

Applied Physiology of Rugby League

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Abstract

Rugby league football is played in several countries worldwide. A rugby league team consists of 13 players (6 forwards and 7 backs), with matches played over two 40-minute halves separated by a 10-minute rest interval. Several studies have documented the physiological capacities of rugby league players and the physiological demands of competition, with the physiological capacities of players and the physiological demands of competition increasing as the playing level is increased. However, there is also evidence to suggest that the physiological capacities of players may deteriorate as the season progresses, with reductions in muscular power and maximal aerobic power and increases in skinfold thickness occurring towards the end of the rugby league season, when training loads are lowest and match loads and injury rates are at their highest.

Player fatigue and playing intensity have been suggested to contribute to injuries in rugby league, with a recent study reporting a significant correlation ($r = 0.74$) between match injury rates and playing intensity in semi-professional rugby league players. Studies have also reported a higher risk of injury in players with low 10-m and 40-m speed, while players with a low maximal aerobic power had a greater risk of sustaining a contact injury. Furthermore, players who completed <18 weeks of training prior to sustaining their initial injury were at greater risk of sustaining a subsequent injury. These findings provide some explanation for the high incidence of fatigue-related injuries in rugby league players and highlight the importance of speed and endurance training to reduce the incidence of injury in rugby league players.

To date, most, but not all, studies have investigated the movement patterns and physiological demands of rugby league competition, with little emphasis on how training activities simulate the competition environment. An understanding of the movement patterns and physiological demands of specific individual positions during training and competition would allow the development of strength and conditioning programmes to meet the specific requirements of these positions. In addition, further research is required to provide information on the repeated effort demands of rugby league. A test that assesses repeated effort performance and employs distances, tackles and intensities specific to rugby league, while also simulating work-to-rest ratios similar to rugby league competition, is warranted.

1. Description of Rugby League

Rugby league football originated in the north of England in the 1890s and is played at junior and senior levels in several countries worldwide, including Australia, New Zealand, France, Russia, Wales, Scotland, Ireland, Papua New Guinea, Fiji, Samoa and South Africa.^[1,2] The game is played over

two 40-minute halves, separated by a 10-minute rest interval. Players compete in a challenging contest involving frequent bouts of high-intensity activity (e.g. running and passing, sprinting, tackling), separated by short bouts of low-intensity activity (e.g. standing, walking and jogging). The physiological demands of rugby league are complex, requiring players to have highly developed speed, agility,

muscular strength and power, and maximal aerobic power.^[3]

A rugby league team consists of 13 players, with junior and amateur rugby league matches typically (but not always) played under an unlimited interchange rule, whereas professional rugby league teams are permitted a maximum of 12 interchange movements during the course of a match. Each team is allowed six tackles with the ball. The objective is to advance the ball down the field into the opposition's territory and score a try (touch down).^[4,5] The ball must be passed backwards, but can be carried or kicked into the opposition's territory.^[5] At the completion of each set of six tackles, the ball is immediately given to the opposition team to commence its set of six tackles.^[4] Therefore, the same players are involved in both attack and defence.

The two major playing groups within a rugby league team are the forwards and backs. Team positions can also be classified according to the specific individual position played (i.e. prop, hooker, second row, lock, halfback, five-eighth, centre, wing and fullback), or according to four subgroups reflecting positional commonality (i.e. props, hookers and halves, back-rowers and outside backs).^[2,6-8] The demands placed on players vary according to the specific position played.^[2,6-8] Forwards are predominantly involved in large numbers of physical collisions and tackles, while backs spend more time in free running. Due to the high intensity of the game and the large number of physical collisions and tackles, musculoskeletal injuries are common.^[9]

2. Rationale for the Review

A review article addressing the applied physiology of rugby league has been published.^[1] However, a paucity of scientific literature existed at the time this review was published, and the majority of the scientific research was conducted on elite-level players. In addition, since the review of Brewer and Davis^[1] was published, a change in defensive rules,

requiring defensive players to retreat 10 m (rather than 5 m) following each tackle,^[10] and the introduction of the limited interchange replacement rule, have resulted in increased physiological demands on rugby league players.^[11,12] With this in mind, the purpose of the present article is to provide a comprehensive review of the applied physiology of contemporary rugby league football.

3. Physiological and Anthropometric Characteristics

3.1 Body Composition

Excess body fat has been shown to negatively influence sporting performance (e.g. power to body mass ratio, thermoregulation and aerobic capacity).^[2] Rugby league players have been shown to have higher body mass and percentage body fat than other team sport players, such as soccer and Australian footballers.^[7] Mean body mass measurements of senior rugby league players have been reported to be in the range of 86–90 kg^[13-15] with no significant differences amongst amateur, semi-professional and professional players.^[14] Most,^[2,13,14,16-18] but not all,^[19] studies have shown a higher body mass in forwards than backs. Interestingly, body mass is the only physical characteristic that successfully predicts selection into a first-grade rugby league team,^[14] or as a forward or back.^[19] Amateur rugby league players have 31% higher percentage body fat than professional players, however, percentage body fat is reported to be similar for forwards and backs.^[13] The percentage body fat of professional rugby league players is reported to be significantly higher in forwards (15.2%) than backs (12.6%) [table I].^[16] Props and back-rowers are predominantly responsible for the higher percentage body fat of forwards.^[7] Meir^[17] reported that elite forwards had significantly greater skinfold thickness than elite backs at all stages during the competitive season. Forwards spend significantly more playing time in-

Table 1. Height, body mass, skinfold thickness and estimated body fat of rugby league forwards and backs competing at amateur, semi-professional and professional levels

	Amateur ^[13]		Semi-professional ^[23]		Professional ^[16]	
	forwards	backs	forwards	backs	forwards	backs
Height (cm)	178.4 ± 8.7	178.0 ± 5.2	178.2 ± 7.2	176.0 ± 5.9	184.0 ± 7.0	178.0 ± 7.0
Body mass (kg)	90.8 ± 10.2	79.7 ± 10.1	90.3 ± 14.0	80.7 ± 10.4	92.1 ± 10.4	79.8 ± 8.0
Skinfold thickness (mm) ^a	52.4 ± 14.7	46.1 ± 18.6	47.3 ± 17.9	38.8 ± 13.9	NR	NR
Estimated body fat (%)	19.9 ± 3.7	17.5 ± 5.0	17.6 ± 4.4	15.2 ± 4.1	15.2 ± 3.4	12.6 ± 3.2

a Data are sum of four skinfold sites (biceps, triceps, subscapular, suprailiac).

NR = not reported.

involved in tackles^[20] and physical collisions^[21,22] than backs, so it is likely that the larger body mass of forwards assists in the development of greater impact forces associated with these events. It has also been suggested that higher percentage body fat in forwards may act as a means of protection from impact injuries;^[17] however, to date, no scientific evidence exists to support or refute this claim.

3.2 Maximal Aerobic Power

Several studies have documented the physiological characteristics of rugby league players, with the fitness of players increasing as the playing level increases.^[2,7,13,14,16,19,24,25] Professional rugby league players train 5–6 days per week,^[22,26] often performing multiple training sessions each day.^[14] As a result, the physiological characteristics of professional rugby league players are well developed. Larder^[21] reported a mean maximal oxygen uptake ($\dot{V}O_{2\max}$) of 62.6 mL/kg/min in an international squad prior to an overseas tour, while Allen^[27] reported a mean $\dot{V}O_{2\max}$ of 55.8 mL/kg/min in regional (and national) representative rugby league players at the completion of a competitive rugby league season. Other studies of the physiological characteristics of professional rugby league players have reported mean estimated $\dot{V}O_{2\max}$ scores in the range of 48.6–56.4 mL/kg/min.^[7,15,16] In contrast, the maximal aerobic power of amateur rugby league players is poorly developed, with a recent study demonstrating that estimated $\dot{V}O_{2\max}$ was 20–42% lower than in professional rugby league players.^[13] The rela-

tively poor aerobic fitness of amateur rugby league players has been attributed to a low playing intensity, infrequent matches of short duration, and an inappropriate training stimulus,^[13] although the higher percentage body fat may also contribute to the lower estimated $\dot{V}O_{2\max}$ in these players. The mean estimated $\dot{V}O_{2\max}$ of semi-professional rugby league players at the beginning of a competitive season was reported to be 46.0–48.5 mL/kg/min^[14,28] and 50.0 mL/kg/min during the competitive phase of the season after players had gained match fitness.^[19] Mean estimated $\dot{V}O_{2\max}$ measurements of junior sub-elite rugby league players are in the range of 32.1–46.1 mL/kg/min and progressively improve as the playing level increases.^[19] However, Gabbett and Herzig^[24] reported significantly higher mean estimated $\dot{V}O_{2\max}$ scores (48.7–54.6 mL/kg/min) in junior elite rugby league players.

