Behind enemy lines: using oppositional data to measure relative match performance in elite women's rugby league

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Behind enemy lines: using oppositional data to measure relative match performance in elite women's rugby league.

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Abstract

Background: Rugby league is a contact sport played by men, women, and wheelchair athletes. In 2020 there were forty-five member nations, with men's professional leagues in both the northern and southern hemisphere. Research has primarily focused on the male athlete and examined the physical, technical, and tactical differences between playing level, starters vs nonstarters, playing position, and successful and non-successful teams. The research is utilised by practitioners (Coaches, S&C Coaches, Sports Scientists, Physiotherapists etc) to apply evidence-based approaches to optimise athlete performance. However, applying the research of male athletes to women's sport is inaccurate, due to differences in their physical ability, technical skills, and game tactics used. Female athletes make up the fastest growing contingent of rugby league players yet the research in female rugby league is scarce. It is therefore the goal of this project to provide new insight into women's rugby league and utilise a novel analytical approach. This project examines the movement profiles (GPS metrics) and performance indicators of teams in the Australian women's elite rugby league competition, the NRLW, to determine which GPS metrics and performance indicators can predict points scoring and match outcome. Traditionally performance analysis is done with absolute sums of data (data averaged over an 80 minute game), yet with the data made available to this project, the analysis of opposing teams relative data (data relative to the opposition team both on a per minute basis, and score line difference) was conducted to determine if this approach could offer unique insight compared to traditional absolute data analysis.

Method: This study examined 117 players from the four NRLW clubs during the 2018 & 2019 NRLW seasons, with data collected using 10 Hz Optimeye S5 (Catapult) GPS units. The GPS metrics analysed were total distance (m); average speed (m.s); distance covered greater than 12 km·h^{-1} (i.e. high-speed running (HSR); distance covered greater than 18

km·h^{-1} (i.e. sprint distance; SD); and average acceleration load (total sum of accelerations performed). Technical performance indicators used were `All Running Metres', 'Tackles', 'Missed Tackles', and 'Tackle Breaks'. The technical performance indicators were analysed for a full match, and the GPS data analysed for the full match, and half by half. The analysis of oppositional data was separated into three separate steps: i) absolute sum of data vs absolute score (total points scored), ii) absolute sum of data vs relative score (difference in score line), iii) relative difference of metrics (% difference between teams per minute) vs relative score (difference in score line). Generalised linear mixed models (GLMM) were employed (R version 3.5.211).

Results: 'All Running Metres' was found to be the only significant performance indicators, and was related to positive points scoring and match outcomes. Although not significant 'Tackles' and 'Missed Tackles' negatively impacted points scoring. There were three GPS metrics found to be significant predictors of points scoring and match outcome. 'Average High Speed' and 'Average Sprinting Speed' had a positive relationship, whereas 'Accelerations' had a negative relationship, with points scoring and match outcome. Total distance was not a significant indicator of match outcome.

Discussion: The performance indicators of 'All Running Metres', 'Average High Speed', 'Average Sprinting Speed', and 'Average Acceleration' were found to be significant predictors of success. 'All Running Metres' was significant in the absolute and relative analysis, with the relative analysis finding 'All Running Metres' to be more influential than in the absolute analysis. This suggests having higher run metres relative to your opposition is more important than having a high total amount of 'All Running Metres'. 'Average Sprinting Speed' was significant in the absolute and relative analysis, with 'Average High Speed' significant in the half by half relative analysis. These findings indicate that running at higher speeds relative to your opposition will contribute positively to match outcome. ‘Accelerations’ were significant in the half by half analysis of absolute values, and were negatively associated with match outcome. This suggests over the full duration of the game ‘Accelerations’ do not impact match outcome; however, within smaller periods of a match the disparity between oppositions ‘Accelerations’ may impact match outcome.

Conclusion: This study was the first to examine performance indicators in women’s rugby league, and identify which GPS and performance indicators metrics could explain points scored and match outcome. ‘All Running Metres’, ‘Average High Speed’, and ‘Average Sprinting Speed’ had a positive relationship with points scoring and match outcome. The relative analysis approach was able to provide more inference than the absolute analysis. The relative analysis highlighted the increased influence of each significant metric in points scoring opportunities and match outcomes. By identifying the technical and physical qualities related to success, coaches and athletes in women’s rugby league can design training programs to improve player performance; devise game tactics to exploit the opposition; and aid in talent identification and player recruitment of athletes who exhibit qualities that will contribute positively to match outcome.

Practical application: The findings support the training and development of attacking play and maximising possession; in addition to training and developing speed and identifying and recruiting players with these qualities. Defensive work should also be prioritised as our findings show that ‘Missed Tackles’ are negatively associated with match outcome.

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

[redacted]

Jonathan Ward

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way meant I could focus on my studies and coaching, which allowed me to complete two degrees, and now live and coach professional rugby in France. Whilst you may not understand fully what I do, you are always there for support, offer invaluable guidance, and have a good chin wag.

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Chapter One – Introduction

Women's sport is growing in participation and broadcasting. In Australia there are now nationwide competitions in Australian Rules Football, Cricket, Netball, Rugby Union, Rugby League, and Soccer, with matches televised on live TV. Whilst participation and broadcasting are growing, research in women's sport is lagging. Research is used by practitioners (Coaches, S&C Coaches, Sports Scientists, Physiotherapists, Sport Psychologists etc) to apply evidence based approaches to optimise athlete performance (Emmonds et al. 2019); however, as the majority of this research is in men's sport, the research cannot be utilised by practitioners in women's sport with accuracy. Previous studies have found that physical and technical capacities of females differ to men, and for these reasons women utilise different game tactics (Casal et al. 2020a; Pedersen et al. 2019; Pyne et al. 2012; Clarke et al. 2017a; Bradley et al. 2013). These differences manifest themselves through different movement patterns (Clarke et al. 2017a) and technical performance indicators (Thibault et al. 2010) and make findings from women's research specific to women's sport.

There have been numerous studies analysing men's professional rugby league (Austin et al. 2011; Black and Gabbett 2014; Gabbett et al. 2008; Gabbett and Gahan 2016; Kempton and Coutts 2016; Gabbett 2016; Waldron et al. 2011). Researchers aim to uncover the physical, physiological, and mental demands placed on athletes during competition, which enable coaches and performance staff to better prepare athletes for optimal performance, manage workloads and recovery, as well as minimise illness and injury. There are a range of strategies used to monitor the physical, physiological, and mental loads placed on athletes including subjective (e.g., athlete wellness questionaries, rate of perceived exertion; RPE) and objective measures (e.g., movement patterns or power output) and internal measures of workload (e.g. heart rate) (Burgess 2017).

Athlete tracking technology has been used in sports since 2003. The tracking devices, termed GPS units, collect athletes displacement and velocity via information gathered from the Global Navigation Satellite System (GNSS) and receivers within the unit (Quinn et al. 2020; Aughey 2011; Edgecomb and Norton 2006). Quantifying the locomotor movements (i.e. movement patterns) reveal the proportion of match-play that is spent at varied velocities (i.e. walking, running, or sprinting) as well as rapid change of direction movements and acceleration/decelerations of each player. Depending on the manufacturer of the receiver and software, the metrics that are collected can vary; however, all GPS units aim to provide coaches and sports scientists with an estimate of the volume (distance and time) and intensity (velocity, accelerations, decelerations) of the work performed by athletes.

There are a range of factors that can significantly influence the movement patterns during rugby league match-play including: i. Athlete characteristics (e.g., gender, position, and physiology), ii. Competition level (e.g., junior vs. open-age groups; domestic vs. international competitions), iii. Game strategy, and iv. Environmental conditions (Newans et al., 2020; Dalton-Barron et al. 2020). Further, it must be acknowledged that movement patterns are dependent on several contextual factors. The concept that absolute measures of volume such as distance, duration, relative distance, and speed are significantly associated with performance risks underestimating the relative performance of a lower ranked team (O'Donoghue 2013). It might be intuitive for some coaches and sports scientists to think that completing more work in matches equates to a better performance, yet data comparing distance covered during rugby league match-play in higher- (e.g., international, higher ladder position) compared to lower-ranked (e.g., domestic, lower ladder position) teams indicates that this relationship may not always be true (Hulin et al. 2015). No single, or combination of GPS metric has been able to accurately predict match outcome in men's rugby league, supporting the notion that a greater volume of work does not necessarily equate to superior performance. The reporting of GPS data from games is valuable in understanding the load imparted on the athlete, thus impacting the subsequent training and recovery prescription; however, it does not provide coaches with any comparative performance indicators i.e., the team's performance relative to its opposition.

The opportunity to compare a team's performance data to their opposition often arises at the end of season using "all-teams" aggregate data provided by the governing body (e.g., National Rugby League; NRL, Australia), or by searching the research literature for comparable data. It is not common practice in professional sport to share data collected in-house throughout the season which may make recreating this study difficult. However, the data does not provide individual match files with which to make direct comparisons within the same game. Further, authors have acknowledged the direct influence that opposition has on a team's movement patterns during football match-play (Folgado et al. 2014; Lago-Peñas and Dellal 2010; Rampinini et al. 2007), however no previous study has expressed movement patterns relative to the movement patterns of the opposition team. The provision of distance, time, acceleration, and velocity metrics expressed in terms relative (%) to the opposition is an important perspective for teams to consider as they review their own performance.

Only two previous studies have reported GNSS-derived metrics to describe the movement patterns of women's rugby league players (Quinn et al. 2020; Newans et al., 2020), whilst to our knowledge there has been little to no research conducted on performance indicators in women's rugby league. It is therefore the goal of this study to examine the movement demands and performance indicators relative (% difference) to the opposition that can predict match outcome (i.e., score-differential) in elite women's rugby league.

Chapter Two – Review of the Literature

The Game of Rugby League

Rugby league began in 1895 when the clubs in the north of England broke away from the governing body of rugby in England, the Rugby Football Union (RFU). Players of that era often took time off work to play and the northern clubs wanted to compensate their players to reimburse their lost wages. The RFU, wanting to keep the game amateur, did not agree with paying the players and therefore the northern clubs broke away over the disagreement to form a new competition. Over the years the rules between the newly made rugby league competition changed from those in rugby union in an attempt to make the game faster and attract spectators (RFL 2020). The change also occurred in Australia and New Zealand, with the allure of professionalism drawing the best rugby union players to league, bringing with them the supporters. From the early 1900's rugby league has been the preferred code of football in New South Wales and Queensland, Australia, and in 1998 the National Rugby League (NRL) was formed as the national competition in Australia and New Zealand, with the game celebrating 112 years of professionalism in 2020 (NRL 2020; RFL 2020).

Rugby league boasts forty-five member nations, with professional teams in Australia, Canada, England, France, New Zealand, Papua New Guinea, and Wales (International Rugby League 2020). The pinnacle competition of rugby league is the World Cup held every four years and was first contested in 1954. In 2021 the World Cup will increase from fourteen to sixteen teams, and will feature competitions for men, women, and wheelchair players (RLWC 2020). Other international competitions of note include the Four Nations contested between Australia, England, and New Zealand, with an additional team qualifying for the fourth position. The location of the competition, either in the northern or southern hemisphere, will dictate the location of the fourth team. The World Cup 9s is held every four years, two years after the thirteen-a-side world cup. The first

World Cup 9s was held in 2019, and consists of teams of nine players instead of thirteen, and is played with 9 minute halves (NRL 2019b).

The playing field

Rugby league is played on a field 68 m wide, and 100 m long, marked every 10 m with lines across the width of the pitch. At the end of each field are try scoring areas, termed the ‘in goal’, that can vary in size depending on the club, however they are generally 8-10 m in length. Goal posts in the shape on an ‘H’ are erected in the middle of each in goal area for the purpose of scoring via kicks; either penalties, drop kicks, or conversions.

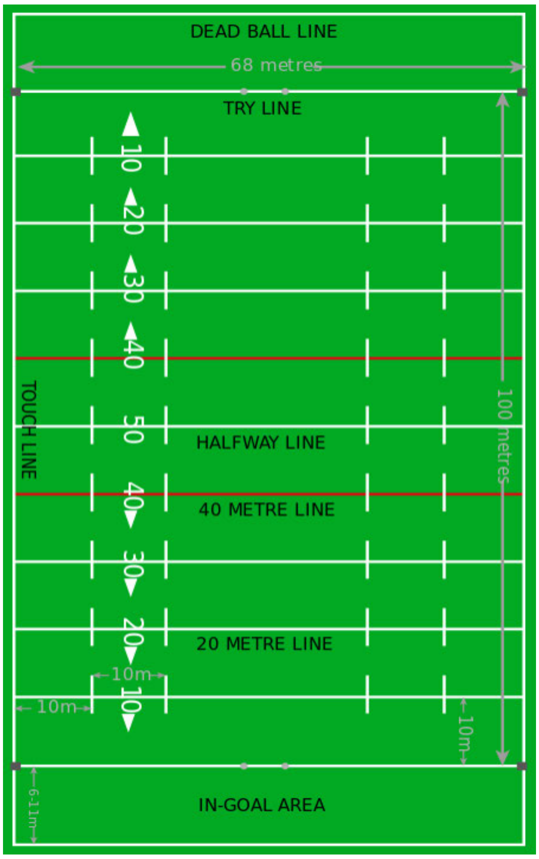

Figure 1. Rugby League Field

Players

Rugby league is played with thirteen players on each team, with twenty-six players on the field at one moment. Each team has four substitutes, termed interchange players, with playing jerseys numbered 1-17 in relation to the position played. Unlike rugby union or football (i.e. soccer) where players who are substituted are not allowed back onto the field, in rugby league you are allowed eight interchanges. This allows players to be inserted into the game for impact and taken off for rest.

