; stature: 182.6 ± 7.5 cm) completed a battery of tests, which included: 10 m + 40 m sprint, yo-yo intermittent recovery (Yo-Yo IRT), repeated sprint ability test (RSA), and had their in-game running demands evaluated. Positional differences between forwards and backs were reported ($p<0.05$) for Yo-Yo IRT: 19.2 ± 2 vs 21.1 ± 2; 10 m sprint: 1.7 ± 0.1s vs 1.6 ± 0.0s; 40 m sprint test: 5.4 ± 0.3s vs 5.1 ± 0.1s; 5 m RST: 738.9 ± 31.1m vs 767.3 ± 20.9m. Additionally, a significant difference in-game distances between forwards and the backs (absolute: 5564.1 ± 842.5m vs 6955.9 ± 780.9m; relative: 54.7 ± 9.0 $m.min^{-1}$ vs 60.6 ± 8.7$m.min^{-1}$) were obtained. The assessment of university-level rugby players showed that backline players tend to record higher aerobic capacity, acceleration and sprint values than forwards. Evidence has shown that during matches, backs tend to cover more distance and spend more time in each speed band than forwards. The findings were discussed in the light of their implications for competitive rugby performance.

Keywords: Distance covered, positional differences, Rugby Union, GPS.

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Introduction

A rugby game is typically played for 80 mins, divided into two 40 mins halves where the ball is typically in play for an average of 30 minutes (Duthie, Pyne & Hooper, 2003; Cahill, Lamb, Worsfold, Heady & Murray, 2013). The remaining time consists of kicking attempts, scrummages and line-outs. This results in-game demands consisting of high-intensity efforts interspersed with recovery periods

(Read, Jones, Williams, Phibbs, Darrall-Jones, Roe *et al.*, 2018). Physical fitness characteristics in sport have been shown to be important as they are key indicators for both sporting success and injury (Arnason, Sigurdson, Gudmundsson, Holme, Engebretsen & Bahr, 2004; Smart, Hopkins, Quarrie & Gill, 2014; George, Olsen, Kimber, Shearman, Hamilton & Hamlin, 2015).

Owing to technological advances, the use of GPS to track athletes has become a convenient, efficient and popular method to quantify and analyse physical demands in sport (Petersen, Pyne, Portus & Dawson, 2009; Cahill *et al.*, 2013). This technique has been used in many sports as the preferred method of quantifying movement demands as the data are recorded in real time and can track multiple players at once (Jennings, Cormack, Coutts, Boyd & Aughey, 2010).

Specific to rugby, GPS has been used to quantify the in-game demands of various levels of competition. Total distance covered has been documented in multiple studies which documented different teams, ages and playing levels ranging in distances from 4800 m – 5370 m for forwards and 6200 m – 6500 m for backs (Cahill *et al.*, 2013; Swaby, Jones & Comfort, 2016; Cunningham, Shearer, Drawer, Eager, Taylor, Cook & Kilduff, 2016; Venter, Opperman & Opperman, 2011).

A necessary individual skill for rugby is the ability to occupy space by means of high running speeds or acceleration. That is, to achieve competence, a team needs to have the ability to occupy open spaces in the field quicker than their opponents. Thus, it may be beneficial for individuals to maintain a high velocity over time or have the ability to accelerate (Cummins, Orr, O'Connor & West, 2013). The ability to accelerate and reach high velocities is reliant on a well-developed anaerobic energy system, while the ability to repeatedly accelerate or repeatedly reach high velocities is reliant on a well-developed aerobic energy system (Kramer, Du Randt, Watson & Pettitt, 2019). Due to the increasing professionalization of the sport, even at a university competition level in South Africa. This increased popularity has led to a need to collect objective data regarding the physical and physiological attributes of the players. Recent advances in technology, such as GPS, may allow for increasingly in-depth evaluations, helping researchers have a better understanding of the physical and fitness demands of the various positions. Therefore, this study aims to investigate the running performances and in-game running demands of university level rugby players.

Methodology

Participants

A total of 29 South African male rugby players (age: 22.5 ± 1.2 years; body mass: 96.1 ± 13.26 kg; stature: 182.6 ± 7.5 cm) participated in the study.