Despite having contrasting match-play activities, the physiological characteristics of rugby league forwards and backs are remarkably similar, suggesting that fitness training for rugby league is similar for all positions.^[15] Brewer et al.^[16] reported mean $\dot{V}O_{2\max}$ values of 56.4 and 55.4 mL/kg/min for professional rugby league forwards and backs, respectively. Consistent with this finding, Gabbett^[13,14] has reported similar mean $\dot{V}O_{2\max}$ values between amateur rugby league forwards (38.1 mL/kg/min) and backs (40.0 mL/kg/min) and semi-professional rugby league forwards (45.8 mL/kg/min) and backs (48.0 mL/kg/min). The finding of similar physiological characteristics between amateur rugby

league forwards and backs most likely reflects the similar training patterns of players, with a recent study finding no significant differences between forwards and backs in the training time devoted to the development of muscular power, speed and aerobic fitness.^[13] Although most studies have found no significant differences in the physiological characteristics of rugby league forwards and backs, in a study of 260 professional rugby league players, O'Connor^[7] reported significant differences amongst positional playing groups for $\dot{V}O_{2\max}$. Props (48.6 mL/kg/min) and back-rowers (51.1 mL/kg/min) had significantly lower $\dot{V}O_{2\max}$ scores than outside backs (52.8 mL/kg/min), hookers (55.2 mL/kg/min) and halves (52.0 mL/kg/min). Using distance achieved during a 5-minute run as an estimate of endurance, Meir et al.^[2] found no significant differences between forwards and backs for distance achieved. However, distributors (hookers and half-backs) achieved a significantly greater running distance (1353 m) than all other positions (1264–1309 m). In a study of 415 sub-elite rugby league players, Gabbett^[23,29] reported significant differences amongst positional playing groups for $\dot{V}O_{2\max}$. In agreement with results from professional rugby league studies,^[7] props (42.6 mL/kg/min) and back-rowers (44.9 mL/kg/min) had significantly lower $\dot{V}O_{2\max}$ scores than outside backs (46.1 mL/kg/min) and hookers and halves (46.5 mL/kg/min).^[23] Finally, the $\dot{V}O_{2\max}$ of Under-16 backs (49.5 mL/kg/min) is reported to be significantly higher than forwards (42.9 mL/kg/min), suggesting that the volume and intensity of training may differ between forwards and backs in this age group.^[19]

3.3 Speed

Rugby league players require the ability to move quickly in order to position themselves in attack and defence.^[2] However, professional rugby league studies have shown that players rarely sprint distances of >40 m in a single bout of intense ac-

tivity.^[20] This is particularly true for forwards, who seldom sprint further than 10 m in a single bout of intense activity.^[20] While no significant differences have been observed between forwards and backs for 10-m speed, backs are consistently faster over 40 m than forwards.^[2,6,7,13,14,16,24] No significant differences were reported between junior sub-elite rugby league forwards and backs for 10-, 20- or 40-m speed.^[19] However, junior elite backs are reported to be significantly faster than forwards.^[24] A progressive increase in speed has been reported as the playing level is increased.^[14,19,24] Mean times of 2.58 and 6.63 seconds over 10 and 40 m, respectively, have been reported for amateur rugby league players.^[13] Semi-professional rugby league players are significantly faster than amateur players, with mean 10- and 40-m times of 2.17 and 6.04 seconds reported, respectively.^[14] The mean 10- and 40-m sprint times of professional rugby league players is in the range of 1.71–1.83 and 5.08–5.66 seconds, respectively.^[2,7,16,30] Outside backs are typically the fastest over 10–40 m.^[6,7,23] In a study of professional rugby league players, Clark^[6] reported that outside backs were significantly faster than props, hookers and halves, and back-rowers over 10 and 40 m. O'Connor^[7] also reported that outside backs and halves were significantly faster than back-rowers, props and hookers in professional rugby league. In a study of sub-elite rugby league players, Gabbett^[23] reported that the outside backs and hookers and halves were significantly faster over 10 and 40 m than the props and back-rowers. Centres (5.81 seconds), fullbacks (5.84 seconds) and hookers (5.88 seconds) had the fastest speed over 40 m.^[23]

3.4 Repeated Sprint Ability

Given the highly intense, intermittent nature of rugby league, repeated sprint ability is extremely important. For example, a player who makes the effort to move quickly off the defensive line, make a cover-defending tackle, and then chase from first

marker requires the ability to generate high levels of power, and then recover quickly in order to produce further high-intensity efforts. Surprisingly few studies have investigated the repeated-sprint ability of rugby league players.^[6,7] Clark^[6] and O'Connor^[7] used a 6×40 and 8×40 -m sprint (each sprint performed every 30 seconds), respectively, to assess repeated sprint ability. The objective of the repeated sprint ability test was for players to complete each repetition as close as possible to his maximum sprint time.^[7] O'Connor^[7] reported no significant differences amongst playing positions for repeated sprint ability in professional rugby league players. However, a subsequent study found significant differences amongst playing positions, with hookers and halves demonstrating the lowest speed decrement (5.1%), followed by back-rowers (6.2%), outside backs (6.2%) and props (7.1%).^[6] Furthermore, a lower speed decrement in elite players (3.0%) compared with lower grade (6.8%) players was also reported. Research is yet to investigate the repeated sprint ability of junior, amateur, or semi-professional rugby league players. A limitation of the 6×40 and 8×40 -m sprint test performed every 30 seconds is that repeated sprint efforts in rugby league can vary in distance and recovery duration.^[10] In a time-motion study of professional rugby league players, Meir et al.^[10] reported that every 4 seconds of high-intensity activity was followed by approximately 30–80 seconds of low-intensity activity. Furthermore, sprint efforts ranged over distances of 5–60 m.^[10] These findings suggest that the repeated sprint ability tests employed previously^[6,7] may not provide an accurate assessment of the high-intensity intermittent nature of rugby league. Further research is required to provide information on the repeated effort demands of rugby league. A test that assesses repeated effort performance and employs distances, tackles and intensities specific to rugby league, while also simulating work-to-rest ratios similar to rugby league competition is required.

3.5 Agility

Rugby league players require the ability to rapidly accelerate, decelerate and change direction.^[20,31,32] Given that several different tests have been used to assess agility in rugby league players, comparisons between studies is difficult. Using the L-run to assess agility in professional rugby league players, Meir^[18] reported an average agility time of 5.46 and 5.37 seconds for forwards and backs, respectively. Gabbett^[14] reported mean Illinois agility times of 17.1 seconds in semi-professional rugby league players. No significant differences in agility were found between first-grade (16.9 seconds) and second-grade (17.4 seconds) players; however, backs (16.6 seconds) showed significantly greater agility than forwards (17.2 seconds).^[14] Illinois agility scores for junior (Under 13–19) sub-elite rugby league players are in the range of 17.9–22.0 seconds, with agility improving as the playing level is increased.^[19] However, no significant differences were found between junior forwards and backs for agility. O'Connor^[7] evaluated the agility of professional rugby league players using the 'glycolytic agility test'. No significant differences were detected amongst outside backs, halves, back-rowers and hookers, although as expected, props had significantly lower agility scores than outside backs. Gabbett^[23] also reported no significant differences amongst outside backs, hookers and halves, and back-rowers for agility; however, props had the slowest agility scores for all positional playing groups.