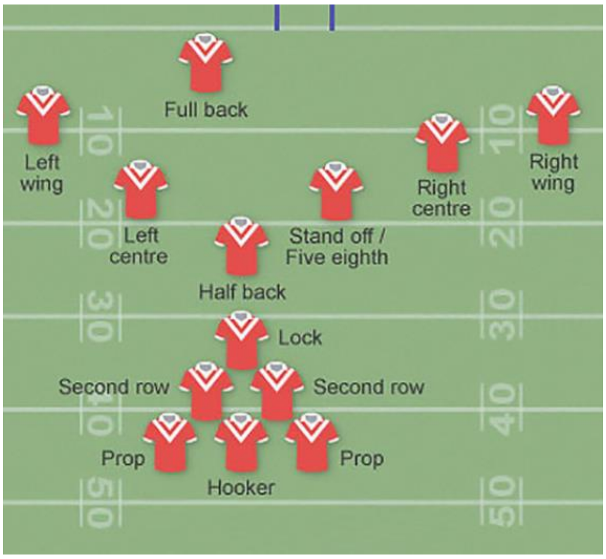

Figure 2. Playing positions in Rugby League

Official international rules and general purpose

Rugby league is played over two, 40-min halves, separated by a 10 min half time break. The aim of the game is to score more points than your opposition. Tries are worth four points, conversions, and penalties worth two, and drop kicks worth one. If there is a tie at the end of the 80 min, the game goes into ‘golden point’ for 10 min, whereby the first team to score wins. If after the additional 10 min no points are scored, then the game is deemed a tie.

During match play, teams aim to defend their in-goal area from the opposition, whilst attempting to score points in their opposition's in-goal. The attacking team has a 'set' of six tackles, meaning they can be tackled six times, before they must hand over possession to the defending team. The goal of the attacking team is to advance as far down field as possible to score points, whereas the defending team's goal is to limit how far the attacking team advances, limit points being scored, and retake possession. A tackle is completed when the attacking player is taken to the ground. When the tackle is completed the defending team has to 'retreat' 10 m back from where the tackle was made and cannot advance towards the attacking team until the ball has been 'played'. If a defending player does not retreat 10m back before advancing towards the attacking team he is deemed offside and a penalty is given. The term 'play the ball' refers to the tackled player standing up from the tackle, placing the ball on the ground, and rolling it back towards his team with his foot. The ball can only be passed backwards or to the side. If the ball travels forward in a pass it is termed a 'forward' pass and possession is handed over. There is one referee on the field, assisted by two touch lines assistants., and they are responsible for enforcing the rules of the game.

Women's rugby league rules are like men's, with only a handful of modifications. The first is each team is allowed ten interchanges, compared to the men's eight. The game is played over two, 30-min halves, compared to two, 40-min halves, and the tactical game play rule of 40/20 is replaced by the 40/30 (Bungard 2018).

Women's Rugby League History

In Australia, women have played rugby league since 1920, with local competitions held in New South Wales and Queensland. Australian women make up the fastest growing contingent of rugby league participants. The NRL allocated $3.75 million (AUD) in 2017 to increase women's participation in and professionalism of rugby league, and in 2018 launched the elite women's competition, the NRL Women's (NRLW). The NRLW comprises three Australian and one New Zealand team. The competition is a round robin event with the grand final contested between the top two teams. There is also the Women's State of Origin contested between New South Wales and Queensland, which draws together the best players from each state to compete for the title of best rugby league state. In 2019, women players were awarded "central" contracts which provide the players with individual and team coaching, wellbeing and education services and leadership and development training camps (NRL 2019a). In 2020, the New Zealand Rugby League introduced the National Women's Championship (second division) and Premiership (first division) competitions, which are nationwide. Players are then selected for the New Zealand Warriors team who participate in the NRLW competition, and the women's national team the 'Kiwi Ferns'.

Whilst women have been coaching rugby league in England since the 1940s, it was not until the 1970s that women began to play. By 1986 six team formed to create the first women's league, and in 1991 there were 18 teams across two divisions (Collins 2020). In England Women's rugby league is organised by the Rugby Football League. There are three women's divisions; "League One" is the third division and contested by eight teams; the second division "Championship" is contested by eight teams; and the "Super League" is the elite women's competition contested by ten teams. In 2019 the RFL launched the Women's Challenge Cup which is a six-round knockout competition contested between the twenty-seven teams from the three divisions, plus a team from the armed forces. On the international stage the team Great Britain represented England, Ireland, Scotland, and Wales and competed up until 2007, when it was decided that each nation would represent themselves going forward.

Internationally, women's rugby league is still considered amateur whereby athletes do not derive the majority of their income from playing. Nonetheless, athletes from Australia, New Zealand, and England are being remunerated, in part, for their commitment and performance for their national teams. Today there are fifteen international women's teams including Australia, Brazil, Canada, Cook Islands, Greece, Fiji, France, Italy, England, Lebanon, New Zealand, Papua New Guinea, Samoa, Serbia, and Turkey.

Premier world competitions

The pinnacle of women's rugby league competition is the World Cup, first held in the year 2000 in England, and has been won by New Zealand three times, and Australia twice. Up until 2013 the Kiwi Ferns were considered the benchmark team by winning the previous three world cups; however, with successive victories in the 2013 & 2017 Rugby World Cups, the Australian 'Jillaroos' now hold the number one ranking. In 2021 the competition will be played in England and contested by eight teams, with the USA hosting the tournament in 2025. In 2019 the inaugural Rugby World Cup 9s was held in Australia, with Australia, England, New Zealand, and Papua New Guinea competing for the title. New Zealand took out the competition with a 17-15 win over Australia in the final.

NRLW competition

In 2016, the women's teams from Cronulla Sutherland Sharks and St George Illawarra Dragons played an exhibition 9s match as a curtain raiser to an NRL game, with the Sharks winning 16-12. In March 2017, the Sharks played another exhibition 9s match against the Canberra Raiders, again winning 28-10. After the World Cup in 2017 the NRL announced the inaugural NRLW competition to be played in September 2018. Newcastle

Knights, St. George Illawarra Dragons, Brisbane Broncos, New Zealand Warriors, Sydney Roosters, South Sydney Rabbitohs and Cronulla-Sutherland Sharks all declared their interest in applying for the inaugural season of NRLW (Bollen 2018). After the bidding process the NRL decided to award the Brisbane Broncos based in Brisbane, Australia; the Cronulla Sutherland Sharks and Sydney Roosters, based in Sydney, Australia; and the New Zealand Warriors, based in Auckland, New Zealand, five-year licenses to compete in the NRLW. Each team plays each other once over three weeks before the top two sides progress to the Grand Final, to be played prior to the men's NRL Grand Final. The games are broadcast on live TV and on the NRL website. Further, the NRL offers forty players elite player contracts. These semi-professional contracts give players access to elite training camps, coaching, medical, and high-performance staff throughout the year. The NRL also used a draft system to promote a spread of talent amongst the clubs, to avoid the likes of Broncos and Warriors holding onto their representative players, as they are both major clubs within their respective regions. Each has a maximum fifteen marquee players, signed from both the Australian and New Zealand elite squads, with the remainder of squads made up of local juniors, cross-code players, Talent ID athletes and free agents (Newton 2018). To date, the Brisbane Broncos have won the first three seasons of the NRLW, beating the Roosters 34-12 in 2018, the Dragons 30-6 in 2019, and the Roosters 20-10 in 2020.

Gender Differences in Sports

Physiological differences between genders in other sports have been well researched. Studies have found elite female athletes from rugby sevens, soccer, and cross country skiing all have lower physical capacities compared to males (Mujika et al. 2009; Bradley et al. 2014a; Sandbakk et al. 2012; Pyne et al. 2012). Further, females substrate utilisation was found to differ to males, with females demonstrating greater lipid utilization and less carbohydrate and protein metabolism than equally trained males (Tarnopolsky et al. 1990). Another study (Bradley et al. 2014b) found technical differences between elite male and female soccer players during match play, with males having a higher passing success rate in UEFA international soccer competition. Whilst in youth soccer, males performed better than females when dribbling and shooting (Perroni et al. 2018). A study by Althoff et al (Althoff et al. 2010) compared men's and women's soccer at the World Cup competition. The authors found that men are more likely to score from distance and complete more dribbles and short passes, whereas female soccer players complete more long passes and score more goals in a closer proximity to the goal, highlighting the difference in tactics between genders. Further they found technical differences when completing kicks with men frequently using the inside of the shoe to kick, whilst women used an instep and full instep kicks more frequently since they could put more power into their kicks (with the instep technique) compared to using the inside of their foot.

In Rugby Sevens, elite male athletes performed significantly better than elite female athletes in speed, power, change of direction, and fitness testing, and from this the researchers recommended gender specific programming to address the difference in these capacities (Pyne et al. 2012; Clarke et al. 2017b; Freitas et al. 2019). Further research in rugby sevens also found that male athletes were exposed to higher intensities during game play than females (Clarke et al. 2017a).

Research in Women's Rugby League

There have been numerous studies examining the physical capacity and game movement demands in male rugby league (Gabbett 2005; Hulin et al. 2015; Gabbett et al. 2008; Gabbett 2013b; Glassbrook et al. 2019b; Austin and Kelly 2013; Glassbrook et al. 2019a; Sirotic et al. 2009; Waldron et al. 2011; King et al. 2009; McLellan et al. 2011), and determinants of performance (McLellan and Lovell 2013; Gabbett and Gahan 2016; Gabbett 2016). However, at the time of writing this thesis, to our knowledge only six published studies have examined performance in women's rugby league (Jones et al. 2016a; Jones et al. 2016b; Quinn et al. 2019; Gabbett 2007; Newans et al. 2021; Emmonds et al. 2020). Indeed, the study by Newans et al. (Newans et al. 2021) is the only study to report locomotive movement patterns in athletes participating in the NRLW competition to date.

The study by Jones et al (Jones et al. 2016a) examined the physical qualities of international female rugby league players by playing position, with the purpose to investigate the anthropometric, body composition, and fitness characteristics of female rugby league players by playing position. Data were collected on 27 players in the English elite women's rugby league squad. Player assessments included anthropometric (stature and body mass), body composition (DEXA) and fitness (lower-body power (countermovement jump [CMJ], 20 kg jump squat [JS], and 30 cm drop jump), 5, 10, 20, 30, and 40 m sprint, 505 agility, Yo-Yo intermittent recovery test level 1) measures. Players were classified into playing position (i.e., forwards and backs) before analysis. The study found significant ($p \leq 0.05$) differences for body mass, stature, total fat, lean mass, and percentage body fat between forwards and backs, with positional differences also observed for speed, agility, and lower-body power. Significant relationships were observed between total body fat and all fitness variables, and total lean mass was related to CMJ and JS peak power. This study provided comparative data for forwards and backs, and found body fat was strongly associated with performance and should be considered when developing fitness characteristics.

A second study by Jones et al (Jones et al. 2016b) investigated the habitual hydration status on arrival, sweat loss, fluid intake, sweat Na loss, and blood [Na+] during field training and match-play in 10 international female rugby league players. Players experienced a body mass loss of 0.50 ± 0.45 and 0.56 ± 0.53% during match-play and training, respectively. The findings of this study show mean blood [Na+] seems to be well regulated despite losses of Na in sweat and electrolyte-free fluid consumption. For the duration of the study, players did not experience a body mass loss (dehydration >2%) indicative of a reduction in exercise performance, thus habitual hydration strategies seem adequate.

Quinn et al (Quinn et al. 2019) described the movement patterns of the Australian Women's Rugby League team during international competition using GPS technology. Data from 31 players were recorded from seven matches. A subgroup of players (n=18) that played at least 80min in a match were categorized into three positional groups: forwards (n=7), backs (n=7) and halves (n=4), and analysed for external outputs that were classified into multiple speed zones. Mean speed (mmin-1) and mean speed when travelling >12kmh-1 (MS12; mmin-1) were calculated for each 10% interval of playing time of both groups to assess changes in match intensity. The paper found the total distance travelled was greater in the first half (3332.9m compared to 3249.0m), along with distances travelled at speeds >15kmh-1 (p<0.05), whereas players travelled further at speeds <6kmh-1 in the second half (p=0.005). Backs travelled further at speeds <6kmh-1 (p=0.002) and >15kmh-1 (p=0.007) compared to forwards. Mean speed significantly reduced across the first and second halves (p<0.05), while MS12 reduced by ~40% in the first half of the match (i.e. first ~5min compared to the last ~5min). The researchers stated that given that match-intensity deteriorated across the first and second halves, programs could be targeted at improving endurance and supramaximal exercise tolerance in order for female players to withstand high match-demands of international competition.