Procedures and testing techniques

Body mass and stature were measured using a wall-mounted measuring tape (Seca Mechanical measuring tape, 206, Seca, USA) and electronic scale, respectively (Micro T3, 11816034, Micro, China). These measurements were reported to the nearest 0.1 cm and 0.1 kilogram, respectively. The Yo-Yo Intermittent Recovery Test (IRT) was used to evaluate cardiorespiratory capacity (Woolford, Polglaze, Rowsell & Spencer, 2013). Sprint times were assessed using a 40 m + 10 m test using timing gates (Smart speed pro, Fusion Sports, Queensland, Australia) placed at 0 m, 10 m and 40 m (Higham, Pyne & Mitchell, 2013). Each participant performed two trials and the fastest time was recorded. Repeated Sprint Ability (RSA) was evaluated using validated test protocols (Bishop, Spencer, Duffield & Lawrence, 2001) Briefly, the test consisted of six repetitions of a 30s maximal shuttle sprint over 5 m, 10 m, 15 m, 20 m and 25 m alternatively, interspersed by a recovery period of 35 s. During each recovery period, the players returned to the starting position. Distance covered during the 30 s bout per player was recorded to the closest 5 m using the pre-set cones (Ammar, Bailey, Hammouda, Trabelsi, Merzigui & Abed *et al.*, 2019). In-game demands were collected for the 23 match-day cup players, over the entire season, using wearable GPS sensors (Optimeye X4, Catapult, Australia). GPS data were collected at 10 Hz and included mean total distance covered, mean total distance covered in specific speed band (1–5) and mean total time spent in a specific speed band (1–5). Speed band 1 = 0 - 6 $km.h^{-1}$, speed band 2 = 6 - 16 $km.h^{-1}$, speed band 3 = 16 - 20 $km.h^{-1}$, Speed band 4 = 20 - 25 $km.h^{-1}$ and speed band 5 = 25 - 40 $km.h^{-1}$ (Aughey, 2011). Distances covered in each velocity band was normalised for time spent on field and presented as $m.min^{-1}$ (Tee, Lambert & Coopoo, 2017).

Ethical considerations

Institutional (University of Johannesburg) ethical clearance (REC-241112-035) was received and written informed consent obtained from each participant prior to data collection. The participants were also informed that they could withdraw from the study at any stage without repercussion. All participants' data remained confidential throughout the duration of this study.

Statistical analysis

All data distributions and statistical tests were performed in SPSS (Statistical Package for the Social Sciences, IBM version 25). All data are presented as mean±standard deviation. T-tests were performed to assess the differences between forwards and backs with the significance value set at $p \leq 0.05$. Effect size was evaluated using Cohen's *d* to describe differences between the groups. Descriptors defined by Hopkins (2002) were used: trivial – *d:* 0–0.2, small – *d:* 0.2–0.6, moderate – *d:* 0.6–1.2, large – *d:* 1.2–2, very large – *d:* 2–4, nearly perfect – *d:* 4–infinity, perfect – a difference in mean size of infinity.

Results

The results of running performance tests are reported in Table 1. The forwards were significantly slower than the backs over 10 m (p=0.000) and 40 m (p=0.005). A large significant difference (p=0.04) was reported in cardiorespiratory endurance between forwards and backs. Repeated sprint ability test reported a moderate significant difference (p=0.01) between playing positions (Table 1). Time spent in each velocity band decreased as the bands increased across all playing position groups (Table 2) The most time was spent in velocity band 1, and the least was spent regarding velocity band 5 (Table 2). Additionally, differences ($p<0.005$) in distances covered between forwards and backs were noted in speed bands 2-5 (Table 2).

Speed band data showed that backs significantly ($p<0.005$) covered more grounds in all speed bands, apart from 1 (Table 3). Additionally, backs covered significantly more distance during the games (p=0.000). These positional differences range from large to very large ($1.7<d<2.0$). A second comparison involves the normalised running demands. From these results, it is reported that backs covered more metres per minute in speed bands 3-5 than forwards ($p<0.005$) (Table 4). These differences in normalised running demands range from moderate to very large ($0.6<d<2.1$).

Table 1: Sprint times, field-based estimate of anaerobic capacities and repeated sprint ability of 29 Varsity Cup players.

	Playing positions						Effect size (*d*)
Test	**Forwards (n = 15)**	**Backs (n = 14)**	**Tight five (n = 10)**	**Loose forwards (n = 5)**	**Inside backs (n = 10)**	**Outside backs (n = 4)**	**Forwards vs Backs**
Yo-Yo Intermittent Recovery Test (level)*	19.2 ± 2	21.1 ± 2	18.7 ± 1.2	19.6 ± 0.6	21.2 ± 1.2	20.2 ± 2.4	0.95
10 m sprint (split) (s)*	1.7 ± 0.1	1.6 ± 0.0	1.8 ± 0.0	1.7 ± 0.03	1.6 ± 0.0	1.6 ± 0.07	1.41
40 m sprint test (s)*	5.4 ± 0.3	5.1 ± 0.1	5.6 ± 0.2	5.2 ± 0.5	5.2 ± 0.1	5.1 ± 0.2	1.34
5 m Repeated Sprint Test (m)*	738.9 ± 31.1	767.3 ± 20.9	718.1 ± 17.7	764.0 ± 23.0	768.0 ± 18.7	768.8 ± 27.2	1.07

*significant difference ($p<0.05$) forwards vs backs.