3.6 Muscular Strength and Power

The capacity to rapidly generate high levels of muscular force is a key characteristic of successful rugby league players. Players are required to have high levels of muscular strength in order to effectively tackle, lift, push and pull opponents during a match.^[2] In addition, high levels of muscular

strength and power are required to provide fast play-the-ball speed and to facilitate effective leg drive in tackles. Several studies have examined the strength characteristics of rugby league players.^[2,7,30,33-41] Meir^[18] reported significant differences in one repetition maximum (1RM) squat (188 vs 168 kg) and bench-press (119 vs 113 kg) strength in forwards and backs, respectively. These findings were confirmed by O'Connor^[7] who reported significantly greater 3RM squat, bench-press and power-clean results in props and back-rowers compared with hookers, halves and outside backs. Baker and colleagues^[30,38,39] reported 3RM squat and power-clean values of 158 and 102 kg, and 1RM bench-press and squat values of 130 and 165 kg in professional rugby league players. Significant differences have been reported between younger (<24 years) and older (>28 years) professional rugby league players for strength, with younger players having higher 1RM squat (183 vs 153 kg) and bench-press (143 vs 127 kg) scores than older players.^[37] However, professional rugby league players had significantly greater upper-body strength and power than college-aged and junior high school-aged rugby league players.^[34,36] The greater strength and power in professional rugby league players was attributed, in part, to neural adaptations (e.g. increased efficiency of neural patterning of the skill of strength exercises, diminished levels of antagonist co-contraction, synchronous firing of motor units, and reduced inhibitory feedback from force receptors) that occurred with long-term periodized strength and power training.^[36] The greater strength and power of professional rugby league players has been attributed to more extensive myogenic adaptations (e.g. changes in the muscle fibre or myosin heavy chain).^[36] Warman et al.^[40] reported 3RM squat and bench-press strength of 158 and 112 kg, respectively, in semi-professional rugby league players. No study has investigated the muscular strength of amateur rugby league players.

Most investigations that have examined strength in rugby league have assessed leg muscular power using the vertical jump test.^[7,13,14,19] A progressive improvement in muscular power as the playing level increased has been reported in junior elite^[24] and sub-elite^[14,19] rugby league players. Vertical jump scores for junior (Under 13–19) sub-elite rugby league players ranged from 28.2 to 37.9 cm, with no significant differences between forwards and backs.^[19] Junior elite rugby league players have been reported^[24] to have significantly greater vertical jump scores (50.0–58.9 cm) than junior sub-elite^[19] and junior regional development^[41] rugby league players. A progressive improvement in muscular power was also observed among amateur, semi-professional and professional rugby league players.^[14] Studies of amateur rugby league players have reported vertical jump scores of 38.1 cm, a value 30% lower than professional rugby league players.^[13] The high percentage body fat of amateur rugby league players most likely contributes to the inferior speed and muscular power of these athletes by attenuating the power to body mass ratio and reducing performance in match-specific tasks.^[42] The vertical jump height of amateur rugby league forwards (37.1 cm) and backs (39.3 cm) is reported to be similar.^[13] No significant differences existed between first grade and second grade semi-professional rugby league players for vertical jump height, although forwards had a significantly lower vertical jump than backs (40.7 vs 46.7 cm).^[14] Furthermore, there were no positional differences amongst professional rugby league players for muscular power, with vertical jump scores ranging from 52.2 to 56.1 cm.^[7] Finally, Baker^[37] reported significant differences between younger and older professional rugby league players for upper- and lower-body muscular power, as measured from a bench-press throw and jump-squat test, respectively.

3.7 Physiological and Anthropometric Characteristics of Female Rugby League Players

While rugby league is predominantly played by male competitors, women have also recently begun playing the game. There are female rugby league competitions in Australia, with elite players selected to the Queensland, New South Wales and Australian National Rugby League teams based on playing performances at state- and national-level competitions. Gabbett^[43] investigated the physiological and anthropometric characteristics of elite female rugby league players competing in the Australian national women's rugby league team. Measurements of skinfold thickness, speed, agility, vertical jump, glycolytic capacity and estimated $\dot{V}O_{2\max}$ were 6.0–38.1% poorer than previously reported for other elite female team sport athletes (e.g. touch football, soccer and hockey) [table II].^[44–47] These findings demonstrate the need to develop all physiological parameters to allow elite female rugby league players to more effectively tolerate the physiological demands of competition, reduce fatigue-related errors in skill execution and decrease the risk of injury.

3.8 Changes in Physiological and Anthropometric Characteristics Over a Competitive Season

While several studies have documented the physiological and anthropometric characteristics of rugby league players, few studies have investigated the changes in fitness of rugby league players over a competitive season.^[28,48–50] The physiological and anthropometric characteristics of amateur,^[28] semi-professional^[48] and junior elite^[49] rugby league players significantly change over the course of the season. The greatest improvements in fitness occur in the early stages of the season^[28,48–50] and there is evidence to suggest that fitness may deteriorate as the season progresses.^[28,49] The significant improvements in fitness in the early stages of the season have been attributed to the high training loads experienced during this period,^[28,48] while reductions in fitness as the season progresses may be due to increased playing commitments.^[28,49] Indeed, Gabbett^[28] reported increases in $\dot{V}O_{2\max}$ and muscular power and reductions in skinfold thickness in amateur rugby league players during the early phases of the rugby league season when training loads were highest. However, muscular power and $\dot{V}O_{2\max}$ decreased and skinfold thicknesses increased towards the end of the rugby league season, when training loads were lowest and match loads and injury rates were at their highest. These findings were attributed to a high overall playing intensity in end-season

Table II. Comparison of physiological and anthropometric characteristics among elite female team sport athletes

	Rugby league ^[43]	Soccer ^[44,45]	Hockey ^[46]	Touch football ^[47]
Age (y)	18.9 ± 5.7	23.1 ± 3.4	NR	22.1 ± 3.2
Height (cm)	167.6 ± 6.1	164.5 ± 6.1	166.7 ± 5.1	162.5 ± 7.6
Body mass (kg)	70.1 ± 11.6	58.5 ± 5.7	61.1 ± 5.5	56.8 ± 4.2
Skinfold thickness (mm) ^a	128.0 ± 32.4	95.9 ± 23.0	68.2 ± 13.6	71.3 ± 11.8
10-m sprint (sec)	2.00 ± 0.11	1.85 ± 0.07	1.98 ± 0.07	1.82 ± 0.09
40-m sprint (sec)	6.46 ± 0.36	NR	6.04 ± 0.22	5.71 ± 0.22
Vertical jump (cm)	35.4 ± 7.0	51.0 ± 5.0	46.0 ± 4.0	NR
Estimated $\dot{V}O_{2\max}$ (mL/kg/min)	33.8 ± 4.2	50.3 ± 5.1	51.3 ± 4.7	50.8 ± 3.2

a Data are sum of seven skinfold sites (biceps, triceps, subscapular, supraspinale, abdomen, thigh, calf).