A study by Gabbett (Gabbett 2007) investigated the physiological and anthropometric characteristics of elite women rugby league players, and developed physical performance standards for these athletes. Thirty-two elite women rugby league players underwent measurements of body mass, height, sum of 7 skinfolds, muscular power (vertical jump), speed (10-, 20-, and 40-m sprint), agility (505 test), glycolytic capacity (glycolytic agility test), and estimated maximal aerobic power (multistage fitness test). Significant differences ($p < 0.05$) were detected between forwards and backs for body mass, skinfold thickness, 10-, 20-, and 40-m speed, and estimated maximal aerobic power. It was found that the hit-up forwards positional group were heavier, had greater skinfold thickness, and had lower 10-, 20-, and 40-m speed, muscular power, glycolytic capacity, and estimated maximal aerobic power than the adjustables and outside backs positional groups. The results of this study showed that elite women rugby league players have slower speed and agility, lower muscular power, glycolytic capacity, and estimated maximal aerobic power, and greater body mass and skinfold thickness than previously reported for other elite women team sport athletes. These findings showed the need to develop all physiological parameters to allow elite women 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.

Emmonds et al (Emmonds et al. 2020) examined the locomotor characteristics of the women's super league competition (England) and the rugby league world cup to help rugby league coaches optimise training prescription. The aim was to compare whole match and peak locomotor characteristics of women's rugby league competition at international and domestic level. Microtechnology data were collected from 58 players from three domestic clubs and one international team. Participants were classified into forwards (n = 30) and backs (n = 28). Through analysis the researchers established which variables were important to discriminate between the level of competition (international vs. domestic) and positional group (forwards vs. backs). International forwards were most likely exposed to greater peak 1-min average acceleration and peak 3-min average acceleration than domestic forwards. International backs likely completed greater peak 1-min average acceleration than domestic backs and possibly greater high-speed-distances. The findings highlighted the need for positional specific training across levels to prepare representative players for the increased match characteristics of international competition.

The study by Newans et al (Newans et al. 2021) quantified the position-specific demographics, technical match statistics, and movement patterns of the National Rugby League Women's (NRLW) Premiership and identified whether there was a change in the intensity of play as a function of game time played. Data from 117 players were collected using global positioning system, demographic, and match statistics from all NRLW clubs across the full 2018 and 2019 seasons and were compared between the ten positions. The GPS data were separated into absolute (i.e., total distance, high-speed running distance, and acceleration load) and relative movement patterns (i.e., mean speed, mean high speed (>12 $km \cdot h^{-1}$), and mean acceleration). For absolute external outputs, fullbacks covered the greatest distance (5,504 m), greatest high-speed distance (1,081 m), and most ball-carry meters (97 m), while five-eighths recorded the greatest acceleration load (1,697 $m \cdot s^{-2}$). For relative external outputs, there were no significant differences in mean speed and mean high speed between positions, while mean acceleration only significantly differed between wingers and interchanges. Only interchange players significantly decreased in mean speed as their number of minutes played increased. The authors stated that by understanding the load of NRLW matches, coaches, high-performance staff, and players can better prepare as the NRLW Premiership expands.

The physiological and technical differences that exist between genders impacts the tactical approach utilised by coaches, and how each team physically prepares for competition. It is important to understand the movement patterns specific to women's rugby league, particularly given the differences in physiological attributes of female players compared to men. As more data on game movement patterns emerge from elite women's games the coaches and high-performance staff can improve their practices due to a greater understanding of level required of elite women's players. This research paper looks to provide further insight into women's rugby league by examining the game movements, and technical performance indicators, between successful and unsuccessful teams to enable practitioners to plan training to improve performance.

Player monitoring in collisions sports

The role of the performance staff is to increase the athlete and team's performance. This is done by ensuring each athlete is healthy and can perform at the level required. Part of this process involves collecting, monitoring, analysing, and interpreting athlete data with the goal to improve performance and manage injury risk (West et al. 2020). Data is collected on the individual athletes physical, physiological, and psychological state. By monitoring the physical and mental readiness of athletes practitioners can more accurately prescribe programs, or interventions, to increase performance (Kelly and Coutts 2007). Depending on the resources available they can utilise a range of internal or external methods. Internal load monitoring involves the collection of physiological data, such as Heart Rate (HR), and psychological data, such as wellness questionnaires. External load monitoring involves the collection of data measuring the physical work performed by an athlete, such as distances run, weight lifted, jump height, or physical movement screens.

Each tool can also be categorised as an objective or subjective measure. For example, the total amount of weight lifted, or distance run, is an objective measure. Conversely the rate of perceived exertion (RPE) is a subjective measure as it depends on the individual athlete's interpretation of what they deem an easy, moderate, or hard stimulus.

By monitoring athlete performance, individual adaptations, recovery status, and risk of injury or illness, the performance staff can manage each athlete and adjust individual training as needed. Another added benefit of player monitoring is the communication, athlete education, and relationship building that occurs among staff and athletes, as the athletes feel involved and take ownership of their actions (Halson 2014). In addition, monitoring tools can be used as a talent identification tool and infer potential performance.

Internal load

Internal load is the relative physiological and/or psychological effect of the work performed (Halson 2014; Burgess 2017). Internal load monitoring techniques include session rate of perceived exertion (sRPE); training impulse (TRIMP); heart rate (HR) measures; biochemical assessments; sleep; and wellness questionnaires. Session RPE considers the session intensity, as reported by the athlete on a numeric scale of 6-20 (original Borg scale) or 1-10 (modified Borg scale) (Chen et al. 2002), and session duration to then calculate the training load (Herman et al. 2006). Athletes should be familiarised with the scale their performance staff utilise, to ensure validity and reliability in reporting. Session RPE is a simple, non-invasive, inexpensive, and valid and reliable (Haddad et al. 2017), which makes it a common monitoring tool amongst sporting teams. Session RPE also correlates positively with several objective markers, such as HR max, lactate threshold, and oxygen uptake during exercise (Haddad et al. 2017).

Training Impulse (TRIMP) is a unit of physical effort calculated by using training duration, max HR, average HR, and resting HR during a training session. The initial model was created by a researcher called Eric Banister, however there have been adaptions from the original to include Edwards (Edwards' TRIMP), Lucia's (Lucia's TRIMP), and individualised TRIMP (iTRIMP) (Halson 2014). Each utilises a slightly different method for calculation, but all assess the training load imposed on the athlete. It is up to the team's performance staff to determine what method they utilise due to the scientific expertise required for this type of monitoring (Halson 2014).

Heart rate measures are an objective, convenient, and inexpensive method to monitor player internal load (Alexandre et al. 2012). Measures taken include resting, exercise, recovery, and variability of HR (Buchheit 2014). HR recovery refers to the rate at which the HR declines post exercise, and is most commonly utilised by taking the HR at the end of exercise, and the HR at 60 seconds post exercise (Shetler et al. 2001). The study by Buchheit (2014) recommends daily recordings of resting HR for 5 minutes, along with 30-60s recordings during submaximal exercise, as the best practice for monitoring. However, these should be utilised with a range of other monitoring tools to create a help create a bigger picture of an athletes training status.

Biochemical assessments refer to blood, saliva, and hormone markers. These include creatine kinase, testosterone, cortisol, lactate, and c-reactive protein (Burgess 2017). Testing of these markers is used to estimate fatigue and immunological stats, and direct responses to training and competition (Burgess 2017). Whilst relationships between markers and performance have been found (Hunkin et al. 2014), there have been studies that found no meaningful relationship between blood markers, fatigue, and performance

(Cormack et al. 2008). In addition, the time, cost, and practicality associated with these methods have meant limited research has been done into the effectiveness of this tool (Halson 2014).

Athletes are exposed to high training loads and stressful environments of competition, which can impact their ability for quality sleep, and as such teams use subjective and objective measures to monitor athletes sleep quality and quantity (O'Donnell et al. 2018). The two commonly used objective measures are the gold standard polysomnography, and the cheaper and more practical measure actigraphy (a wristwatch like device), although the latter has limitations. Subjective measures include sleep questionnaires, and sleep logs and diaries. Typical questions ask for the athletes sleep duration, and for them to rate the quality of sleep, and can be used for early detection and intervention before health and performance benefits are realised (Halson 2014).

Athlete wellness questionnaires have been developed to assess perceived fatigue and wellness in team sports (Gastin et al. 2013). The RESTQ-Sport and POMS are two questionnaires that have been validated in team sports, however many teams create their own questionnaires depending on what questions and information the sports performance staff deem relevant to their situation (Burgess 2017). One of the main attractions of these questionnaires is that they are cheap, and the data easy to collect (Halson 2014). The main limitation with questionnaires is the athlete’s ability and desire to provide accurate information on an almost daily basis.

External load

External work refers to work performed by the athlete and has been the foundation of most monitoring systems (Halson 2014). The tool most associated with external monitoring in team sports is the GNSS; in particular, the Global Positioning System (GPS) which is a GNSS satellite-based radionavigation system. Commercially available GPS 'Units' comprise a receiver, gyroscope, magnetometer and accelerometer; and software has been designed to store and analyse the movement data collected during training and competition (McLellan et al. 2011; Delaney et al. 2016; Glassbrook et al. 2019a; Delaney et al. 2015; Twist et al. 2014). Other measures of external load monitoring include measuring power output, testing neuromuscular function (Halson 2014) and totalling the volume of work completed in the gym. However, it is beyond the scope of this review to provide further assessment of these practices.

GPS units are commonplace in many elite sporting teams. It allows practitioners to quantify the type, duration, and frequency of game movements within their sports; detect fatigue (Randers et al. 2010); determine worst case movement scenarios (Delaney et al. 2017); and create activity profiles by position, competition level, and sport (Clarke et al. 2017b; Vigh-Larsen et al. 2018; Venter et al. 2011). The reliability of GPS units depends on the sampling rate, velocity, type of task, and environmental factors (Aughey 2011; Scott et al. 2016; Cummins et al. 2013), with 10-18hz units found to provide the more accuracy than 1-5hz units. In addition, fast movement velocity, and actions like change of direction, tackling, jumping, and kicking, can also cause reporting error.

To monitor the external load placed on athletes there are various GPS metrics that performance staff collect, monitor, and analyse. The brand of unit and software can determine to an extent what metrics are available to the practitioner, as certain brands have their own algorithms and metrics to determine player load; however, there are standard metrics collected across all brands. These include total distance, relative distance, max velocity, velocity bands, accelerations and decelerations, and impacts.

GPS Metrics

Total distance (m) refers to the total distance covered during the competition or session and gives practitioners an insight into the total work performed.

Relative distance (m.min-^{1}) refers to the distance an athlete travels per minute and depicts the intensity of the work performed. The higher the relative distance, the more intense the work, and the higher load that is placed on the athlete.

Velocity (m·s^{-2}) is captured to determine the speed of the athlete. The most prominent velocity measure is max velocity.

Velocity bands (m) are used to measure the distance travelled at various speeds. These bands can be pre-set by the GPS provider, and depending on the brand can also be modified by the practitioner. It is commonplace for practitioners to group multiple bands together into broader bands termed 'high speed running' (HSR) and 'very high-speed running (VHSR). Research shows that HSR volume has been linked to performance in Australian Rules Football (AFL) (Mooney et al. 2011), and injury in rugby league (Gabbett and Ullah 2012). The velocities that HSR and VHSR encompass varies between team sports (Sweeting et al. 2017), and therefore it is difficult to propose what the minimum velocity should be when gathering this data.

Accelerations and decelerations (m.s-2) are intense activities with a high energetic cost (Osgnach et al. 2010), and occur frequently in training and competition, more so than velocity events. Accelerations and decelerations also have damaging effects on tissues, exposing players to high levels of mechanical stress, neuromuscular fatigue, and soreness (Harper and Kiely 2018; Delaney et al. 2018; Nedelec et al. 2014). For these reasons accelerations and decelerations are recognised as important variables to train and monitor (Buchheit and Simpson 2017).

Impacts/collisions (g) characterise the load placed on the athletes, and is done by counting the occurrences of impacts and then classifying them according to impact bands (Lutz et al. 2019). There are still questions surrounding the viability of this metric, since the GPS units cannot decipher the difference between certain actions, such as a tackle and a try being scored by diving. These are wo different actions that the GPS units registers as the same impact, however they have different physical load on the player.

Performance Analysis

Performance analysis is done to assess self-performance and perform oppositional analyses to identify strengths and weaknesses with the aim of exploiting these in competition (Colomer et al. 2020; Gréhaigne et al. 1999). In an applied setting, a sporting club's performance analysts are responsible for collecting and analysing video footage of team trainings and matches, along with oppositions' matches. Analysts utilise video notation software where they objectively quantify players actions and critical events that occur during training and competition. Recent advancements in performance analysis have been both technological (game analysis, software, motion tracking systems, drones) and statistical (predictive and stochastic) in an attempt to infer or predict performance (Travassos et al. 2017). Current performance analysis can be termed 'traditional' or 'contemporary' depending on the data capture and analytical method employed (Lord et al. 2020). The traditional method uses quantitative measures and analyses performance in isolation, compared to contemporary measures that use quantitative and qualitative measures to collect and analyse data. Team performance analysis techniques have evolved in the last decade with advancements in technology, and the improved perception of performance analysis in team sport.