Table 2: Running demands divided into speed bands (total distance covered) of a senior Varsity Cup rugby team per position.

	Playing positions	Effect size (*d*)

Speed band Total distance (m)	Forwards (n = 15)	Backs (n = 14)	Tight five (n = 10)	Loose forwards (n = 5)	Inside backs (n = 10)	Outside backs (n = 4)	Forwards vs Backs
1:	2540.0 ± 211.8	2995.4 ± 541.6	2525.8 ± 176.9	2450.3 ± 542.7	2797.5 ± 468.5	3524.0 ± 132.5	1.11
2*:	2559.1 ± 559.3	2947.1 ± 880.6	2466.1 ± 596.7	2838.0 ± 311.2	2911.1 ± 862.9	3001.2 ± 596.7	0.53
3*:	312.4 ± 165.6	567.2 ± 61.3	202.3 ± 80.1	455.7 ± 85.4	593.7 ± 61.0	522.9 ± 38.4	2.04
4*:	121.8 ± 83.3	295.24 ± 55.3	67.3 ± 27.2	187.9 ± 61.9	283.7 ± 57.3	334.4 ± 47.2	2.45
5*:	21.6 ± 23.5	123.90 ± 77.9	14.0 ± 5.9	19.5 ± 13.1	85.5 ± 47.2	215.7 ± 39.3	1.78
Mean total distance covered per game*:	5564.1 ± 842.5	6955.9 ± 780.9	5153.6 ± 748.6	6141.6 ± 616.0	6703.7 ± 679.0	7650.3 ± 471.8	1.71

Speed band 1 (0–6 km.h^{-1}); speed band 2 (6–16 km.h^{-1}); speed band 3 (16–20 km.h^{-1}); speed band 4 (20–25 km.h^{-1}); speed band 5 (25–40 km.h^{-1}). *significant difference ($p<0.005$) forwards vs backs.

Table 3: Running demands divided into speed bands (total time spent) of a senior Varsity Cup rugby team per position.

	Playing positions						Effect size (*d*)
Speed band Total time spent (s)	**Forwards (n = 15)**	**Backs (n = 14)**	**Tight five (n = 10)**	**Loose forwards (n = 5)**	**Inside backs (n = 10)**	**Outside backs (n = 4)**	**Forwards vs Backs**
1 *:	3916.4 ± 376.3	4371.0 ± 665.7	3827.1 ± 448.5	3943.1 ± 385.0	4079.5 ± 499.7	5093.6 ± 210.2	0.84
2 *:	972 ± 233	1117 ± 321	928 ± 242	1104 ± 149	1087 ± 307	1162 ± 211	0.52
3 *:	60.5 ± 32.4	109.9 ± 10.7	38.8 ± 6.1	91.1 ± 18.7	114.5 ± 4.4	101.9 ± 4.4	2.05
4 *:	18.4 ± 13.3	45.6 ± 9.0	9.7 ± 4.4	29.0 ± 10.4	43.8 ± 9.4	51.7 ± 4.0	2.39
5 *:	2.1 ± 3.0	15.6 ± 1040	1.3 ± 0.8	1.6 ± 1.7	10.4 ± 6.0	27.9 ± 6.3	1.76

Speed band 1 (0–6 km.h^{-1}); speed band 2 (6–16 km.h^{-1}); speed band 4 (16–20 km.h^{-1}); speed band 5 (20–25 km.h^{-1}); speed band 6 (25–40 km.h^{-1}). *significant difference ($p<0.005$) forwards vs backs.

Table 4: Time normalised running demands divided into speed bands (meters per minute) of a senior Varsity Cup rugby team per position.