NR = not reported; $\dot{V}O_{2\max}$ = maximal oxygen uptake.

matches, increases in injury rates in the latter half of the season, and residual fatigue associated with limited recovery time between successive matches.^[28] In a subsequent study of junior rugby league players, Gabbett^[50] reported an improvement in physiological capacities during the early phases of the rugby league season when training loads were highest. However, in contrast to the results from amateur rugby league players, match intensity and match loads decreased throughout the season. As a result, maximal aerobic power and muscular power were maintained throughout the competitive phase of the season. These findings suggest that high training loads in the general preparatory phase of the season and low match loads in the competitive phase of the season allow junior rugby league players to maintain a high level of fitness throughout an entire competitive season.^[50]

4. Relationship Between Physical Fitness and Playing Ability

4.1 Physiological, Anthropometric and Skill Characteristics

The superior playing performance of elite level rugby league players is often attributed to the greater physiological capacities of these athletes.^[51] Although successful performance in rugby league is dependent (at least in part) on well developed physiological capacities, players also require the ability to constantly execute complex skills under pressure and while fatigued.^[14,52] Indeed, the significance of high physical fitness levels is reduced if the physiological parameter does not transfer to improved playing performance. For example, an increase in muscular power is redundant unless the enhanced physiological capacity transfers to improved leg drive in tackles, or greater play-the-ball speed. Similarly, the value of an increase in aerobic fitness is negated if the ability of players to defend for multiple sets is unchanged or players are unable to exhibit

a high level of skill under fatigue. Gabbett et al.^[53] investigated the physiological, anthropometric and skill characteristics of rugby league players competing at three distinct playing levels to determine which, if any, factors discriminated between successful and less successful athletes. In addition, the relationship between physical fitness and playing ability was evaluated. First-grade players had greater basic passing and ball carrying ability, and superior skills while fatigued, tackling and defensive skills, and evasion skills (i.e. ability to beat a player and two vs one skills) than second- and third-grade players. While no significant differences were found among playing levels for body mass, skinfold thickness, height, 10-, 20-, or 40-m speed, agility, vertical jump height, or estimated $\dot{V}O_{2\max}$, all of the physiological and anthropometric characteristics were significantly associated with at least one measure of playing ability. The results of this study demonstrated that selected skill characteristics, but not physiological or anthropometric characteristics discriminate between successful and less successful rugby league players. However, all physiological and anthropometric characteristics were related to playing ability. These findings suggest that while physiological and anthropometric characteristics do not discriminate between successful and less successful rugby league players, a high level of physical fitness contributes to effective playing ability in these athletes.^[53]

4.2 Influence of Fatigue on Skill

Success in rugby league is dependent, at least in part, on tackling ability, the ability to tolerate physical collisions, and the ability to 'win' the tackle contest.^[54] In addition, the demands of the game (and subsequent fatigue), is increased through the large numbers of physical collisions and tackles that players are involved with during a match. Gabbett^[55] investigated the influence of fatigue on tackling technique in rugby league players and examined the

relationship between selected physiological capacities and fatigue-induced decrements in tackling technique. Players performed a one-on-one tackling drill before strenuous exercise, and again following game-specific repeated-effort exercise comprised of progressively increasing intensities (corresponding to 'moderate', 'heavy' and 'very heavy' intensity), in order to induce fatigue that was representative of match conditions. Video footage was taken from the rear, side and front of the defending player, and tackling technique was objectively assessed using standardized technical criteria. In addition, all players underwent measurements of standard anthropometry, speed, muscular power, agility and estimated $\dot{V}O_{2\max}$. Consistent with a progressive increase in fatigue, total repeated effort time, heart rate, blood lactate concentration and ratings of perceived exertion each increased throughout the repeated effort protocol. Fatigue resulted in progressive reductions in tackling technique. Players with the best tackling technique in a non-fatigued state demonstrated the greatest decrement in tackling technique under fatigued conditions. In addition, a significant association was found between $\dot{V}O_{2\max}$ ($r = -0.62$) and agility ($r = 0.68$) and fatigue-induced decrements in tackling technique. From a practical perspective, these findings suggest that strength and conditioning programmes designed to develop endurance, change of direction speed and anticipation skills may reduce fatigue-induced decrements in tackling technique. Furthermore, any defensive drills designed to improve tackling technique should be performed prior to, and under fatigue.^[55]

5. Performance Analysis

5.1 Time-Motion Analysis

Time-motion studies have been used to determine the movement patterns of rugby league players.^[10,20] Early studies, performed by Meir and colleagues^[10,20] investigated time-motion analysis of

professional rugby league players before and after the introduction of the 10-m defensive rule. These studies have revealed that the majority of match-play is spent in low-intensity activities such as standing, walking and jogging. However, while the majority of match-play is spent in low-intensity activities, high-intensity activities, such as sprinting, physical collisions and tackles place considerable demands on the anaerobic energy systems.^[20] The respective mean running distance of forwards and backs increased from 6647 and 7336 m during matches played under the 5-m defensive rule to 9929 and 8458 m during matches played under the 10-m defensive rule.^[10,20] Forwards spent a greater percentage of time in high-intensity activities (e.g. jogging backwards and sprinting) during matches played under the 10-m defensive rule (3.3%) than during matches played under the 5-m defensive rule (0.8%). However, the work-to-rest ratio of forwards and backs increased from 1 : 6 and 1 : 8 during matches played under the 5-m defensive rule to 1 : 10 and 1 : 7 for the hooker and prop, respectively, and 1 : 12 and 1 : 28 for the halfback and winger, respectively, under the 10-m defensive rule.^[10] Collectively, these findings suggest that the aerobic energy demands on professional rugby league players have increased with the introduction of the 10-m defensive rule. However, it has also been suggested that the increased work-to-rest ratios may reflect the increased intensity of work performed when actively involved in play, resulting in the need for longer periods of recovery between high-intensity efforts.^[10] Research is yet to compare time-motion analysis between amateur and semi-professional rugby league players. It is possible that due to differences in fitness and skill (e.g. poor ball control), the time spent in low-intensity activities may be greater in amateur than in semi-professional and professional rugby league. It has been suggested that the greater running distances required during match-play under the 10-m defensive rule would provide

an additional challenge to amateur rugby league players in defence, thereby reducing the likelihood of effective tackles, and increasing the risk of injury.^[9] Studies investigating the impact of the 10-m defensive rule change on the physiological demands of amateur rugby league players are warranted.

While the studies by Meir et al.^[10,20] were the first to provide important insight into the demands of rugby league, these studies are dated. To address these concerns, several recent rugby league time-motion analysis studies have been published.^[56,57] In a preliminary study of elite (National Rugby League, first grade) and semi-elite (National Rugby League, second grade) rugby league players, it was shown that elite players covered a greater total distance than semi-elite players and greater distance in high-intensity running.^[56] A limitation of this study was that no information was provided on the demands of tackling, or the repeated-effort demands of rugby league. King et al.^[57] completed a time-motion analysis on professional rugby league players during three matches of the Australian National Rugby League competition and reported an average work-to-rest ratio of 1 : 6 for the outside backs and hit-up forwards positional groups, and 1 : 5 for the adjustables positional group. The average numbers of tackles and collisions for hit-up forwards, outside backs and adjustables were 51, 27 and 35, respectively. It was also reported that the longest periods of high-intensity exercise players endured without recovery were 27, 35 and 22 seconds for the outside-backs, adjustables and hit-up forwards, respectively. Furthermore, some passages of high-intensity play included striding, sprinting, tackling and lateral movement for periods of up to 25 seconds with rest periods where the players stood, jogged or walked for a short time (sometimes for as little as 2–3 seconds) before repeating a high-intensity effort lasting from 10–20 seconds. Many of these repeated bouts of high-intensity efforts were at critical stages of the game where players were either defending

their try-line or attempting to score against the opposition. Collectively, these findings demonstrate that modern rugby league is considerably more demanding than previously reported by Meir and colleagues.^[10,20]

5.2 Physiological Demands of Competition

The physiological demands of competition have been investigated in amateur (unpublished observations), semi-professional^[58] and junior elite^[59] rugby league players. As expected, the intensity of matches increases as the playing level is increased. In one amateur rugby league match, Gabbett (unpublished observations) found an average heart rate of 152 beats/min, which equated to 78% of maximal heart rate (HR_{max}). The average heart rate of semi-professional and junior elite rugby league players during competition was 166 beats/min^[53] and 172 beats/min,^[59] respectively. These values corresponded to an exercise intensity of 84% and 93% of HR_{max} , respectively. Moreover, players spend a considerable percentage (30–44%) of total match-play in high-intensity (>85% HR_{max}) activities,^[58,59] with the average intensity of semi-professional matches reported to be 81.1% $\dot{V}O_{2max}$.^[58] Mean blood lactate concentrations of 5.2, 7.2 and 9.1 mmol/L have been reported during competition for amateur (unpublished observations), semi-professional^[58] and professional^[60] rugby league players, respectively, with blood lactate concentration significantly higher in the first half of matches (8.4 vs 5.9 mmol/L).^[58] The blood lactate concentration during competition is higher for forwards (8.5 mmol/L) than for backs (6.5 mmol/L).^[58] Collectively, these findings demonstrate that competitive rugby league places considerable physiological demands on both the aerobic and anaerobic glycolytic energy systems.