A recent systematic review of performance analysis techniques used in team invasion sports (Lord et al. 2020) identified five-hundred and thirty-seven articles. Two-hundred and thirty-six articles examined game actions, for example goals, shots at goal, passes, tackles, and rebounds. One-hundred and one articles examined dynamic game actions. These are technical actions that include the spatial locations on the field, speed of play, or opposition interaction. Examples include possession per area on field, controlled versus counterattack, or level of defensive pressure during points scoring attempts. One-hundred and thirty-seven articles examined movement patterns, defined as a sequence of offensive or defensive play from when a team gains possession, loses possession, or achieves an outcome (e.g. penalty or points scored). Twenty-eight articles examined collective team behaviour. This refers to how a team is structured or positioned across the field and in relation to the opposition. Measures can include a team's length, width, or surface area covered. Twenty-eight articles examined social network analysis, referring to a team's passing networks, and frequency of passes between players. Seven articles examined game styles. This method examines the frequencies of game actions and incorporates speed of play and spatial variables. These are recorded and clustered into common styles of playing to reflect the attacking and defensive strategies used consistently by a team.

Sports are dynamic and complex, and analysis methods must reflect this to provide effective outcomes and recommendations to enhance team performance (Lord et al. 2020). This masters project utilises a relative analysis method that has not been attempted before using GPS data. The research team has access to opposing team's technical performance and GPS data, and with this can determine what metrics, relative to that of the opposition, can predict match outcome in women's rugby league.

Performance Analysis in Rugby League

In rugby league it is the performance analysts who are responsible for collecting, analysing, and reporting training and match data. Part of their role is to record all the actions and events in training or games, which include but are not limited to completed number of sets; missed tackles; tackle success; line breaks; offloads; kicks metres; and contextual factors. Contextual factors are variables that provide information about the match at any given time, such as the score line, the positions of the players on the pitch, or the environmental conditions (Dalton-Barron et al. 2020). Recent research into player actions between opposing teams has resulted in the coining of the term key performance indicators, which are performance indicators that differ significantly between successful and less successful teams (Lord et al. 2020; Parmar et al. 2018b).

Performance indicators in rugby league that characterise successful and non-successful teams

Rugby league research has focussed mainly on male athletes, which is why the data being analysed in this section is from men's studies. Previous research has examined the anthropometric and physiological qualities of players; injury rates; time motion analysis; and performance indicators that delineate competition level, playing position, starters vs nonstarters, and successful vs non successful teams. Due the abundance of research examining performance within rugby league, this section will focus on the performance indicators that characterise successful and non-successful teams, with nine known papers examining the characteristics of successful and non-successful rugby league teams (Parmar et al. 2018b; Parmar et al. 2018a; Gabbett 2013a; Kempton et al. 2017b; Woods et al. 2017; Hulin et al. 2015; Gabbett 2013c; Hulin and Gabbett 2015; Gabbett and Hulin 2018).

Gabbett examined the performance indicators and game movements of a sub-elite rugby league competiton to determine the performance indicators and game movements that were significantly different between successful and less successful teams. The study analysed the GPS game files and video footage of 1-3 players per team, for 26 games (20% of all matches) during the season. Teams were split into 'Top 4', 'Middle 4', and 'Bottom 4' on the ladder at the end of a season. Gabbett found that 'Top 4' teams were likely to cover more sprint distance than the other teams; and cover more distance in attack and concede fewer metres in defence compared to the 'Bottom 4' teams. Further, 'Middle 4 'teams had the greatest reduction in high-speed running from the first to second half, while 'Bottom 4' teams completed more high-speed running in the second half than the first half compared to the other teams (Gabbett, 2013) .

A second study by Gabbett (Gabbett 2013c) examined how the playing standard (versing higher or lower ranked teams), and winning and losing, influence the physical demands in elite rugby league competition. 22 elite rugby league players were analysed across 16 matches, with their activity profiles analysed when competing against high-ranked 'Top 4' and low-ranked 'Bottom 4' teams, and if the game was won or lost. The author found players covered significantly greater absolute and relative distance at high speeds (>5.0 m.s) when playing against 'Bottom 4' teams compared to when they competed against 'Top 4' teams. Further, the total relative distance (m/min) and relative distance at low speeds (<5.0 m.s) were higher in matches that were won. In addition, in matches that were won players had geater absolute and relative number of maximal accelerations and repeated high-intensity effort bouts compared to matches that were lost. Gabbett summaries by saying the physical demands are greater when winning than losing, and when competing against lower ranked teams. The paper also suggests that successful elite rugby league teams have the ability maintain a higher playing intensity than less successful teams.

Hulin and Gabbett in 2015 (Hulin and Gabbett 2015) investigated whether match intensities differed among successful and less successful semi-elite rugby league teams. Four semi-elite rugby league teams were split into 'high-success' and 'low-success' based on the percentage of matches won throughout the team's season. The athletes movements were recorded with GPS with a total of 20 matches analysed. Further, the analysis split the players into positional groups, and each match was separated into 16 periods of 5-minutes. The peformance indicators analysed were ball-in-play time, total distance, high-intensity running (>5.0 m.s) distance, number of collisions, and number of RHIE bouts. The authors found no significant difference between teams with time spent in attacking possession. Further, the paper found that greater amounts of high-intensity running and total distance are not related to success. Instead, success is associated with a greater number of collisions from hit-up forwards, and the ability of successful teams to maintain a higher ball-in-play time following the peak period.

A study in 2015 (Hulin et al. 2015) examined the game movements that differed between a successful and less successful elite rugby league team. 31 players from two NRL teams participated in the study. The two teams were classified as high success, and the other low success, depending on their season results, with 25 matches analysed from the season (15% of all matches). The GPS files were analysed and the game split into 16 equal periods of approximately 5 minutes. The authors reported that total distance, and high-intensity running (>5.0 m/s), were not related to success, and instead suggestested that technical and tactical performance indicators (e.g. number of collisions, rather than activity profiles, distinguish successful and less-successful rugby league teams. Further, they stated that success is the “result of a multifactorial relationship between technical and tactical effectiveness and activity profiles”.

The study by Kempton et al (2017) examined the differences in physical and technical performances between a successful and less-successful NRL team. Data from 54 players from two NRL teams was collected and analysed. The successful team’s data was collected in the 2014 NRL season, with the unsuccessful team’s data collected in 2012 season. Players were categorised into four positional groups, with their GPS and video match footage analysed. For the physical analysis the authors summarised that the successful team had lower higher-speed running (>14km/h) and fewer physical collisions than the less-successful team, although they had more accelerations (>2.78.m.s^2) and decelerations (> -2.78.m.s^2). Technically the successful team gained more territory in attack, had more possessions, and committed fewer errors. Whereby the less-successful team attempted more tackles, missed more tackles, and likely had a lower tackle success percentage. The authors concluded by stating successful match performance was not reliant on higher running outputs or physical collisions; instead, it was the proficiency in technical performance that differentiated successful and less-successful teams.

The study by Woods et al (2017) analysed 14 performance indicators from the 2016 NRL season, with the teams ranked 1st-8th on the end of season ladder classified as successful, and teams ranked 9th-16th classified as unsuccesful. With this data the authors then examined which performance indicators could be used to explain match outcome. The authors found that positive match outcome in the NRL was related to the following performance indicators; try assists, all run metres, line breaks, dummy half runs, and offloads, whilst lower ladder position was shown to be related to missed tackles, kick metres (giving away possession), and dummy half runs.

A study in the English Super League (ESL) (Parmar et al. 2018b) looked at performance indicators that predicted match outcome in the ESL. 567 matches from three seasons of ESL competition (2012-2014) were analysed, with draws being excluded from the analysis. A total of 20 performance indicators were identified for analyses, with the authors coining the term ‘Key Performance Indicators’ to describe the performance indicators that were significant between winning and losing teams. The study found that teams had a higher chance of winning and scoring more points when scoring first and increasing their completed sets (offensive possession). Whereas teams who ran more from dummy half (scoots) had less chance of winning, referencing that passing was a better option from dummy half. However, the authors did note that teams can win, even when outperformed in performance indicators and KPIs.

The second study by Parmar et al (Parmar et al. 2018a) analysed 567 matches from three seasons of ESL competition (2012-2014). The study wanted to determine if grouping performance indicators together could predict match outcome, rather than analysing performance indicators in isolation. The reason for this was that the authors wanted to provide a “guide on how teams can increase their chances of success by improving performances on a collection of variables (ball carries, metres, and line breaks etc)” leading to a better chance of success. The researchers found teams who retained possession of the ball, and made quick ground, were more likely to be successful. From the research they suggested training, and devising tactics, that allowed the team to maintain attacking possession and make quick ground.

In 2018 Gabbett and Hulin (Gabbett and Hulin 2018) investigated the differences in technical performance indicators (termed “skill” by the authors) between successful and unsuccessful teams in the NRL from 2004-2014. Teams were divided into 4 groups according to final ladder position (1st–4th, 5th–8th, 9th–12th, and 13th–16th), with video footage from all games during the period analysed. The authors found the top teams (1st-4th) completed significantly more play-the-balls (a factor of attacking possession) than teams in 12th-16th, with these bottom ranked teams having significantly less tackle breaks, and a higher total, and missed number, of tackles (non-attacking possession and errors). Of note however was the bottom ranked teams having significantly more offloads than those ranked 1st-4th.

To our knowledge there have been no studies examining the indicators of successful and non-successful teams in women's rugby league. Further, no studies in rugby league have examined the relative difference of indicators between opposing teams. This project will therefore provide unique insight into women's rugby league and determine what indicators relative to the opposition are significant in determining match outcome.

Limitations of current performance analysis techniques in rugby league

The current practices used in rugby league performance analysis focus on recording the frequency of isolated player actions with minimal reference to the context of the match and the interactions between players (Travassos et al. 2017). It is recommended that future performance analysis should utilise a holistic approach that includes the description of players in space (location on field, space between players) and time; the behaviours and relationships of players between teams (opposition) and intrateam (own team); and the characterisation of patterns of play that precede or influence a successful performance (Travassos et al. 2017; Colomer et al. 2020; Lord et al. 2020). The rationale behind this approach is to help coaches understand the why and how performance occurs.

An example in rugby league would be examining the play leading up to a try being scored. A traditional quantitative approach would register that a try has been scored, by a certain player, at a certain time in the match. Additionally, the team may have ‘Completed a Set’ and added 50m to their ‘All Run Metres’ in doing so. However, this approach does not provide the description of how a try was scored, or what performance indicators preceded the event. By utilising descriptions, and player relationships in space and time, we can gain an understanding of the actions, behaviours, and performance indicators that occurred leading to this successful outcome. An example of this is: the passage of play lasted 172 seconds, with the scoring team having possession for 20 seconds before a try was scored. A rushed defensive line caused the opposition team to knock on as the player was not focussed on receiving the ball, rather the imminent tackle. The defending team gained possession of the ball and launched a counterattack. The ball was passed twice to the left with the winger attacking space on the left side of the field and advancing 40m. The attacking team kept their width; however, the defending team were not organised when retreating, with 9 of their 13 players grouped within 20m of the touchline. The winger was able to play the ball within 3 seconds of being tackled (quick play), and the hooker performed a cut out pass to the right. More quick passes to the right allowed the attacking team to take advantage of the space and lack of defenders on the right-hand side of the field to score. From this passage of play we can gleam that the try was scored after 172 seconds of ball in play; defensive pressure caused a turnover; the ball was spread quickly to space to allow a fast counterattack; the attacking team kept their width; the attacking team were able to play the ball quickly; and identified defensive misalignment to score a try.

Utilising a complimentary approach of quantitative (recording of performance indicators) and descriptive data (player relationships, characteristics of play), it provides coaches with an in depth understanding on the why and how performance occurs, and is beneficial when analysing opposition teams to determine the events that precede their positive performances. The thesis will look to provide new insight into the performance indicators that can predict match outcome. By having access to oppositional performance indicators and GPS data the analysis can determine what metrics, relative to the opposition, can predict points scoring and match outcome. With this information coaches can design effective training programmes, devise opposition specific game tactics, and select athletes that best suit the game plan.

Global Navigation Satellite System

The Global Navigation Satellite Systems (GNSS) is a constellation of earth orbiting satellites. Currently there are four global systems; the Global Positioning System (GPS) built by the United States of America (USA); the Global Navigation Satellite System (GLONASS) built by Russia; the European Union's Galileo; and the Chinese Bei-Dou. Further, there are two regional systems, one in India (IRNSS), and one in Japan (QZSS).

Satellites work by broadcasting a radio signal with their exact location and time. The time delay between when the satellite transmits its signal and when the receiver receives the signal is proportional to the distance between the satellite and the receiver. When a receiver receives a signal from at least four satellites it can calculate its exact position on earth, taking into account its longitude, latitude, and altitude, in a process called trilateration (Maddison and Ni Mhurchu 2009). Satellite navigation is used in telecommunications, agriculture, wildlife, mining, law enforcement, and sports

(Tomkiewicz et al. 2010; Krenn et al. 2011). In sport, the current satellite systems used to track player movement are the GPS and GLONASS.