	Playing positions						Effect size
Speed band Total distance (m/min)	**Forwards (n = 15)**	**Backs (n = 14)**	**Tight five (n = 10)**	**Loose forwards (n = 5)**	**Inside backs (n = 10)**	**Outside backs (n = 4)**	**Forward vs Backs**
1:	25.5 ± 7.3	26.6 ± 5.9	26.0 ± 7.8	24.3 ± 5.9	25.5 ± 5.8	27.4 ± 5.3	0.17
2:	25.1 ± 2.7	25.5 ± 3.7	24.6 ± 2.8	26.3 ± 2.2	27.5 ± 3.9	24.2 ± 2.9	0.12

3 *:	2.8 ± 1.1	5.0 ± 1.1	2.2 ± 0.7	4.3 ± 0.6	5.5 ± 1.1	4.6 ± 1.0	2.00
4 *:	1.0 ± 0.6	2.5 ± 0.8	0.7 ± 0.3	1.8 ± 0.5	2.2 ± 1.0	2.7 ± 0.6	2.12
5 *:	0.2 ± 0.1	1.0 ± 0.7	0.1 ± 0.2	0.2 ± 0.1	0.4 ± 0.3	1.4 ± 0.7	1.60
Total *:	54.7 ± 9.0	60.6 ± 8.7	54.0 ± 9.2	57.0 ± 8.3	61.2 ± 10.3	60.2 ± 7.7	0.67

Speed band 1 (0–6 $km.h^{-1}$); speed band 2 (6–16 $km.h^{-1}$); speed band 3 (16–20 $km.h^{-1}$); speed band 4 (20–25 $km.h^{-1}$); speed band 5 (25–40 $km.h^{-1}$). * significant difference ($p<0.05$) forwards vs backs.

Discussion

Rugby is a physically demanding contact sport. Players, irrespective of position, are required to accelerate over short distances or accelerate and reach high velocities to get into position or execute specific movements (Duthie, Pyne, Marsh & Hooper, 2006a). These variables are key in the assessment of positional running capabilities of university rugby players. The results from the current study indicated that backline players have greater aerobic, anaerobic and sprint capacities than forwards. Additionally, in-game running demands were greater for backline players.

Differences in physical performances of rugby players have been previously reported between forwards and backs (Barnard, Pote & Christie, 2020; Read *et al.*, 2018; Sewry, 2014). The current study reported positional differences in cardiorespiratory endurance, sprint times and repeated sprint ability. A moderate difference between the forwards and backs was reported for the Yo-Yo IRT. The findings of the current study are consistent with those reported by Duthie *et al.* (2003), Jarvis, Sullivan, Davies, Wiltshire & Baker (2009) and Urquhart (2018). Although any consideration of aerobic capacity must be done with caution, as giving body size differences, forwards may report lower VO_{2max} than backs (Scott, Roe, Coats, & Piepoli, 2003). Therefore, aerobic capacity as indicated by the Yo-Yo IRT may not be the sole variable distinguishing between playing positions and capacities. Consequently, additional laboratory tests are required to substantiate the correlation between playing position and aerobic capacities. Research has also shown that modern rugby is played at a higher tempo, containing less standing and jogging, with more high-intensity bouts and longer periods of continuous play (Austin, Gabbett & Jenskins, 2011; Urquhart, 2018). As such, the ability to rapidly cover considerable ground and perform multiple repeated efforts seems to be essential in the modern game.

Elite rugby players are required to have an improved anaerobic capacity with greater physiological demands when compared to other athletes performing other high-intensity activities (Austin *et al.*, 2011). Among these high-intensity efforts

are sprint accelerations and high velocity sprints. Maximum sprinting speed is regularly assessed in rugby players to determine the efficacy of training programmes for developing and maintaining speed (Roe, Darrall-Jones, Black, Shaw, Till & Jones, 2017). Acceleration phase times have been reported between 1.7-1.98s and velocity phases (Dobbs, Wong, Watkins, Barillas, Rivera & Coburn *et al.*, 2018; Sewry, 2014; Smart *et al.*, 2014; Gabbett, Kelly & Sheppard, 2008; Cunningham *et al.*, 2016; Pienaar & Coetzee, 2013) and velocity sprint phase of 5.16 ± 0.12 s for professional league rugby players (Meir, Newton, Curtis, Fardell & Butler, 2001). The current study showed that forwards were significantly slower than the backs over 10m and 40m. Such differences in positional performances have been previously reported (Sewry, 2014; Smart *et al.*, 2014; Gabbett, *et al.*, 2008; Cunningham *et al.*, 2016; Pienaar & Coetzee, 2013; Urquhart, 2018).

In the current study, the backs outscored the forwards in the RSA test. Previous studies have also reported similar findings using comparable samples (Urquhart, 2018; Durandt, Tee, Prim & Lambert, 2006). The RSA test may be best explained in the context of the VO_{2max} data. Forwards have been shown to have a lower VO_{2max} and RSA than their backline counterparts (Urquhart, 2018; Durandt *et al.*, 2006). These findings have been attributed to anthropometric differences between the two positional groups (Duthie, Pyne, Hopkins, Livingstone & Hooper, 2006b). Additionally, forwards tend to have a higher percentage of body fat, which does not actively contribute to force development. However, this variable was not reported in the present study.