To date, most^[10,20,58,59] studies of the movement patterns and physiological demands of rugby league competition have investigated matches played under an unlimited interchange rule (i.e. unlimited number

of interchanges during a match). In 2001, the Australian National Rugby League introduced the limited interchange rule. This rule change, which allows teams a maximum of 12 interchange replacements during a match, and which has also recently been adopted by sub-elite rugby league competitions, is likely to increase the physiological demands on players, forcing many to compete in a fatigued state.^[12] Research is required to evaluate the movement patterns and physiological demands of players competing under the limited interchange rule.

6. Thermoregulatory Responses during Training and Competition

Several investigators have studied the thermoregulatory responses during rugby league training^[61] and competition.^[59-65] Strategies to prevent thermoregulatory stress are imperative as even a small amount of dehydration (1% or greater reduction in body mass) can impair performance and may be medically dangerous.^[66] Meir et al.^[63] investigated the thermoregulatory responses of 22 Australian professional rugby league players during matches. Body mass and estimated core (tympanic) temperature were measured pre-match, at half-time and immediately post-match. The mean temperature and relative humidity for the matches were 24°C and 67–73%, respectively. Mean tympanic temperature for the forwards increased from 37.7°C pre-match to 38.2°C at half-time, and 38.8°C post-match. Mean tympanic temperature for the backs increased from 37.9°C pre-match to 38.3°C at half-time, and 38.5°C post-match. Body mass decreased by 2.2 kg (2.4%) and 1.2 kg (1.5%) in forwards and backs, respectively. Jennings et al.^[62] investigated body mass changes during 16 matches in professional rugby league players competing in the English Super League. The mean temperature and relative humidity was 22.9°C and 73%, respectively. The mean reduction in body mass was 1.1 kg (1.2%) with the reduction in body mass significantly greater in forwards (1.5 kg, 1.5%)

than backs (0.9 kg, 1.1%). Over the course of the study, 13% of players experienced a 2–3% reduction in body mass, with 71.4% of players experiencing 2–3% reductions in body mass when the temperature exceeded 29°C. The mean reduction in body mass following training for rugby league is reported to be 0.5–1.1 kg.^[61]

Meir et al.^[64] investigated the effect of three different jersey types on thermoregulatory responses during warm, humid conditions. Subjects were required to perform four, 50-minute treadmill efforts at 50% $\dot{V}O_{2\max}$ in an environmental chamber with mean temperature and relative humidity of 27.6°C and 65%, respectively. The four trials were conducted with subjects wearing: (i) a traditional rugby league jersey with plastic patching; (ii) a traditional rugby league jersey without plastic patching; (iii) a lightweight alternative rugby league jersey without plastic patching; and (iv) no upper-body garment. The reduction in body mass was greater with the traditional rugby league jersey with plastic patching (1.05 kg) than with the traditional rugby league jersey without plastic patching (0.99 kg) and lightweight alternative rugby league jersey without plastic patching (0.96 kg). In addition, the mean skin temperature throughout the entire exercise bout was significantly lower in the lightweight alternative rugby league jersey without plastic patching than with the traditional rugby league jerseys. The authors concluded that the traditional rugby league jersey worn by professional rugby league players may have a negative effect on heat dissipation mechanisms in warm, humid conditions. Collectively, these results suggest that rugby league training and competition may pose considerable thermoregulatory demands on players. Strategies to reduce the impact of thermoregulatory stress on rugby league players may include weighing players before and after training and matches, educating players about the role of fluid intake and its relevance to perform-

ance and recovery, and implementing appropriate fluid intake and acclimatisation protocols.^[61]

7. Relationship Between Physiological Factors and Injury

7.1 Influence of Player Fatigue on Injury Rates

Over 70% of amateur rugby league injuries occur in the second half of matches, suggesting that fatigue, or a fatigue-induced reduction in skill contributes to injuries in amateur rugby league players.^[67] Conversely, comparatively fewer (38.5%) injuries are sustained by semi-professional players in the second half of matches.^[9] These findings are somewhat expected given the poor aerobic fitness of amateur players compared with semi-professional players.^[13,14] The lower second-half injury rates of semi-professional players highlights the importance of aerobic fitness in preventing fatigue-related injuries in rugby league. Studies that have examined the incidence of injuries in professional rugby league players have found that second-half injuries are similar,^[68] or only slightly greater than^[69,70] first-half injuries. Research is yet to examine injury occurrence in relation to the time of play (i.e. first-half or second-half) in junior rugby league players. The majority (55.3%) of training injuries occur in the latter stages of the training session.^[9] Rugby league teams often integrate skills and conditioning sessions in order to facilitate the development of skills under fatigued conditions.^[14] The finding of higher injury rates in the latter stages of training sessions again implicates fatigue as the major contributor to rugby league training injuries.^[9]

7.2 Influence of Playing Intensity on Injury Rates

The majority of amateur rugby league match injuries occur in the latter half of the season.^[71] In

addition, a progressive increase in match injuries occurs from the beginning to the end of the season. These findings have been attributed to accumulative microtrauma and/or residual fatigue associated with limited recovery between matches.^[28,67] Studies that have examined semi-professional rugby league injury rates have also found a progressive increase in injury rates during the course of a season, with injury rates peaking in the latter half of the season.^[9] The finding of high match injury rates towards the end of the competitive season in semi-professional rugby league players has been attributed to increases in playing intensity as the 'finals' series approaches.^[9] These findings have been supported by Gabbett^[71] who found a significant correlation ($r = 0.74$) between match injury rates and match intensity in semi-professional rugby league players. Hodgson Phillips et al.^[26] and Alexander et al.^[70] reported that more injuries occurred towards the end of the competitive season in professional rugby league players, while Seward et al.^[68] and Gissane et al.^[72] reported more injuries in the early stages of the season in professional rugby league players. No study has documented the seasonal variations in injury rates of junior rugby league players.

7.3 Influence of the Limited Interchange Rule on Injury Rates

Despite the suggestion that the physiological demands on players have increased under the limited interchange rule, a recent investigation showed that significantly fewer professional rugby league players left the field through injury during matches played under the limited interchange rule compared with the unlimited interchange rule.^[12] However, a subsequent study found that the percentage of professional rugby league players missing through injury each week increased from 12.7% under the unlimited interchange rule (seasons 1999–2000) to 15.2% under the limited interchange rule (seasons 2001–3).^[73] Gabbett^[11] reported that the relative risk

of injury decreased by 30% in sub-elite rugby league players following the introduction of the limited interchange rule. The risk of sustaining thigh and calf injuries, muscular strains and high-intensity running injuries was reduced following the introduction of the limited interchange rule. It was hypothesized that the limited interchange rule increased the physiological demands on players, thereby reducing match speed, and minimising impact forces associated with physical collisions and tackles.^[11]