GPS as a player tracking tool

GPS units have been used in sporting competition and training since 2003 (Edgecomb and Norton 2006). GPS units are small devices that collect player displacement and velocity. The data is collected by the GPS receiver and inertial sensors (accelerometer, gyroscope, magnetometer) inside the unit. The GPS receiver calculates displacement and velocity through trilateration, and as the athletes move, their movement is plotted over time. The quality of the GPS unit will depend on the sampling rate and accuracy of GPS receiver, with first generation GPS units utilising 1Hz sampling rates, and current units 10-18Hz. The accelerometer sensor measures accelerations and force, or in terms of athletic movements; accelerations, decelerations, jumps, and tackles. Current units utilise a tri-axial accelerometer that can measure movement in three axes (up/down, forwards/backwards, sideways), and record at 100Hz. The gyroscope is a sensor that measures rotation around three axis (coronal, frontal, sagittal) and in conjunction with the accelerometer paints a precise picture of athletic movement and has a sampling rate of 100Hz. The magnetometer is an electronic compass to help orientate the unit towards the true magnetic north and contributes towards providing accurate data on athletes change of direction. The magnetometer samples at 100Hz.

GPS units are worn by athletes in a skin tight tailor made GPS vest (sometimes referred to as a GPS bra) with the GPS unit located in a small pouch located between the scapulae It is recommended to use the same brand of GPS unit and vest to ensure the device can fit within the pouch and avoid excess movement of the device. Some GPS unit providers allow practitioners to view the training and game data in real time, termed ‘live’, on tablets or laptops. The data is also stored within the GPS units for viewing and analysing retrospectively. The data files can be accessed when the units are placed or plugged into the charging dock. Each brand of unit will have different software, with some software requiring units to be downloaded onto the computer and then analysed within the software, where as other brands utilise a cloud based software storage system where the data is uploaded directly to be viewed and analysed. The software can create readymade reports of the data, or the data can be exported for analysis and reporting in other software (e.g. Excel, R, Python), depending on the wants and needs of the practitioners.

Figure 3. Catapult GPS Unit

Figure 4. Athlete wearing a GPS unit in the vest.

In the current market there are entry level units targeted towards the amateur and semi-professional, and elite units targeted at professional teams and athletes. The brand and cost of GPS unit will influence the accuracy of the unit; the metrics that are collected; and the ability to individualise metrics for each unit. An entry level unit costs approximately $250 AUD and provides basic data such as total distance, velocity, distance covered in different velocity bands, and number of accelerations and decelerations. These cheaper units may not be waterproof, cannot provide live data, do not provide the practitioner with the ability to customise metrics for each unit, have less memory storage, and the download speed is slower. The units may also lose connection more frequently with the GNSS satellites due to issues with triangulation. GPS units targeted towards elite sporting teams can cost over $1,000 AUD per unit. These units will give the practitioner the ability to customise the metrics for each individual unit. The units will also provide live data to the practitioner if they are utilising a GPS receiver. The software will have more features for reporting and visualising data; more units can be downloaded simultaneously and at a faster speed; and practitioners can export data into a third-party software for further analysis. The most recent Catapult GPS unit, the Vector 7 (pictured above), can also collect Heart Rate data with in-built HR monitoring straps in the GPS vest. The vest must be worn in contact with the skin, and the data can be transmitted live to the practitioner providing both GPS (external) and HR (internal) metrics. It is also worthwhile noting the quality of GPS vests vary depending on the brand and cost.

GPS-derived metrics

There are a multitude of GPS metrics that can be derived from the GPS data. Some metrics are standard across brands, whereas certain brands have created their own algorithms for their specific metrics to determine player load, metabolic power etc. This review will only look at the standard metrics captured by GPS units. These are total distance, relative distance, max velocity, velocity bands, sprint count, and accelerations and decelerations. Total distance is measured in metres (m) and is a sum of volume of work done in a session or game, and encompasses all distance covered from walking to sprinting. Relative distance refers to the distance an athlete travels per minute ($m \cdot min^{-1}$) and depicts the intensity of the work performed. Velocity refers to the speed of the athlete and is recorded as metres per second (m/s). Velocity measures that are important to practitioners include max velocity, and distance covered in different velocity bands. Max Velocity, or top speed, is a metric that is frequently analysed by practitioners, as it is important to develop max velocity for athletic purposes, and from an injury prevention standpoint. Velocity bands, or zones, capture the total distance covered (in metres) in certain velocity zones. These velocity zones can be absolute or relative to the individual. Absolute bands can be arbitrary (pre-set from the GPS provider) or set by practitioners to capture positional cohorts (e.g. wings or hookers). Examples of absolute arbitrary velocity bands are 0-1.5m/s; 1.5-3.0/s; 4.0-5.5m/s; 5.5-7.0m/s; and >7.0m/s (STAT Sports). Bands can be individualised to athletes depending on their max velocity, and it is also recommended that bands differ between genders (Clarke et al. 2015). Velocity bands are a contentious issue in sports science, as there is no consensus on determining bands, which has made comparisons of research difficult (Sweeting et al. 2017). It is also common practice for practitioners to create broad high-speed running (HSR) and very high-speed running (VHSR) bands. Again, different teams may decide on different HSR and VHSR bands depending on their sport and athletes. Sprint count refers to the number of times an athlete has performed a high speed sprinting action, considered above 85% of an individual's max velocity (Edouard et al. 2019a; Malone et al. 2017). Practitioners can decide whether there is a minimum distance or time spent above this threshold for the unit to then register that a sprint has occurred. The lack of consensus between what classifies a sprint is a limitation when it comes to comparing research (Sweeting et al. 2017). Accelerations and decelerations ($m \cdot s^{-2}$) are intense activities with a high energetic cost (Osgnach et al. 2010), and occur frequently in training and competition, more so than velocity events.

Accelerations and decelerations also have damaging effects on tissues, exposing players to high levels of mechanical stress, neuromuscular fatigue, and soreness (Harper and Kiely 2018; Delaney et al. 2018; Nedelec et al. 2014). For these reasons accelerations and decelerations are recognised as important variables to train and monitor (Buchheit and Simpson 2017). Accelerations can be monitored in arbitrary or relative bands (zones) as number of occurrences (number of entries into the band) or averaged over a session. The limitation to these approaches is again the lack of consensus on acceleration bands, and that averaging accelerations and decelerations does not paint an accurate picture of load imparted on an athlete.

Validity and reliability of GPS

Validity is the ability of an instrument to accurately measure what it is intended to measure, whilst reliability refers to the reproduction of same values over repeated tests (Theodoropoulos et al. 2020). There have been many studies looking at the validity and accuracy of GPS units (Varley et al. 2012; Coutts and Duffield 2010; Scott et al. 2016; Barr et al. 2017; Johnston et al. 2014; Beato et al. 2018; Rawstorn et al. 2014; Cummins et al. 2013), with the research finding differences in accuracy and reliability arise due to the sampling rate (Hz), distance travelled, velocity, change of direction (COD), and impact measures. It is important for GPS units to be accurate and reliable to give practitioners confidence when designing, monitoring, and comparing sessions (Scott et al. 2016).

GPS units with higher sampling rates of 10Hz, 15Hz, and 18Hz have improved accuracy and reliability compared to 1Hz and 5Hz units when it comes to measuring distance (Scott et al. 2016; Hoppe et al. 2018). Of note, one study found that 10Hz units are more accurate and reliable than 15Hz units (Johnston et al. 2014). Change of direction (COD) tasks and high velocity running both decrease the accuracy of units. To counter for this it is recommended that practitioners utilise low and high velocity bands when collecting distance travelled, in conjunction with the six velocity bands recommended (Scott et al. 2016; Johnston et al. 2014; Rawstorn et al. 2014) When it comes to comparing between units, intra-unit reliability is greater than inter-unit reliability. It is therefore advised that athletes utilise one device for monitoring to ensure greater accuracy and reliability. In addition inter-unit reliability is increased during match play, whereas linear and curvilinear running decrease inter-unit reliability (Scott et al. 2016) The accelerometers within the units do not rely on the use of satellites, therefore the measures recorded (accelerations, decelerations, body load, and impact) provide good reliability between and within a device. However the validity of body load and impact measures are still yet to be determined (Scott et al. 2016).

Application of GPS in rugby league

In rugby league it is the role of the athletic performance staff to ensure players are conditioned to meet the demands of the competition. One of the ways in which practitioners achieve this is through monitoring GPS data within training and games. Historically GPS data was analysed using absolute values i.e. data averaged over a whole game or training session. However recent improvements in data analysis techniques have led to smaller time blocks (epochs) being utilised, along with rolling average approaches. This provides practitioners with a better understanding of the relative intensity and movement demands of competition. A meta-analysis by Glassbrook et al (2019) found that forwards cover an average of 5367m, adjustables 7057m, and backs 7064m in a game. If practitioners were to divide these total distances by game time, 80 min, to gain a relative per minute distance travelled, forwards covered 67m per minute, and adjustables and backs 88m per minute. The limitation in this absolute analysis is that it severely underestimates the running requirements (Delaney et al. 2015), and if utilised by coaches would severely underprepare the players for competition. This is where the utilisation of rolling one-minute averages is superior, as it accurately captures the running requirements of competition. The paper by Delaney et al (2015) examined the rolling one-minute average method, and found that forwards can cover 157m, adjustables 159m, and backs 166m per minute in a worst-case scenario. This rolling average technique can also be applied to other metrics like acceleration, decelerations, and RHIE.

Another method utilised by practitioners when designing training and analysing games is the ball in play time (i.e. playing cycle) which is how long a passage of play lasts before a stoppage occurs. A study by Tim Gabbett (2011) found the average ball in play time in the NRL was 81 seconds before a stoppage, and the average longest cycle in a game was 5 minutes and 18 seconds (Gabbett 2011). Practitioners can access their own historical game data to determine their teams ball in play time, and combining this with their GPS data, practitioners can accurately design training sessions to mimic competition requirements to ensure players are prepared for the worst case scenario.

Metrics utilised by rugby league practitioners include total distance; relative distance; velocity; velocity bands; sprint count; accelerations and decelerations; impacts; repeat high intensity actions (RHIE); and metabolic power. Total distance is the most reported GPS-derived metric in rugby league research and provides a global activity profile for each athlete. Research has found that total distance varies depending on playing position and inter-change players (Hausler et al. 2016). Relative distance can be reported amongst positions, and interchange vs non-interchange players. Research found that adjustables cover greater relative distance than forwards and backs (Hausler et al. 2016), greater relative distances is covered by teams defending compared to attacking (Gabbett et al.

2014), and interchange players cover higher relative distance than players who play the whole match (Black and Gabbett 2014). These findings can be used when designing and prescribing training sessions to prepare players for competition.

Max velocity, or top speed, is a metric that is frequently analysed by practitioners, as they aim to expose players to high velocity speeds during the training week to improve athletic performance and mitigate injury risk (Malone et al. 2017; Edouard et al. 2019b). Monitoring distance covered during training in different velocity bands is done to ensure training targets are being met to improve performance and reduce the risk of injury. Velocity bands can be absolute or individualised depending on resources of the club and the practitioner. Relative bands are more accurate and require testing of each athlete's max velocity. Velocity bands are then assigned a percent of max velocity, e.g. band one 0-20%mv, bands two 0-40%mv; band 6 >85%mv etc. Furthermore, coaches can create broad velocity bands termed high speed running (HSR) and very high-speed running (VHSR) metres, which groups the total distance covered within those bands. The classification of these bands can vary depending on sport, club, gender, and the individual practitioner.

Accelerations and decelerations are important measures of external load and are monitored during training sessions to ensure players are meeting targets and adequately prepared for the demands of the game (Harper et al. 2019). Accelerations have a higher metabolic cost (Hader et al. 2016) whereas decelerations impose a higher mechanical load (Dalen et al. 2016). The frequency of these high intensity actions is associated with decrease in neuromuscular performance capacity and increase in muscle damage post-match (Harper et al. 2019). A study (Johnston et al. 2015) found elite players have the ability to perform more accelerations and decelerations at a greater magnitude compared to lower performing players, with these fast changes of in velocity contributing to match performance outcomes. Coaches use a variety of methods when collecting the data, such as number of accelerations and decelerations (count); counts within acceleration bands; distance and time spent accelerating and decelerating; or averaging acceleration and deceleration load within the session (Delaney et al. 2018). However, there are still inconsistencies between teams reporting data. In addition, the averaging of accelerations and decelerations does not capture the total load imparted on an athlete by these actions. An athlete that accelerates when already moving at a higher velocity will have a higher load imparted onto them due to the higher energetic cost of work, compared to an athlete that is accelerating from a lower starting velocity. Therefore averaging accelerations is a limitation as the acceleration bands (zones) cannot decipher the difference between the two, and therefore the unit classes both accelerations within the same band.