Backline players are required to reach a higher percentage of their maximal sprinting velocity in training and matches. Sprint training positively affects aerobic and anaerobic attributes due to the high degree of neuromuscular and metabolic stress placed on the physiological systems (Taylor, Macpherson, Spears & Weston, 2015). Furthermore, strength and power production are key abilities required by athletes to produce acceleration and reach maximum velocities which form part of their in-game demands profile (Cunningham *et al.*, 2016). Therefore, in the present study, the backs may have refined aerobic and anaerobic systems compared to forwards, allowing them to perform better in the RSA test.

During in-game demands, backs covered more distances and spent longer durations in speed bands compared to the forwards. Numerous studies have reported this positional difference in game distances, specifically citing positional requirements (Reardon, Tobin & Delahunt, 2015; Cahill *et al.*, 2013; Gabbett, Jenkins &Abernathy, 2012; Austin *et al.*, 2011; Roberts, Trewartha, Higgitt, El-Abd & Stokes, 2008). Backs are in open spaces more often allowing them to attain greater velocities and forwards are usually required to remain in close proximity to the ball which is linked to the physical collisions of tackles, rucks, mauls and scrums (Read *et al.*, 2018; Lacome, Piscione, Hager & Bourdin, 2014; Cahill *et al.*, 2013; Austin *et al.*, 2011; Roberts *et al.*, 2008;). Forwards tend to spend three

to four times the amount of time in largely static situations such as rucking, scrumming and mauling compared to backs (Read *et al*., 2018; Austin *et al.*, 2011; Roberts *et al.*, 2008).

The results of this study, together with those reported previously, have shown that the largest portion of rugby matches were spent in speed band 1 and the smallest portion in speed band 5, attesting to the intermittent nature of match-play where forwards are involved in more static movements such as scrums and rucks and backs being more involved in broken play (Venter *et al.*, 2011. Quarrie *et al.*, 2013; Read, Till, Beasley, Clarkson, Heyworth & Lee *et al.*, 2017). As such, forwards have lower running demands, including repeated high-intensity efforts, yet have higher contact demands, such as rucks and scrums, than backline players (Jones, West, Blair, Christian & Killduff, 2015). Quarrie and colleagues (2013) stated that backs are possibly outperforming forwards in higher speed bands due to the inability of forwards to maintain or even reach the higher velocities during match play. Therefore, evaluating GPS using individual relative maximal velocity speed bands might present a true reflection of in-game efforts.

In the current study, the relative distance in each velocity band was also assessed. Evaluating time-normalised distances allows for comparisons to be made across matches of varying durations (Tee *et al.*, 2017). Additionally, this normalising technique reduces the time effects of substituted players. The current study showed a significant difference between the relative distance of the forwards and that of the backs. These values oppose the findings with regards to relative distances reported in a study of Tee *et al.* (2017), which indicated little difference between the two groups for most part of the match. Studies by Read *et al.* (2017) and Tee and Coopoo (2015) on university rugby union players indicated values of 66.6 ± 5.0 - 69 ± 8 $m.min^{-1}$ and 69 ± 9 - 71.1 ± 5.5 $m.min^{-1}$ for forwards and backs, respectively. Average relative distances have been documented as high as 73.6 ± 8.4 $m.min^{-1}$ for forwards and 79.8 ± 10.5 $m.min^{-1}$ for backs, whereas peak 1 min relative distances as high as 157.3 ± 18.1 $m.min^{-1}$ for forwards and 174.9 ± 23.9 $m.min^{-1}$ for backs (Read *et al.*, 2017) have also been reported. These differences in distances covered per minute for both playing positions across studies could be due to the disparity in levels of competition as well as sample sizes. It is important to note that all matches are unique. Every match will have varying GPS data, due to the uniqueness of competitions, teams and individual players (Vaz, Vasilica, Kraak & Arrones, 2015; Villarejo, Palao, Ortega, Gomez-Ruano & Kraak, 2015).

Conclusions and Recommendations

This unique study, conducted on university level rugby players, is descriptive and could provide trainers and coaches with more knowledge about the game demands. This in turn, can be used for more effective planning, training and conditioning of players. The current study showed that a local Varsity Cup team has many

similarities to a semi-professional/elite side with regards to match demands as well as physical requirements. In summary, the backline players recorded higher aerobic capacity, acceleration and sprint values than the forwards. An assessment of in-game demands showed that backline players in a Varsity Cup group tend to cover more distances in all speed bands than their forward counterparts and spent more time in each speed band.