7.4 Influence of Training Load on Injury Rates

Recent data from semi-professional players have shown that the majority of rugby league training injuries occur in the early stages of the season.^[9,74] The early season incidence of injury of 116.1 per 1000 training hours is 2.6-fold higher than the seasonal average injury rate (45.3 per 1000).^[9] Training loads have been shown to be greatest during the early stages of the season.^[74] In addition, training injury rates are significantly correlated ($r = 0.86$) with increases in training loads, suggesting that the harder rugby league players train, the more injuries they will sustain.^[71] Based on this evidence, the influence of reductions in pre-season training loads on the incidence of training injuries and improvements in fitness was investigated in 220 semi-professional rugby league players over three consecutive pre-season periods.^[74] Following the initial pre-season period, training loads were reduced by 10.6–15.7% through reductions in training duration and training intensity. The reductions in training loads were associated with a 39.8–50.0% reduction in training injury rates. Furthermore, $\dot{V}O_{2\max}$ progressively increased across the three seasons. Using the minimum clinically important difference to determine practical significance, there was a 62–88% probability that the pre-season improvements in $\dot{V}O_{2\max}$ in the latter seasons were of greater physiological significance than the improvements in

$\dot{V}O_{2\max}$ in the initial season. These results demonstrate that reductions in pre-season training loads may reduce training injury rates and result in greater improvements in $\dot{V}O_{2\max}$ in rugby league players.^[74]

7.5 Relationship Between Training Load, Injury and Fitness

In a subsequent study, Gabbett and Domrow^[75] developed a statistical model that related training with performance and estimated the influence of training load on training injury and physical fitness in rugby league players. 183 rugby league players underwent measurements of height, body mass, skinfold thickness, vertical jump, 10-, 20- and 40-m speed, agility, and estimated $\dot{V}O_{2\max}$ in the off-, pre-, mid- and end-season training periods. Training load and injury data were summarized into pre-season, early-competition and late-competition training phases. While physical fitness improved with training, there was no significant association between training load and changes in physical fitness during any of the training phases. However, increases in training load during the early-competition training phase were significantly related to a decrease in agility. A significant relationship was observed between the log of training load and injury risk during each training phase, resulting in a 1.50–2.85 increase in injury risk for each unit increase in training load. Furthermore, during the pre-season training phase, there was a significant relationship between training load and injury incidence within the training load range of 155 and 590 units. During the early- and late-competition training phases, increase in training load of 175–620 and 145–410 units, respectively, resulted in no further increase in injury incidence. The authors concluded that increases in training load, particularly during the pre-season training phase, significantly increased the risk of injury in rugby league players. Furthermore, these findings demonstrated that while

moderate increases in training load during the early-competition training phase result in no further increase in injury incidence, significant reductions in agility performances may occur. From a practical perspective, these findings suggest that reductions in training load during the early-competition training phase may reduce the odds of injury without compromising agility performances in rugby league players.

7.6 Risk Factors for Injury

The implementation and evaluation of effective injury prevention strategies is dependent on the identification of injury risk factors.^[76] To date, only one study has investigated risk factors for injury in rugby league players.^[77] In a 4-year prospective study of sub-elite rugby league players, Gabbett and Domrow^[77] reported a higher risk of injury in players with low 10-m and 40-m speed. Players with a low estimated $\dot{V}O_{2\max}$ had a greater risk of sustaining a contact injury. In addition, players who completed <18 weeks of training prior to sustaining their initial injury were at greater risk of sustaining a subsequent injury. These findings provide some explanation for the high incidence of fatigue-related injuries in rugby league players.^[67] Furthermore, these findings highlight the importance of speed and endurance training to reduce the incidence of injury in sub-elite rugby league players.

8. Strength and Conditioning

8.1 Specificity

The greatest training benefits occur when the training stimulus simulates the specific movement patterns and physiological demands of the sport.^[78] Based on observations from time-motion studies, several recommendations for training have been made.^[57] Due to the high number of physical confrontations in a match (e.g. tackling, being tackled,

playing the ball after being tackled to the ground), it is necessary to develop the strength and power of players. In addition, King et al.^[57] found that in professional rugby league, on average, every 4 seconds of high-intensity activity was followed by approximately 21 seconds of low-intensity activity, and that continuous periods of high-intensity work could be as long as 35 seconds. Collectively, these findings implicate the need for specific training of the anaerobic alactic (adenosine triphosphate-creatine phosphate), anaerobic glycolytic and aerobic energy systems in rugby league players.

8.2 Skill-Based Conditioning Games and Interval Training

Interval training using distances and activities specifically related to competition, such as moving up and back over 10 m for periods of 30–90 seconds, repeat tackling efforts on a bag for 5–10 repetitions, and sprint efforts over distances ranging from 5 to 60 m with varying work-to-rest ratios have been suggested as a specific training stimulus for rugby league players.^[10] More recently, skill-based conditioning games have been used to develop the skill and fitness of rugby league players. The advantage of skill-based conditioning games over traditional interval training is that skill-based conditioning games also provide the opportunity to develop decision-making and problem-solving skills.^[79] Gabbett^[79] investigated the incidence of training injuries in semi-professional rugby league players and identified the training activities that were most likely to result in injury. The majority of training injuries (90.9 per 1000 training hours, 37.5%) were sustained in traditional conditioning activities that involved no skill component (i.e. running without the ball). In contrast, the incidence of injuries sustained while participating in skill-based conditioning games (26.0 per 1000 training hours, 10.7%) was low.

In a subsequent study, the specificity of skill-based conditioning games as a training stimulus was investigated (unpublished observations). Using skill-based conditioning games designed to develop scrambling defence and support play, play-the-ball speed, defensive line speed, ball control and patience, it was shown that the mean heart rate and blood lactate responses during skill-based conditioning games (155 beats/min and 5.2 mmol/L) were almost identical to those obtained during competition (152 beats/min and 5.2 mmol/L).

Gabbett^[80] compared skill-based conditioning games and traditional conditioning for improving speed, agility, muscular power and maximal aerobic power in rugby league players. Players completed a 9-week in-season conditioning programme consisting entirely of skill-based conditioning games or traditional conditioning (i.e. running activities with no skill component). Skill-based conditioning games induced a significant improvement in 10-, 20- and 40-m speed, muscular power and maximal aerobic power, whereas traditional conditioning activities improved 10-m speed and maximal aerobic power only. Both groups won six of their eight matches played within the training period, resulting in a win-loss ratio of 75%. However, on average, the skill-based conditioning games group scored more points in attack, and had a greater points differential than the traditional conditioning group. Collectively, these findings suggest that skill-based conditioning games offer a safe, effective and specific method of conditioning for rugby league players. In addition, given that skills learnt from skill-based conditioning games are more likely to be applied in the competitive environment, their use may provide a practical alternative to traditional conditioning for improving the physiological capacities and playing performance of rugby league players.

8.3 Training and Adaptation in Junior and Senior Rugby League Players

Several studies have reported various adaptations of rugby league players to training.^[40,41,79-85] Warman et al.^[40] reported a 1.5–30.4% increase in 3RM squat and bench-press strength, chin-ups to failure and $\dot{V}O_{2\max}$ in response to a 6-month pre-season strength and conditioning programme in semi-professional rugby league players. Baker^[35] reported a significant improvement in 1RM bench-press strength and unchanged upper- and lower-body muscular power over a 19-week in-season strength programme in semi-professional rugby league players. A 29-week in-season strength programme failed to elicit significant changes in 1RM bench-press strength, and upper- and lower-body muscular power in professional rugby league players.^[35] O'Connor^[81] conducted a 10-week in-season anaerobic training programme in professional rugby league players, and this resulted in a significant increase in the anaerobic capacity of the players (as evidenced from greater lactate tolerance and total work outputs during a 60-second maximal effort test). Coutts et al.^[82] investigated changes in $\dot{V}O_{2\max}$ in semi-professional rugby league players in response to over-reaching. Two groups completed either 6 weeks of being well trained or deliberately over-reached. The $\dot{V}O_{2\max}$ was significantly reduced in the over-reaching group throughout the training period. However, following a 7-day taper, $\dot{V}O_{2\max}$ increased to a greater extent in the over-reaching group.