Repeat High Intensity Efforts (RHIE) are characterised by two (2-RHIE) to three (3-RHIE) high intensity actions being performed with less than 30 seconds separating each action. These include maximal acceleration, sprinting, tackling, or hitting up (Black and Gabbett 2015). RHIE can differ between positions, therefore it is important to simulate match play in training to provide a suitable training stimulus. Research also shows that 70% of total RHIE occurred within five minutes of a try being scored, highlighting the importance of RHIE in critical periods during a match (Austin et al. 2011).

Impacts are graded in zones depending on intensity (0-10g+) and are set by the GPS manufacturers. There are validity and reliability issues when recording impacts, as impacts capture all forces a player is exposed to (hit up, tackle, foot strike, scoring a try), and also depend on the weight and movement of the athlete (Hausler et al. 2016). For example, a GPS unit can record a tackle, and scoring a try by diving, as the same intensity impact, when they impart two different loads onto the athlete. Although still to be validated, understanding the frequency and forces associated with collisions (hit up & tackle) can provide the opportunity to develop position-specific collision conditioning programs (Hausler et al. 2016).

Metabolic power ($W \cdot kg^{-1}$) is used to assume the energy cost or physical demand of matches (Osgnach et al. 2010) and is used by some practitioners as another metric to monitor load. However there are limitations in its use as an accurate measure of total energy cost (Kempton et al. 2015; Cummins et al. 2016). The main limitations are that the algorithm only considers player movements from linear GPS data. It does not account for the change of directions, collisions, and impacts that players are subjected to which impart an energetic demand on players (Brown et al. 2016). Therefore programming using metabolic power will not be accurate, as it does not quantify the physical component of rugby league match-play, which is important from both an injury prevention and physical conditioning aspect (Hausler et al. 2016).

GPS can be used to monitor player fatigue and help determine when to use interchanges within a match. Research indicates that players who stay on the field for the whole match have greater decreases in running outputs compared to players who are used as interchange, however interchange players are also impacted by fatigue in the final stages of the match (Hausler et al. 2016). GPS data can also be used to discriminate between positional groups and playing level (Senior, Semi-Professional, Junior), and allow practitioners to prescribe training sessions to ensure players are adequately prepared to play their position and level (Hausler et al. 2016).

As practitioners it is important to be able to interpret the results from the GPS reports. A recent systematic review by Dalton-Barron et al (2020) summarised the impact of contextual factors on match running in rugby league. The contextual factors were individual characteristics; match result; team strength; opposition strength; match conditions; technical and tactical demands; spatial and temporal characteristics; and nutrition. The paper noted that contextual factors impact the complex nature of match running, and practitioners should consider contextual factors when analysing and interpreting GPS-derived data. It must be noted that analysing contextual factors individually is also a limitation. A systematic review in soccer looked at the effects of situational (e.g. ball possession, score line, congested schedule) and environmental-related (e.g. temperature, altitude) contextual factors on match running (Trewin et al. 2017), and authors concluded all contextual factors had the potential to influence match running, and that analysing a single contextual factor in isolation is not appropriate and would provide a one-dimensional view of the match.

The recent advancements in GPS technology and analysis have allowed practitioners to quantify the sport specific demands of rugby league. This project will contribute to previous research by providing data specific to women's rugby league that can be used for devising game tactics, designing physical preparation programs, and aid in player recruitment and talent identification.

Using oppositional data to measure relative match performance

In team sports it is common practice to analyse your opposition through video footage or analysis of statistical data. The purpose, to find weaknesses in your opposition that can be exploited during competition via targeted training and devising of tactics. Recent advancements in technology and analysis techniques have improved analysis beyond the traditional isolated notations of activity, to methods incorporating qualitative and quantitative techniques (Lord et al. 2020). Data of your opposition can be sourced from sports analytics companies (e.g. OPTA/Stats Perform), or if clubs are registered with a commercial analysis company (e.g. Sports Code, Catapult Vision etc) they can access data and footage from the companies databases. However, analysing data relative (% different per minute) to the opposition is not common practice since it requires advanced statistics, increased resources, and game movement data that may not be publicly available. Due to this there have been only three known studies to analyse performance indicators relative (difference per minute) to the opposition, two in the Australian Football League (AFL) and one in rugby sevens (Young et al. 2019; Higham et al. 2014; Robertson et al. 2015).

A study of international rugby sevens (Higham et al. 2014) analysed the absolute and relative value of 17 performance indicators for all 196 matches in the 2011/2012 International Sevens World Series. The aim was to determine what performance indicators increased the likelihood of points scored, and winning, within and between teams (relative to the opposition). Relative performance indicators associated with points scored were rucks and mauls per min of possession (negative association); penalties and free kicks conceded (negative association); passes per min of possession (negative association); scrum possessions retained (positive association); possession time (positive association); and percentage of ruck and maul retention (positive association). The effect of performance indicators on the likelihood of winning followed the trends for points scoring. Teams were more likely to lose if they had a higher number of rucks and mauls per min of possession, turnovers conceded per min of possession, passes, and passes per min of possession relative to their opposition. Conversely greater ruck and maul retention, possession time, number of scrums, number of lineouts, and scrum possessions retained relative to the opposition were linked to higher chances of winning. The authors summarise that coaches and support staff can use the performance indicators to monitor and assess the performance of their team as well as opposing teams, and devise strategies to increase points scoring opportunities and chances of winning.

The first AFL study (Robertson et al. 2015) compared opposition teams over two seasons in the AFL, reporting KPIs that differentiated between winning and losing teams. The study revealed having more ‘kicks’ and ‘goal conversions’ relative to the opposition were predictors of success. The authors recommended teams focussed on the performance indicators that differentiate successful vs less successful teams during training, and this information would also assist with game tactics and player recruitment. The second study (Young et al. 2019) modelled the relationships between performance indicators and match outcomes relative to the opposition. The authors analysed 91 performance indicators from the 2001 to 2016 AFL seasons, and found the relative performance indicators most predictive of match outcome were: turnovers forced; inside 50s per shot; metres gained; and time in possession. The main theme amongst these two studies were reducing error and increasing time in attacking possession.

Traditional Research Using Oppositional Data & Practical Applications

The fact that relative analysis is difficult to perform due to time constraints; requiring advanced statistics; and potential limited access to performance data (performance indicators and GPS data), means that practitioners rely upon research conducted retrospectively by institutions. Practitioners apply these findings through targeted training, tactics, and recruitment, with the goal of increasing performance and success. Most of the research still largely favours male sports (Castellano et al. 2012; Lago-Ballesteros and Lago-Peñas 2010; Higham et al. 2014; Robertson et al. 2015); however, there have been a two studies, one in female basketball and the other in soccer, examining the difference between successful and less successful teams.

A study in womens soccer (de Jong et al. 2020) found the biggets determinants of match outcome were; scoring first, assists relative to the opponent, the percentage of shots on goal saved by the goalkeeper relative to the opponent, shots on goal relative to the opponent, and the percentage of duels that are successful. In women's Olympic Basketball (Leicht et al. 2017) researchers found that shooting proficiency (accuracy) and defensive actions were KPI for success. Through statistical modelling they found the combination of 'field-goal percentage', 'defensive rebounds', 'steals' and 'turnovers' provided the greatest probability of winning. Both papers recommened developing the skills that contribute to positive match outcomes, and selecting athletes that display these skills, to improve chances of success.

There have been multiple reserch papers examining the technical and physical differences between successful and less successful rugby league teams, with one of the first papers by Gabbett in 2013. The research separated sub-elite rugby league teams into 'Top 4', 'Middle 4', and 'Bottom 4' teams from the end of season ladder position. The author found that 'Top 4' teams were likely to cover more sprint distance than the other teams; and cover more distance in attack and concede fewer metres in defence compared to the 'Bottom 4' teams. Further, 'Middle 4 'teams had the greatest reduction in high-speed running from the first to second half, while 'Bottom 4' teams completed more high-speed running in the second half than the first half compared to the other teams (Gabbett, 2013). These findings are inline with what is termed 'positive inhibition' and 'negative facilitation'. 'Positive inhibiton' suggests once teams have gained positive momentum through scoring they begin to 'cruise' to economise efforts and eventually coast when the goal is within reach. Whereas ‘negative facilitation’ is where teams increase their efforts after failure (e.g. conceding points, behind on the score board) in an effort to regain momentum and reinsert themselves back in the game (Perreault et al. 1998).

A second study by Gabbett (Gabbett 2013c) examined how the playing standard (versing higher or lower ranked teams), and winning and losing, influence the physical demands in elite rugby league competition. The author found players covered significantly greater absolute and relative distance at high speeds (>5.0 m.s) when playing against lower ranked oppostion, compared to when they competed against higher ranked teams. Further, the total relative distance (m/min) and relative distance at low speeds (<5.0 m.s) were higher in matches that were won. In addition, in matches that were won players had geater absolute and relative number of maximal accelerations and repeated high-intensity effort bouts compared to matches that were lost. Gabbett summaries by saying the physical demands are greater when winning than losing, and when competing against lower ranked teams and suggest successful teams have the ability maintain a higher playing intensity than less successful teams.

A study by Hulin et al (Hulin et al. 2015) examined the game movements that differed between successful and less successful elite rugby league teams. The authors collected two teams data, one classified as high success, and the other low success, depending on their season results. The authors reported that total distance, and high-intensity running (>5.0 m/s), were not related to success. They suggest that technical and tactical performance indicators (e.g. number of collisions), rather than activity profiles, distinguish successful and less-successful rugby league teams.

A second study by Hulin and Gabbett (Hulin and Gabbett 2015) investigated whether match intensities differed among successful and less-successful semi-elite rugby league teams. The authors found no difference between teams in time spent attacking, and that greater amounts of high-intensity running and total distance are not related to success. Instead, greater number of collisions from hit-up forwards, and the ability of successful teams to maintain a higher ball-in-play were associated with success. Again, the authors suggested that technical and tactical differences, rather than physical, distinguish successful and less-successful rugby league teams.

The study by Kempton et al in 2017 examined both GPS and performance indicators metrics that differed between successful and less successful NRL teams. The authors found no differences in total distance or low-speed running distances between the two, but did note that the successful team very likely had lower higher-speed running demands, and most likely demonstrated more accelerations and decelerations. The same study found the successful team very likely gained more territory in attack (running metres with ball in hand), and had more possessions, whereas the less-successful team was likely required to attempt more tackles, and most likely missed more tackles (Kempton et al. 2017b).

A study from the NRL in 2017 (Woods et al. 2017) found that match outcome was related to the following performance indicators; try assists, all run metres, line breaks, dummy half runs, and offloads, whilst ladder position was shown to be related to missed tackles, kick metres, and dummy half runs. A study from the ESL (Parmar et al. 2017) found teams had a higher chance of winning when scoring first and increasing their possession (completed sets and metres gained), with a second paper from the ESL (Parmar et al. 2018) also finding successful teams retained more offensive possession than their opposition. However, the authors did note that teams can win even when outperformed in performance indicators and KPIs.

In 2018 Gabbett and Hulin (Gabbett and Hulin 2018) investigated the differences in technical performance indicators between successful and unsuccessful teams in the NRL from 2004-2014. The authors found the top teams (1^{st}-4^{th}) completed significantly more play-the-balls (a factor of attacking possession) than teams in 12^{th}-16^{th}, with these bottom ranked teams having significantly less tackle breaks, and a higher total, and missed number, of tackles (non-attacking possession and errors).

There are discrepancies between the research in rugby league as to what separates successful and unsuccessul teams. These discrepencies are related to the running performance (GPS metrics) rather than the technical performance indicators (attacking possession, tackles, missed tackles etc). For example one study in sub-elite rugby league (Gabbett 2013a) found successful teams covered more distance at high speed, whereas other research in both sub-elite and elite rugby league (Hulin et al. 2015; Kempton et al. 2017a; Hulin and Gabbett 2015) found distance covered at high speed was no different between successful and non-successful teams. These discrepencies could be due to differences in the data collection, classification of metrics, and statistical methods employed, such as:

- Research only analysing one team, and the data from when that team was winning vs losing.
- Studies not analysing all games within a season, therefore did not provide a true representation of the competition.

- Studies that analysed the actions of only a few (1-3) players per team, and not the full playing squad of 17 athletes, therefore not providing an accurate representation of competition.
- Studies that used multiple teams but did not provide relative comparison between oppositions.
- Studies that used different classifications for their metrics i.e. high-speed running was classified as >3.9m.s in one study and >5.0m.s in another, not allowing accurate comparison between studies.

Beyond the discrepancies and limitations, the consensus from the research of successful vs non successful rugby league teams points towards successful teams having more attacking possession of the ball. This is characterised by covering more running metres with ball in hand, more completed sets, more tackle busts, and faster play the ball relative to the opposition. Additionally, unsuccessful teams tend to spend more time defending and this is seen with the higher numbers of tackles missed tackles recorded.