Owing to the constraints of the Varsity Cup competition and sport as well as the limited availability of GPS pods, the sample size was very small. Multiple seasons and teams would have contributed to a greater accuracy as the small sample size brought into question typical error of measurement and wider confidence levels. Further studies should be done to measure each individual player's maximal running velocity and then adjust their relative speed bands accordingly. Doing so should give researchers, coaches and sports professionals a more detailed profile of the individual in-game demands of a Varsity Cup player. Furthermore, the playing positions could be more individually investigated in greater sample sizes, where individual positions could be assessed instead of groups.

References

Ammar, A., Bailey, S.J., Hammouda, O., Trabelsi, K., Merzigui, N., El Abed, K., Driss, T., Hoekelmann, A., Ayadi, F., Chtourou, H. & Gharbi, A. (2019). Effects of playing surface on physical, physiological, and perceptual responses to a Repeated-Sprint Ability Test: Natural grass versus artificial turf. *International Journal of Sports Physiology and Performance*, 14(9), 1219-1226. https://doi.org/10.1123/ijspp.2018-0766

Arnason, A., Sigurdson, S.B., Gudmundsson, A., Holme, I., Engebretsen, L. & Bahr, R. (2004). Physical fitness, injuries, and team performance in soccer. *Medicine & Science in Sports and Exercise*, 36(2), 275–285. doi: 10.1249/01.MSS.0000113478.92945.CA

Austin, D., Gabbett, T. & Jenkins, D. (2011). The physical demands of Super 14 Rugby Union. *Journal of Science and Medicine in Sport*, 14, 259–263. https://doi.org/10.1016/j.jsams.2011.01.003

Aughey, R.J. (2011). Applications of GPS technologies to field sports. *Journal of Sports Physiology and Performance*, 6, 295–310. https://doi.org/10.1123/ijspp.6.3.295

Barnard, D.V., Pote, L. & Christie, C. (2020). Workloads of forward and backline adolescent rugby players: A pilot study. *South African Journal of Sports Medicine*, *32*(1), 1-5. http://dx.doi.org/10.17159/2078-516x/2020/v32i1a7427

Bishop, D., Spencer, M., Duffield, R. & Lawrence, S. (2001). The validity of a repeated sprint ability test. *Journal of Science and Medicine in Sport*, 4(1), 19-29. https://doi.org/10.1016/S1440-2440(01)80004-9

Cahill, N., Lamb, K., Worsfold, P., Headey, R. & Murray, S. (2013). The movement characteristics of English premiership rugby union players. *Journal of Sports Sciences*, 31(3), 229–237. https://doi.org/10.1080/02640414.2012.727456

Cummins, C., Orr, R., O'Connor, H. & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Medicine*, 43(10), 1025–1042. https://doi.org/10.1007/s40279-013-0069-2

Cunningham, D., Shearer, D.A., Drawer, S., Eager, R., Taylor, N., Cook, C. & Kilduff, L.P. (2016). Movement demands of elite U20 international rugby union players. *PLoS One*, *11*(4). https://doi.org/10.1371/journal.pone.0153275

Dobbs, I.J., Wong, M.A., Watkins, C.M., Barillas, S.R., Rivera, M., Coburn, J.W., Costa, P.B. & Brown, L.E. (2018). Correlation between isometric horizontal push force and sprint times in collegiate rugby union players. *Journal of Australian Strength and Conditioning*, 26(4), 16–23. https://www.researchgate.net/profile/Lee_Brown2/publication/327249753_Correlation_between_isometric_horizontal_push_force_and_sprint_times_in_collegiate_rugby_union_players/links/5b8979c492851c1e123f8a47/Correlation-between-isometric-horizontal-push-force-and-sprint-times-in-collegiate-rugby-union-players.pdf

Durandt, J., Tee, J.C., Prim, S.K., & Lambert, M.I. (2006). Physical fitness components associated with performance in a multiple-sprint test. *International Journal of Sports Physiology and Performance*, 1(2), 150–160. https://doi.org/10.1123/ijspp.1.2.150

Duthie, G.M., Pyne, D. & Hooper, S. (2003). Applied physiology and game analysis of Rugby Union. *Sports Medicine*, 33(13), 973–991. https://doi.org/10.2165/00007256-200333130-00003

Duthie, G.M., Pyne, D.B., Marsh, D.J. & Hooper, S.L. (2006a). Sprint patterns in Rugby Union players during competition. *Journal of Strength and Conditioning Research*, 20(1), 208–214. doi:10.1519/00124278-200602000-00034