Gabbett^[83] investigated the relationship between training loads and changes in physical performance in response to a 14-week field conditioning programme in junior and senior rugby league players. Improvements in agility, muscular power and maximal aerobic power were observed in both the junior and senior players following training; however, the improvement in maximal aerobic power (8.6% vs 5.1%) and muscular power (7.7% vs 4.7%) were

greatest in the junior players. Training loads were significantly higher in the senior players (448 vs 341 units). These findings demonstrated that despite having lower training loads, junior rugby league players exhibit greater adaptations in maximal aerobic power and muscular power than senior rugby league players.^[83]

The adaptive responses to training have also been investigated in young (Under-15) and older (Under-18) junior rugby league players.^[84] Gabbett et al.^[84] performed a 10-week pre-season training programme in junior rugby league players, monitoring changes in anthropometry (body mass and sum of seven skinfolds), speed, muscular power, agility and estimated $\dot{V}O_{2\max}$ before and after training. In addition, changes in upper-body (push-ups, sit-ups and chin-ups) and lower-body (multiple effort vertical jump) muscular endurance were monitored at regular intervals throughout the training period. The Under-15 players recorded larger increases in body mass, and greater improvements in speed, muscular power, muscular endurance and $\dot{V}O_{2\max}$ than the Under-18 players. Collectively, these results suggest that young and slightly older junior rugby league players adapt differently to a given training stimulus and that training programmes should be modified to accommodate differences in maturational and training age.

9. Conclusions

The purpose of this article was to provide a comprehensive review of the applied physiology of rugby league football. Several studies have documented the physiological capacities of rugby league players and the physiological demands of competition, with the physiological capacities of players and the physiological demands of competition generally increasing as the playing level increases. However, there is also evidence to suggest that the physiological capacities of players may deteriorate as the sea-

son progresses, with reductions in muscular power and maximal aerobic power and increases in skinfold thickness occurring towards the end of the rugby league season, when training loads are lowest and match loads and injury rates are at their highest. Player fatigue and playing intensity have been suggested to contribute to injuries in rugby league, with a recent study reporting a significant correlation between match injury rates and playing intensity in semi-professional rugby league players. Studies have also reported a higher risk of injury in players with low 10- and 40-m sprint times, while players with a low maximal aerobic power have greater risk of sustaining a contact injury. Furthermore, players that completed <18 weeks of training prior to sustaining their initial injury are at greater risk of sustaining a subsequent injury. These findings provide some explanation for the high incidence of fatigue-related injuries in rugby league players and highlight the importance of speed and endurance training in reducing the incidence of injury in rugby league players.

To date, most, but not all, studies have investigated the movement patterns and physiological demands of rugby league competition; however, there has been little emphasis on how training activities simulate the competition environment. An understanding of the movement patterns and physiological demands of specific individual positions during training and competition would allow the development of strength and conditioning programmes that specifically meet the requirements of these positions. In addition, further research is required to provide information on the repeated sprint ability of rugby league players. A test that assesses repeated sprint performance that employs distances and intensities specific to rugby league, while also simulating work-to-rest ratios similar to rugby league competition is warranted.

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References

- Brewer J, Davis J. Applied physiology of rugby league. *Sports Med* 1995; 20: 129-35
- Meir R, Newton R, Curtis E, et al. Physical fitness qualities of professional rugby league players: determination of positional differences. *J Strength Cond Res* 2001; 15: 450-8
- Meir R. A model for the integration of macrocycle and microcycle structure in professional rugby league. *Strength Cond Coach* 1994; 2: 6-12
- Gibbs N. Injuries in professional rugby league: a three-year prospective study of the South Sydney professional rugby league football club. *Am J Sports Med* 1993; 21: 696-700
- Gissane C, Jennings D, Kerr K, et al. A pooled data analysis of injury incidence in rugby league football. *Sports Med* 2002; 32: 211-6
- Clark L. A comparison of the speed characteristics of elite rugby league players by grade and position. *Strength Cond Coach* 2003; 10: 2-12
- O'Connor D. Physiological characteristics of professional rugby league players. *Strength Cond Coach* 1996; 4: 21-6
- Gabbett TJ. Influence of playing position on the site, nature, and cause of rugby league injuries. *J Strength Cond Res* 2005; 19: 749-55
- Gabbett TJ. Incidence of injury in semi-professional rugby league players. *Br J Sports Med* 2003; 37: 36-44
- Meir R, Colla P, Milligan C. Impact of the 10-meter rule change on professional rugby league: implications for training. *Strength Cond J* 2001; 23: 42-6
- Gabbett TJ. Influence of the limited interchange rule on injury rates in sub-elite rugby league players. *J Sci Med Sport* 2005; 8: 111-5
- Orchard J, Steet L, Walker C. Effect of the limited interchange rule on players leaving the field at an NRL club [online]. Available from URL: <http://www.injuryupdate.com.au/images/research/LimitedInterchangeRule.pdf> [Accessed 2003 Sep]
- Gabbett TJ. Physiological and anthropometric characteristics of amateur rugby league players. *Br J Sports Med* 2000; 34: 303-7
- Gabbett TJ. Influence of physiological characteristics on selection in a semi-professional rugby league team: a case study. *J Sports Sci* 2002; 20: 399-405
- O'Connor D. Fitness profile of professional rugby league players [abstract]. *J Sports Sci* 1995; 13: 505
- Brewer J, Davis J, Kear J. A comparison of the physiological characteristics of rugby league forwards and backs [abstract]. *J Sports Sci* 1994; 12: 158
- Meir R. Seasonal changes in estimates of body composition in professional rugby league players. *Sport Health* 1993; 11: 27-31
- Meir R. Evaluating players fitness in professional rugby league: reducing subjectivity. *Strength Cond Coach* 1993; 1: 11-7
- Gabbett TJ. Physiological characteristics of junior and senior rugby league players. *Br J Sports Med* 2002; 36: 334-9
- Meir R, Arthur D, Forrest M. Time and motion analysis of professional rugby league: a case study. *Strength Cond Coach* 1993; 1: 24-9
- Larder P. The rugby league coaching manual. 2nd ed. London: Kingswood Press, 1992
- Stephenson S, Gissane C, Jennings D. Injury in rugby league: a four year prospective study. *Br J Sports Med* 1996; 30: 331-4
- Gabbett TJ. A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. *J Sports Sci* 2006; 24: 1273-80
- Gabbett TJ, Herzig PJ. Physiological characteristics of junior elite and sub-elite rugby league players. *Strength Cond Coach* 2004; 12: 19-24
- Gabbett T, Kelly J, Ralph S, et al. Physiological and anthropometric characteristics of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. *J Sci Med Sport*. In press
- Hodgson Phillips L, Standen PJ, Batt ME. Effects of seasonal change in rugby league on the incidence of injury. *Br J Sports Med* 1998; 32: 144-8
- Allen GD. Physiological and metabolic changes with six weeks detraining. *Aust J Sci Med Sport* 1989; 21: 4-9
- Gabbett TJ. Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *J Strength Cond Res* 2005; 19: 400-8
- Gabbett TJ. A comparison of physiological and anthropometric characteristics among playing positions in junior rugby league players. *Br J Sports Med* 2005; 39: 675-80
- Baker D, Nance S. The relation between running speed and measures of strength and power in professional rugby league players. *J Strength Cond Res* 1999; 13: 230-5
- Gabbett TJ, Kelly JN, Sheppard JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res*. In press
- Gabbett T, Benton D. Reactive agility of rugby league players. *J Sci Med Sport*. In press
- Atkins SJ. Normalizing expressions of strength in elite rugby league players. *J Strength Cond Res* 2004; 18: 53-8
- Baker D. Comparison of upper-body strength and power between professional and college-aged rugby league players. *J Strength Cond Res* 2001; 15: 30-5
- Baker D. The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *J Strength Cond Res* 2001; 15: 172-7
- Baker D. Differences in strength and power among junior-high, senior-high, college-aged, and elite professional rugby league players. *J Strength Cond Res* 2002; 16: 581-5
- Baker D. The effects of systematic strength and power training during the formative training years: a comparison between