Rationale, Aim & Hypotheses of the Thesis

To our knowledge no previous study has managed to obtain GPS data from a whole competition (data from all teams for all games), or analysed movement patterns relative to the opposition. Further, no previous studies have analysed performance indicators in women's rugby league. It is for these reasons that the aim of this project is to examine the extent at which performance indicators and GPS data could be used to explain point scoring and match outcome between teams in the NRLW. The thesis will examine the differences in distance, acceleration, velocity, and technical performance indicators relative to the opposition (% difference between teams per minute). This is an important perspective for teams to consider as they review their own performance. The findings can enhance the competitiveness of the competition, aid in player selection and talent identification, and assist coaches when designing and implementing training plans and game tactics.

The GPS metrics analysed will be ‘Average Speed’, ‘Average High Speed’ (high speed considered over 12 km/h), ‘Average Sprinting Speed’ (sprint speed considered over 18 km/h), and ‘Average Acceleration’. The performance indicators analysed will be ‘All Running Metres’, ‘Tackles’, ‘Missed Tackles’, and ‘Tackle Breaks’ due to their availability on NRL.com for all NRLW teams, and due to previous research finding these performance indicators differentiate between successful and unsuccessful teams (Woods et al. 2017; Gabbett 2013a).

The project will utilise a full game and half by half analysis. The half by half approach can provide insight into time specific events that contribute to team success, therefore providing an important technical and tactical focus for coaches (Robertson et al. 2015). Only the GPS data can be analysed on a half by half basis since the performance indicators from NRL.com cannot be sourced half by half. Further, the data will be analysed team vs team, but not in positions. Positional data will not be examined as the project is novel and is examining how the overall team GPS and performance indicators affects match outcome.

In conjunction with the findings of previous research we hypothesise that points scoring and match outcome will be postively asscoaited with all run meters (a product of having more attacking possession), and distance covered at higher speeds, whereas the defensive actions of tackles and missed tackles will be associated negatively with points scoring and match outcome.

Chapter Three – Methodology

Subjects

This study obtained data from 117 players from the four NRLW clubs (age = 26.8 ± 5.4 yr; height = 168.4 ± 6.5 cm; body mass = 76.7 ± 11.9 kg). Data was collected during the 2018 & 2019 NRLW seasons. There were no eligibility criteria, nor were players split into positional groups. The mean number of matches played by each player was 4.1 ± 2.2 matches. Ethics was sought from the NRL and approved by the Griffith University Ethics Committee (Griffith Human Research Ethics Number: 2019/359).

Experiment Design

All four NRLW teams' movement patterns were collected during the 2018 & 2019 NRLW seasons using 10 Hz Optimeye S5 GPS units (Catapult Sports, Victoria, Australia) by the individual team's sports scientist. The GPS units were the property of the individual NRL clubs. The data was collected retrospectively, therefore the information regarding when the hardware and software updates were installed is unavailable. It is also unknown if specific GPS units were allocated to individual players for each match, or if units were allocated at random for each match. GPS units were worn in a specially designed GPS bra that fitted to the torso, with the GPS unit held between the scapulae in a stitched pocket. The players were familiarised with the vest and unit during training sessions. The units were switched on and inserted into the vest prior to the warmup, allowing adequate time before the start of the first half to create a connection with overhead GPS satellites. At the completion of the match the sports scientist retrieved the GPS units, placed them in the charging case, uploaded the data to the laptop, then switched off the units. The sport scientist was responsible for coding the match into first half and second half, coding the unit to the respective player, then uploading the data to Openfield (Catapult Sports), Catapult's encrypted storage cloud. Consent to use the relevant data was sought from the National Rugby League (NRL). As part of the player's contract, the club may act on behalf of the player for improvements to the player's performance if it is delivered in a safe and effective manner. Minimal risks were identified as a direct result of this study, however privacy of athlete's data had to be maintained, and therefore all analysed data was de-identified, with all identifiable data remaining in the Openfield software (Catapult Sports).

Equipment

Catapult S5 units (Catapult Sports) contained a GNSS receiver, an accelerometer and a gyroscope (Thornton et al. 2019). The GNSS receiver sampled at 10 Hz to provide location information via orbiting satellite, whilst the accelerometer and gyroscope sampled at 100 Hz to provide acceleration and inertial movement data. Distances covered at various accelerations were derived from the GNSS and accelerometer components. The S5 units (96 x 52 x 14 mm) were found to have excellent intra-device reliability and mixed inter-device reliability for acceleration metrics (Nicolella et al. 2018) whilst distance, speed, and maximal speed showed good intra-unit reliability (Thornton et al. 2019).

Data Collection

The GPS data was collected at each match (14 total) by the sport scientists at each club and amalgamated by the NRL. The GPS files were retrieved retrospectively from Openfield (Catapult Sports). Each game file was opened consecutively and by examining the movement of players on-screen, the point of kick-off was established at the point of first player movement. The same was done at the start of the second half, and when player movement ceased to display actions that were deemed indicative of play it was determined to be the end of each half. The time of these intervals were recorded into an Excel spreadsheet for later reference.

Of the 475 match entries (14 games) only 370 match entries (12 games) were available for GPS analysis due to poor signal in two of matches. This discrepancy was due to several reasons, with poor satellite coverage within the stadium being the main reason for why files were not included. Match files were segmented into halves. The GPS metrics collected were total distance (m); average speed (m.s); distance covered greater than 12 $km \cdot h^{-1}$ (i.e. high-speed running; HSR); distance covered greater than 18 $km \cdot h^{-1}$ (i.e. sprint distance; SD); and average acceleration load (total sum of accelerations performed). Technical match statistics and demographics were publicly sourced from NRL.com (data collected by Stats Perform). Technical performance statistics retrieved were `All Run Metres' was the cumulative distance of all runs with ball in hand, 'Tackles' were when the defender successfully executed a tackle, 'Missed Tackles' were when the defensive player could not bring the attacking player to the ground or successfully complete the tackle, and 'Tackle Breaks' were when the attacking player was able to continue running after a missed tackle.

Data Analysis

To compare relative intensities each metric was totalled then divided by the time on ground. Total time on ground is different to the game clock of 60 minutes in that the time spent on the field includes stoppages. The average time on ground for an NRLW game is 73 minutes. Because data was summed across the whole team there was no minimum amount of time a player was required to be on the field. The technical performance indicators were analysed for a full match as the data for half by half analysis was not available. The GPS match entries were able to be analysed for the full match, and half by half. The analysis of Full Match and Half Match was chosen to allow for comparison to previous research and also due to the small sample size. The movement pattern and technical performance indicators analysis were separated into three separate steps:

1. Absolute movement pattern and technical PI vs absolute score

   This included the absolute team averages for movement pattern and technical statistics as well as the absolute number of points the team scored in the match.

2. Absolute movement pattern and technical PI vs relative score

   This included the absolute team averages for movement pattern and technical statistics as well as the number of points a team scored in comparison to their opposition (i.e., a positive or negative points differential).

3. Relative movement pattern and technical PI vs relative score

This included the team averages for movement pattern and technical statistics expressed as a difference, as well as the number of points a team scored in comparison to their opposition (i.e., a positive or negative points differential). The score differential was included for the same reason as stated above but instead the movement pattern and technical statistics are expressed relative to that of the opposition to account for both how different the movement pattern and technical data was compared to the opposition, as well as the score differential.

e.g.,

	Team 1		Team 2	
	Distance (m)	Score (points)	Distance (m)	Score (points)
Absolute/Absolute	5000	14	5200	26
Absolute/Difference	5000	-12	5200	+12
Difference/Difference	% diff / min	-12	% diff / min	+12

Statistical Analysis

To assess whether there were any significant relationships between movement pattern metrics and match statistics with the points scored/points differential, generalised linear mixed models (GLMM) were employed. All GLMM's were built using the *lme4*[10] package in R version 3.5.2[11], the *afex* package[12] was used to determine significance at $\alpha = 0.05$ for all analyses, the *emmeans* package[13] was used for pairwise comparisons, while the *sjPlot* package[14] was used for model diagnostics. A separate GLMM was built for each comparison with the movement patterns and match statistics being inserted as fixed effects in each respective model, while the team and match (for half-to-half comparisons) being included as random effects.

Chapter Four – Results

Full Match Analysis

Table 1 presents the full match absolute sum of metrics against absolute points scored. ‘All Running Metres’, with a coefficient of 0.022, and ‘Average Sprinting Speed’, with a coefficient of 5.192, proved to be significant (P = <0.05).

Table 1. Full match absolute average sum of metrics for each team vs Absolute Number of Points Scored by each Team

Full Match	**Absolute Sum of Metrics* vs Absolute Sum of Score****			
Metrics	Coefficient	Std. Error	t value	p
All Running Metres	0.022	0.009	2.376	0.027
Tackles	-0.060	0.045	-1.330	0.197
Missed Tackles	-0.268	0.222	-1.207	0.240
Tackle Breaks	0.039	0.214	0.184	0.856
Average Speed	0.463	0.330	1.404	0.174
Average High Speed	2.340	1.414	1.655	0.112
Avg Sprinting Speed	5.192	2.425	2.141	0.044
Average Acceleration	-1.433	1.313	-1.091	0.287

*Absolute value of the team average for each metric.
**Absolute number of points scored by that team.

Table 2. presents the full match absolute sum of metrics vs relative points difference. Only ‘All Running Metres’, with a coefficient of 0.047, was significant (P = 0.05).

Table 2. Full match absolute average sum of metrics for each team vs relative difference between teams score line

Full Match	**Absolute Sum of Metrics* vs Relative Difference in Score****			
Metrics	Coefficient	Std. Error	t value	p
All Running Metres	0.047	0.015	3.162	0.005
Tackles	-0.074	0.079	-0.937	0.359
Missed Tackles	-0.510	0.375	-1.360	0.188
Tackle Breaks	0.130	0.363	0.358	0.724
Average Speed	0.809	0.560	1.445	0.163
Average High Speed	2.373	2.498	0.950	0.353
Avg Sprinting Speed	6.071	4.345	1.397	0.176
Average Acceleration	0.840	2.286	0.367	0.717

*Absolute value of the team average for each metric.
**Score differential between teams.

Table 3. presents the full match relative metrics against relative points difference. 'All Running Metres', with a coefficient of 0.037, and 'Average Sprinting Speed', with a coefficient of 18.036, were found to be significant (P = 0.05).

Table 3. Full match relative difference in teams metrics vs relative difference between teams score line

Full Match	**Relative Sum of Metrics* vs Relative Difference in Score****			
Metrics	Coefficient	Std. Error	t value	p
All Running Metres	0.037	0.012	3.211	0.009
Tackles	-0.047	0.070	-0.674	0.516
Missed Tackles	-0.310	0.306	-1.015	0.334
Tackle Breaks	0.152	0.309	0.494	0.632
Average Speed	0.966	0.700	1.380	0.198
Average High Speed	11.053	5.337	2.071	0.065
Avg Sprinting Speed	18.036	7.135	2.528	0.030
Average Acceleration	2.555	3.981	0.642	0.535

*Data expressed relative (per minute) to the opposition.
**Score differential between teams.

Half by Half Analysis

Table 4. presents the match on half by half basis, examining absolute metrics against absolute points score. ‘Average Sprinting Speed’, with a coefficient of 2.653, and ‘Average Acceleration’, with a coefficient of -1.107, were found to be significant (P = 0.05).

Table 4. Half match absolute average sum of metrics for each team vs Absolute Number of Points Scored by each Team

Half by Half	**Absolute Metrics* vs Absolute Score****			
Metrics	Coefficient	Std. Error	t value	p
Average Speed	1.168	0.616	1.897	0.064
Average High Speed	-0.031	0.128	-0.244	0.808
Avg Sprinting Speed	2.653	1.028	2.581	0.013
Average Acceleration	-1.107	0.480	-2.306	0.026

*Absolute value of the team average for each metric.
**Absolute number of points scored by that team.

Table 5. presents the match on half by half basis, examining the absolute sum of metrics against relative difference in score. ‘Average Sprinting Speed’, with a coefficient of 3.610, was the only significant metric (P = 0.05).

Table 5. Half match absolute average sum of metrics for each team vs relative difference between teams score line

Half by Half	Absolute Sum of Metrics* vs Relative Difference in Score**			
Metrics	Coefficient	Std. Error	t value	p
Average Speed	0.212	0.208	1.023	0.312
Average High Speed	1.452	1.024	1.418	0.163
Avg Sprinting Speed	3.610	1.719	2.100	0.041
Average Acceleration	0.356	0.828	0.430	0.669

*Absolute value of the team average for each metric.
**Score differential between teams.

Table 6. presents the match on half by half basis, examining relative difference in metrics against relative difference in score. ‘Average High Speed’, with a coefficient of 6.364, and ‘Average Sprinting Speed’, with a coefficient of 10.553, were found to be significant (P = 0.05).

Table 6. Half match relative difference in teams metrics vs relative difference between teams score line

Half by Half	Relative Sum of Metrics* vs Relative Difference in Score**			
Metrics	Coefficient	Std. Error	t value	p
Average Speed	0.468	0.353	1.326	0.199
Average High Speed	6.364	1.984	3.207	0.004
Avg Sprinting Speed	10.553	2.502	4.218	0.000
Average Acceleration	90.875	94.743	0.959	0.352

*Data expressed relative (per minute) to the opposition.
**Score differential between teams.