Duthie, G.M., Pyne, D.B., Hopkins, W.G., Livingstone, S. & Hooper, S.L. (2006b). Anthropometry profiles of elite rugby players: quantifying changes in lean mass. *British Journal of Sports Medicine*, 40, 202–207. http://dx.doi.org/10.1136/bjsm.2005.019695

Gabbett, T.J., Kelly, J.N., & Sheppard, J.M. (2008). Speed, change of direction speed, and reactive agility of rugby league players. *The Journal of Strength and Conditioning Research*, 22(1), 174–181. doi: 10.1519/JSC.0b013e31815ef700

Gabbett, T.J., Jenkins, D.G., & Abernethy, B. (2012). Physical demands of professional rugby league training and competition using microtechnology. *Journal of Science & Medicine in Sport*, 15(1), 80–86. https://doi.org/10.1016/j.jsams.2011.07.004

George, T.M., Olsen, P.D., Kimber, N.E., Shearman, J.P., Hamilton, J.G., & Hamlin, M.J. (2015). The effect of altitude and travel on rugby union performance: Analysis of the 2012 Super Rugby competition. *Journal of Strength and Conditioning Research*, 00(00), 1–7. doi: 10.1519/JSC.0000000000001204

Higham, D.G., Pyne, D.B. & Mitchell, J.A. (2013). Protocols for the physiological assessment of rugby players. In *Physiological tests for Elite Athletes*, Champaign, IL: Human Kinetics, 207-248.

Hopkins, W.G. (2002). *A scale of magnitudes for effect statistics*. Available at: https://www.sportsci.org/resource/stats/effectmag.html (Accessed 02 May 2019).

Jarvis, S., Sullivan, L.O., Davies, B., Wiltshire, H. & Baker, J.S. (2009). Interrelationships between measured running intensities and agility performance in sub-elite Rugby Union players. *Research in Sport Medicine*, 17(4), 217–230. https://doi.org/10.1080/15438620903323892

Jennings, D., Cormack, S., Coutts, A.J., Boyd, L. & Aughey, R.J. (2010). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International Journal of Sports Physiology and Performance*, 5(3), 328–341. https://doi.org/10.1123/ijspp.5.3.328

Jones, M.R., West, D.J., Blair, T.C., Christian, J.C. & Killduff, L.P. (2015). Quantifying positional and temporal movement patterns in professional Rugby Union using global positioning system. *European Journal of sport Science*, 15(6), 488–496. https://doi.org/10.1080/17461391.2015.1010106

Kramer, M., Du Randt, R., Watson, M. & Pettitt, R.W. (2019). Energetics of male field-sport athletes during the 3-min all-out test for linear and shuttle-based running. *European Journal of Applied Physiology*, 119(2), 477–486. https://doi.org/10.1007/s00421-018-4047-0

Lacome, M., Piscione, J., Hager, J.P. & Bourdin, M. (2014). A new approach to quantifying physical demand in rugby union. *Journal of sports sciences*, *32*(3), 290-300. https://doi.org/10.1080/02640414.2013.823225

Meir, R., Newton, R., Curtis, E., Fardell, M. & Butler, B. (2001). Physical fitness qualities of professional rugby league football players: Determination of positional differences. *Journal of Strength and Conditioning Research*, 15, 450–458. https://www. researchgate. net/ profile/Rudi_Meir/publication/223128734_Physical_fitness_qualities_of_professional_rugby_lea gue_players_determination_of_positional_differences/links/0fcfd50c11e558e50f000000/Physical -fitness-qualities-of-professional-rugby-league-players-determination-of-positional-differences.pdf

Petersen, C., Pyne, D., Portus, M. & Dawson, B. (2009). Validity and reliability of GPS units to monitor cricket-specific movement patterns. *International Journal of Sports Physiology and Performance*, 4, 381–393. https://doi.org/10.1123/ijspp.4.3.381

Pienaar, C. & Coetzee, B. (2013). Changes in selected physical, motor performance and anthropometric components of university-level rugby players after one microcycle of a combined rugby conditioning and plyometric training program. *The Journal of Strength and Conditioning Research*, 27(2), 398–415. doi: 10.1519/JSC.0b013e31825770ea

Read, D., Till, K., Beasley, G., Clarkson, M., Heyworth, R., Lee, J. & Jones, B. (2017). Peak running intensities in rugby union match-play: Comparisons to whole match data. http://eprints.leedsbeckett.ac.uk/3703/