- younger and older professional rugby league players. *Strength Cond Coach* 2003; 11: 9-11
38. Baker D, Nance S, Moore M. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J Strength Cond Res* 2001; 15: 20-4
39. Baker D, Nance S, Moore M. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *J Strength Cond Res* 2001; 15: 92-7
40. Warman G, Humphries B, Coutts A. The effect of a six-month pre-season conditioning program on muscular strength and aerobic endurance in semi-professional rugby league players [abstract]. Proceedings of the Pre-Olympic Congress. International Congress on Sport Science, Sports Medicine, and Physical Education; 2000 Sep 7-12; Brisbane (QLD), 527
41. Coutts AJ, Murphy AJ, Dascombe BJ. Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players. *J Strength Cond Res* 2004; 18: 316-23
42. McArdle WD, Katch FI, Katch VL. Exercise physiology: energy, nutrition, and human performance. 4th ed. Baltimore (MD): Williams and Wilkins, 1996
43. Gabbett TJ. Physiological and anthropometric characteristics of elite women rugby league players. *J Strength Cond Res* 2007; 21 (3): 875-81
44. Tumilty D, Darby S. Physiological characteristics of Australian female soccer players [abstract]. *J Sports Sci* 1992; 10: 145
45. Tumilty D. Protocols for the physiological assessment of male and female soccer players. In: CJ Gore, editor. *Physiological tests for elite athletes*. Champaign (IL): Human Kinetics, 2000: 356-62
46. Lawrence S, Polglaze T. Protocols for the physiological assessment of male and female hockey players, I. In: CJ Gore, editor. *Physiological tests for elite athletes*. Champaign (IL): Human Kinetics, 2000: 286-301
47. O'Connor D. Profile of elite female touch football players. In: Reilly T, Bangsbo J, Hughes M, editors. *Science and football III: proceedings of the Third World Congress of Science and Football*. London: E and FN Spon, 1997: 7-10
48. Coutts A, Reaburn P, Murphy A, et al. Changes in physiological characteristics of semi-professional rugby league players in relation to training load: a case study [abstract]. *J Sci Med Sport* 2003; 6: 37
49. Pyne D, Duthie G, Johnson B. Interpreting group and individual anthropometric and fitness changes in rugby league [abstract]. *J Sci Med Sport* 2003; 6: 9
50. Gabbett TJ. Physiological and anthropometric characteristics of junior rugby league players over a competitive season. *J Strength Cond Res* 2005; 19: 764-71
51. Gabbett TJ. Science of rugby league football: a review. *J Sports Sci* 2005; 23: 961-76
52. Gabbett T, Kelly J, Pezet T. A comparison of fitness and skill among playing positions in sub-elite rugby league players. *J Sci Med Sport*. In press
53. Gabbett T, Kelly J, Pezet T. Relationship between physical fitness and playing ability in rugby league players. *J Strength Cond Res*. In press
54. Gabbett T, Kelly J. Does fast defensive line speed influence tackling proficiency in collision sport athletes? *Int J Sports Sci Coach* 2007; 2: 467-72
55. Gabbett TJ. Influence of fatigue on tackling technique in rugby league players. *J Strength Cond Res*. In press
56. Sirotic A, Russell N, Knowles H, et al. Time-motion analysis of elite and semi-elite rugby league [abstract]. *J Sci Med Sport* 2005; 8: 67
57. King T, Jenkins D, Gabbett T, et al. Repeated high-intensity efforts in professional rugby league football [abstract]. Australian Institute of Sport Team Sport Conference, Oral presentation; 2006 Jun 21-22; Canberra (ACT)
58. Coutts A, Reaburn P, Abt G. Heart rate, blood lactate concentration and estimated energy expenditure in a semi-professional rugby league team during a match: a case study. *J Sports Sci* 2003; 21: 97-103
59. Estell J, Lord P, Barnsley L, et al. The physiological demands of rugby league [abstract]. Proceedings of the Australian Conference of Science and Medicine in Sport; 1996 Oct 28-31; Canberra (ACT), 388-9
60. O'Connor D. Blood lactate concentrations measured during competitive games throughout a professional rugby league season [abstract]. *J Sports Sci* 2004; 22: 556-7
61. Meir R, Murphy A. Fluid loss and rehydration during training and competition in professional rugby league. *Coach Sport Sci J* 1998; 3: 9-13
62. Jennings S, Robertson S, Jennings D, et al. Body mass as an indicator of dehydration in summer rugby league. *Coach Sport Sci J* 1998; 3: 31-3
63. Meir RA, Davie AJ, Ohmsen P. Thermoregulatory responses of rugby league footballers playing in warm humid conditions. *Sport Health* 1990; 8: 11-4
64. Meir RA, Lowdon BJ, Davie AJ. The effect of jersey type on thermoregulatory responses during exercise in a warm humid environment. *Aus J Sci Med Sport* 1994; 26: 25-31
65. Meir R, Brooks L, Shield T. Body weight and tympanic temperature change in professional rugby league players during night and day games: a study in the field. *J Strength Cond Res*, 2003; 17: 566-72
66. American College of Sports Medicine. Position stand on exercise and fluid replacement. *Med Sci Sports Exerc* 1994; 28: i-vii
67. Gabbett TJ. Incidence, site, and nature of injuries in amateur rugby league over three consecutive seasons. *Br J Sports Med* 2000; 34: 98-103
68. Seward H, Orchard J, Hazard H, et al. Football injuries in Australia at the elite level. *Med J Aust* 1993; 159: 298-301
69. Norton R, Wilson M. Rugby league injuries and patterns. *NZ J Sports Med* 1995; 22: 37-8
70. Alexander D, Kennedy M, Kennedy J. Rugby league football injuries over two competition seasons. *Med J Aust* 1980; 2: 334-5
71. Gabbett TJ. Influence of training and match intensity on injuries in rugby league. *J Sports Sci* 2004; 22: 409-17
72. Gissane C, Jennings DC, Standing P. Incidence of injury in rugby league football. *Physiotherapy* 1993; 79: 305-10
73. Orchard J. Missed time through injury and injury management at an NRL club. *Sport Health* 2004; 22: 11-9

-
74. Gabbett TJ. Reductions in pre-season training loads reduce training injury rates in rugby league players. *Br J Sports Med* 2004; 38: 743-9
 75. Gabbett TJ, Domrow N. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *J Sports Sci* 2007; 25: 1507-19
 76. van Mechelen W, Hlobil H, Kemper HCG. Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Med* 1992; 14: 82-99
 77. Gabbett TJ, Domrow N. Risk factors for injury in subelite rugby league players. *Am J Sports Med* 2005; 33: 428-34
 78. Rushall BS, Pyke FS. Training for sport and fitness. Sydney (NSW): MacMillan, 1990
 79. Gabbett TJ. Training injuries in rugby league: an evaluation of skill-based conditioning games. *J Strength Cond Res* 2002; 16: 236-41
 80. Gabbett TJ. Skill-based conditioning games as an alternative to traditional conditioning for rugby league players. *J Strength Cond Res* 2006; 20: 309-15
 81. O'Connor D. Assessment of anaerobic capacity and blood lactate levels of professional rugby league players [abstract]. Proceedings of the Australian Conference of Science and Medicine in Sport; 1998 Oct 13-16; Adelaide (SA), 187
 82. Coutts A, Reaburn P, Piva TJ, et al. Changes in selected biochemical, muscular strength, power, and endurance measures during deliberate overreaching and tapering in rugby league players. *Int J Sports Med* 2007; 28 (2): 116-24
 83. Gabbett TJ. Performance changes following a field conditioning program in junior and senior rugby league players. *J Strength Cond Res* 2006; 20: 215-21
 84. Gabbett T, Johns J, Riemann M. Performance changes following training in junior rugby league players. *J Strength Cond Res*. In press
 85. Baker DG, Newton RU. Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes. *J Strength Cond Res* 2006; 20: 541-6
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