Read, D.B., Jones, B., Williams, S., Phibbs, P.J., Darrall-Jones, J.D., Roe, G.A., Weakley, J.J., Rock, A. & Till, K. (2018). The physical characteristics of specific phases of play during rugby union match play. *International Journal of Sports Physiology and Performance*, *13*(10), 1331-1336. https://doi.org/10.1123/ijspp.2017-0625

Reardon, C., Tobin, D.P. & Delahunt, E. (2015). Application of individualized speed thresholds to interpret position specific running demands in elite professional rugby union: A GPS study. *PLoS ONE*, 10(7), e0133410. https://doi.org/10.1371/journal.pone.0133410

Roberts, S.P., Trewartha, G., Higgitt, R.J., El-Abd, J. & Stokes, K.A. (2008). The physical demands of elite English Rugby Union. *Journal of Sport Science*, 26(8), 825–833. https://doi.org/10.1080/02640410801942122

Roe, G., Darrall-Jones, J., Black, C., Shaw, W., Till, K. & Jones, B. (2017). Validity of 10-HZ GPS and timing gates for assessing maximum velocity in professional rugby union players. *International Journal of Sports Physiology and Performance*, *12*(6), 836-839. https://doi.org/10.1123/ijspp.2016-0256

Scott, A.C., Roe, N., Coats, A.J.S. & Piepoli, M.F. (2003). Aerobic exercise physiology in a professional Rugby Union team. *International Journal of Cardiology*, 87, 173–177. https://doi.org/10.1016/S0167-5273(02)00211-5

Sewry, N. (2014). *Key performance indicators and predictors in Varsity Cup Rugby* (Doctoral Dissertation, University of Cape Town). http://hdl.handle.net/11427/13267

Smart, D., Hopkins, W.G., Quarrie, K.L. & Gill, N. (2014). The relationship between physical fitness and game behaviours in rugby union players. *European Journal of Sport Science*, 1(1), 8–17. https://doi.org/10.1080/17461391.2011.635812

Swaby, R., Jones, P.A. & Comfort, P. (2016). Relationship between maximum aerobic speed performance and distance covered in rugby union games. *The Journal of Strength & Conditioning Research*, *30*(10), 2788-2793. doi: 10.1519/JSC.0000000000001375

Taylor, J., Macpherson, T., Spears, I. & Weston, M. (2015). The effects of repeated sprint training on field-based fitness measures: A meta-analysis of controlled and non-controlled trials. *Sports Medicine*, 45(6), 881–891. https://doi.org/10.1007/s40279-015-0324-9

Tee, J.C. & Coopoo, Y. (2015). Movement and impact characteristics of South African professional rugby union players. *South African Journal of Sports Medicine*, *27*(2), 33-39. doi: 10.17159/2413-3108/2015/v27i2a489

Tee, J.C., Lambert, M.I. & Coopoo, Y. (2017). GPS comparison of training activities and game demands of professional Rugby Union. *International Journal of Sports Science and Coaching*, 11(2), 200–212. https://doi.org/10.1177%2F1747954116637153

Urquhart, J.C. (2018). *Determination and comparison of anthropometric, physiological and psychological performance measures in elite youth Rugby Union players at four different stages of professional development across three time points during a competitive season and the longitudinal changes of each age group* (Master's Thesis, Glasgow: University of Glasgow). http://theses.gla.ac.uk/id/eprint/30726

Vaz, L., Vasilica, I., Kraak, W. & Arrones, S.L. (2015). Comparison of scoring profile and game related statistics of the two finalist during the different stages of the 2011 Rugby World Cup. *International Journal of Performance Analysis in Sport*, *15*(3), 967-982. https://doi.org/10.1080/24748668.2015.11868844

Venter, R.E., Opperman, E. & Opperman, S. (2011). The use of Global Positioning System (GPS) tracking devices to assess movement demands and impacts in Under-19 Rugby Union match play: Sports technology. *African Journal for Physical Health Education, Recreation and Dance*, *17*(1), 1-8. https://hdl.handle.net/10520/EJC19699

Villarejo, D., Palao, J.M., Ortega, E., Gomez-Ruano, M.Á. & Kraak, W. (2015). Match-related statistics discriminating between playing positions during the men's 2011 Rugby World Cup. *International Journal of Performance Analysis in Sport*, *15*(1), 97-111. https://doi.org/10.1080/24748668.2015.11868779

509 Woolford, S.M., Polglaze, T., Rowsell, G. & Spencer, M. (2013). Field testing principles and
510 protocols. In *Physiological Tests for Elite Athletes* (2nd ed.) (pp. 231-248). Champaign, IL: Human
511 Kinetics.