Chapter Five – Discussion

Research in other sports has examined the relative differences of performance indicators between opposition teams and its relation to success (Higham et al. 2014; Young et al. 2019; Robertson et al. 2015); however, to our knowledge this study is the first to examine the relative differences of performance indicators between teams in rugby league; the first study to examine relative differences in GPS metrics between teams; and the first to examine performance indicators in women's rugby league. Three different analytical methods were chosen to see if they could provide unique insights to determine what metrics could predict match outcome.

Analysis Step One - Absolute vs Absolute Data

Full Match Analysis

The first analysis examined the absolute difference between opposition teams performance indicators and GPS metrics, against the total points the team scored, to determine if any of these metrics could explain match outcome. This approach is what most would consider "traditional" in that it analyses the data of one team without reference to the oppositions data or score. 'All Running Metres', with a coefficient of 0.022, and 'Average Sprinting Speed', with a coefficient of 5.192, were shown to be significant (P = 0.05). The coefficient of 0.022 means that for every 1m of 'All Running Metres' equates to 0.022 points being scored. In the 2020 NRLW competition the average 'All Running Metres' for a team per game was 1,130m (NRL.com). Using the coefficient 0.022 multiplied by the average 'All Running Metres' from the 2020 NRLW season equates to 25 points being scored by a team per game. 'All Running Metres' is a metric that reflects attacking possession, and our finding of 'All Running Metres' being a significant predictor of match outcome supports the previous research (Gabbett 2013a; Woods et al. 2017; Kempton et al. 2017a; Parmar et al. 2018b). Previous authors have found successful teams had higher attacking possession, made more attacking metres, and completed more sets than their opposition.

Although not significant, 'Tackles' and 'Missed Tackles' negatively impacted scoring and match outcome. These are defensive performance indicators and may highlight that teams not in possession of the ball have less chance to score. Additionally, missing tackles in a game can allow the opposition to cover more metres, and potentially lead to points scoring opportunities.

'Average Sprinting Speed' was found to be a significant predictor of match outcome, with everyone unit (m) increase more than your opposition accounting for 5.192 points scored. This supports the research from Gabbett (Gabbett 2013a) who also found that successful teams cover more sprint distance than their opposition. Our finding could suggest that in women's rugby league having superior speed compared to the opposition could be the difference between winning and losing. However, this is in contrast to other researchers (Kempton et al. 2017a; Hulin et al. 2015; Hulin and Gabbett 2015) who found successful teams were likely to cover less high speed distance than their opposition. Total distance was not significant between winning and losing teams, which supports previous findings from Hulin (Hulin et al. 2015) and Kempton (Kempton et al. 2017a). Further, although not significant 'Average Acceleration' was found to be negatively associated with match outcome, which contradicts the findings from Kempton et al (Kempton et al. 2017a) who found successful teams were more likely to have higher accelerations than their opposition.

Half Match Analysis

The half by half analysis provided new insight from the full match analysis. ‘Average Sprinting Speed’, with a coefficient of 2.653, and ‘Average Acceleration’, with a coefficient of -1.107, were found to be significant (P = 0.05). The ‘Average Sprinting Speed’ coefficient of 2.653 was half that of the full match analysis, 5.192. Meaning it has the same influence throughout the full match. However, ‘Average Acceleration’ was found to be significant with a coefficient of -1.107, indicating its negative relationship to match outcome. This finding is in contrast to Gabbetts paper (Gabbett 2013c) that found successful teams had higher absolute and relative maximal accelerations compared to their unsuccessful opposition. The smaller period analysis (approximately 30min) showed that a disparity between oppositions ‘Accelerations’ can impact match outcome. There could be a multitude of reasons for this. It could be characterised by defensive players accelerating (rushing) up off the line in an attempt to stop the attacking team, and then potentially having to turn and chase opposition players, which would contribute to higher accelerations relative to the attacking team. Conversely, more accelerations could be occurring in a match where the ball is in play for longer periods due to less tries being scored. Our finding could potentially be that of ‘negative facilitation’ which is when teams increase their efforts after failure (e.g. conceding points, behind on the score board) in an effort to overcome negative momentum and reinsert themselves back in the game (Perreault et al. 1998).

Analysis Step Two - Absolute vs Relative Data

Full Match Analysis

The second analysis examined the absolute difference between opposition teams performance indicators and GPS metrics, against the relative points difference, to determine if any metrics could explain match outcome. This analysis was included as it accounts for whether the team won (positive differential) or lost the game (negative differential), not solely on the total number of points scored. Using this analysis approach is more insightful than the absolute vs absolute method, as it provides insight into what metrics separate teams with larger or smaller score line differences. For example if the final score was 26-24 (relative score difference of +/-2), and the absolute metrics of both teams were relatively even, this analysis could potentially reveal the performance indicators and GPS metrics that separate winning and losing teams. Additionally, this analysis approach can provide insight into how performance indicators and GPS metrics change due to changes in relative score line.

Previous research in Basketball (Csátaljay et al. 2012) examined the differences between winning and losing teams during closely balanced and unbalanced quarters. The authors found that the style of play, and subsequent performance indicators, changed depending on if the score line was close or unbalanced. Research has also been conducted in soccer (Lago 2009; Lago-Peñas and Dellal 2010; Redwood-Brown et al. 2019; Redwood-Brown et al. 2012; O'Donoghue and Tenga 2001) examining the changes in relative score line and found that as score differential changes the game strategy and technical performance indicators change. A small relative differential will have teams displaying similar behaviours and performance indicators, whereas larger relative differences will result in teams changing behaviours, and thus larger differences will be seen in performance indicators and GPS metrics. In our own research, an example of this can potentially be seen with 'Missed Tackles'. Although not significant, the coefficient for 'Missed Tackles' has almost doubled, from -0.268 to -0.510, potentially indicating that when a team is behind on the score board, their commitment and behaviour can change, and could be manifested by players missing more tackles.

The results from this analysis show ‘All Running Metres’, with a coefficient of 0.047, was the only significant metric to predict match outcome (P = 0.05). Of interest is the doubling of the coefficient from 0.022 to 0.047, indicating that ‘All Running Metres’ is more influential when accounting for the relative difference in score line. This supports previous findings that found gaining more attacking metres, having more offensive possession, and completing more sets compared to the opposition were predictors of success (Gabbett 2013a; Woods et al. 2017; Kempton et al. 2017a; Parmar et al. 2018b).

Half Match Analysis

The half by half analysis provided new insight compared to the full match analysis, as ‘Average Sprinting Speed’ with a coefficient of 3.610 was found to be significant (P = 0.05), whereas in the full match analysis it was not. This could be due to the larger period (approximately 60min) not capturing the mismatches that could be occurring during smaller time periods within the match. Additionally, the coefficient of 3.610 is larger than the ‘Average Sprinting Speed’ coefficient from the previous half by half analysis (2.653), indicating that it is more influential in determining points scored and match outcome relative to the opposition.

Analysis Step Three – Relative vs Relative Data

Full Match Analysis

In this analysis the GPS and performance indicators metrics were analysed relatively (% difference) against the relative score differential, to determine if any metrics could predict match outcome. ‘All Running Metres’, with a coefficient of 0.037, and ‘Average Sprinting Speed’, with a coefficient of 18.036, were found to be significant (P = 0.05). This finding again supports the previous research (Gabbett 2013a; Woods et al. 2017; Kempton et al. 2017a; Parmar et al. 2018b) that ‘All Running Metres’ (metric related to possession) are related to positive outcomes. The coefficient of 0.037 in the relative analysis is higher than that of the absolute analysis, 0.022, indicating that having higher ‘All Running Metres’ relative to your opposition is more important than having a high total ‘All Running Metres’. By limiting the oppositions run metres, it will increase the relative difference between teams, therefore increasing the chances of a positive match outcome. This supports previous research (Gabbett, 2013) that found successful teams had higher attacking metres whilst conceding fewer metres in defence. Although not statistically significant, ‘Tackles’ and ‘Missed Tackles’ (defensive statistics) again had a negative relationship with points scoring, supporting previous research findings (Woods et al. 2017; Kempton et al. 2017a).

‘Average Sprinting Speed’ was statistically significant, with a coefficient of 18.036, and was 3.5 times more influential in determining match outcome compared to the absolute analysis value of 5.192. This infers that having a higher relative ‘Average Sprinting Speed’ compared to your opposition can contribute largely to match outcome. This reinforces the findings from Gabbett who found successful teams are likely to sprint more than less successful teams (Gabbett 2013a). Total distance was again found to be non-significant, in accordance with previous research (Hulin et al. 2015; Kempton et al. 2017a)

Half Match Analysis

The third half by half analysis provided new insight compared to the full match analysis. ‘Average High Speed’, with a coefficient of 6.364, and ‘Average Sprinting Speed’, with a coefficient of 10.553, were found to be significant (P = 0.05). This is the first analysis where ‘Average High Speed’ was found to be a significant predictor of match outcome. The full match analysis did not find ‘Average High Speed’ to be significant, which could be due to the larger time period not capturing the true running demands of the game. In rugby league there are changes in possession, momentum, and tactics occurring throughout. Performing analyses with smaller time periods will provide researchers with a more accurate understanding of how and why relative differences in metrics occur. For example, one team may have multiple attacking possessions back to back and this will increase their attacking statistics relative to the opposition; however, when analysing data over a whole match (60 minutes) the difference between teams may not be observable. 'Average Sprinting Speed', with a coefficient of 10.553, was just over half of the full match analysis coefficient of 18.036, and three times larger than that from the previous half by half analysis (3.610). This indicates that 'Average Sprinting Speed' relative to your opposition, and within each half, is very influential on match outcome. From this half by half analysis it can be said that covering more distance over 12km/h relative to your opponent will likely result in a positive match outcome.

Our findings confirm those of previous research with 'All Running Metres' (a product of attacking and retaining possession) being a predictor of points scoring and match outcome. The research also found teams who cover more high speed distance (i.e. high speed running [>12km/h], and sprinting [>18km/h]) both absolutely and relative to their opposition are more likely to have a positive match outcome. Although our research did not find 'Tackles' and 'Missed Tackles' to be significant in match outcome, they were associated with negative points scoring, which also agrees with previous research findings. The relative analysis approach was able to provide more inference than the absolute analysis, with the relative analysis highlighting the increased importance of having more 'All Running Metres', 'Average High Speed', and 'Average Sprinting Speed' relative to your opposition to ensure a positive match outcome.

Discrepancies between our findings and other studies could be due to:

1) Gender: - research has shown there are physical, technical, and tactical differences between men and women competing in the same sport (Casal et al. 2020b; Clarke et al. 2017a; Pyne et al. 2012; PALADE et al. ; Bradley et al. 2013), and these gender differences could manifest themselves through different movement patterns and technical performance indicators.
2) Playing Level: - Our data supports the findings from research conducted with sub-elite male rugby league players (Gabbett 2013a), and suggests that successful and unsuccessful teams in women's rugby league can be separated by physical qualities (high speed running and sprinting) and technical qualities. This contradicts the findings of elite men's rugby league competitions (Hulin et al. 2015; Kempton et al. 2017a), whereby at the elite level, technical and tactical differences separate winning and losing teams, not physical qualities alone.
3) Data Collection: - Our data was collected across two seasons and analysed all players and games within the 2018 and 2019 NRLW competition. Previous research has collected data differently, with potentially discrepancies arising due to: using different technology (GPS and video); collecting data from only one team or two teams; only analysing a select number of games per season; selecting only a few players from each team to analyse; collecting and comparing data from two different seasons; and using different classification methods for their metrics.
4) Analysis Techniques: - Our research analysed the relative differences between teams as a percentage difference per minute. Discrepancies could be due to the studies using different statistical models; only performing absolute analyses; classifying relative difference as the absolute difference between metrics; grouping performance indicators together for analyses; and using different time periods (e.g. 5min)

Limitations of Research

- The small sample size of the NRLW competition may not provide an accurate representation of GPS and performance indicators that are important to match outcome in women's rugby league. The findings can only provide inference for how Australian and New Zealand elite rugby league teams play. Whereas sub-elite teams, and elite teams from England, may have a different playing style, and compete in different environmental conditions, which would result in differing GPS and performance indicators data.
- Positional data was not analysed; however, this was due to the small sample size, and not wanting to provide data that was uninterpretable and not applicable.
- Not all players had working GPS units which meant that some data was missing from the analysis. Research by Hulin et al. (Kempton et al. 2014) has cautioned against the use of GPS data being used as a match analysis tool due to the high variability of some GPS metrics, excluding total distance, between rugby league games. This could be offset however by utilising a large sample size.
- The performance indicators analysis was only conducted for a full game and not half by half. This was due to not having access to this data.
- Only a select range of GPS and performance indicators data was analysed.
- The analysis could be considered reductionist in that it only examined GPS and performance indicators data without considering other contextual variables that can impact match outcome (environment, opposition strength, opposition tactics etc).
- Sharing of oppositional data that is collected in-house (i.e. GPS data) is not common place therefore it may be difficult to use opposing teams GPS data for analysis and devising game plans.

Practical Applications

- 'All Running Metres' and high-speed running (all distance covered >12km/h) are significant factors in positive scoring outcomes. The findings support the training and development of attacking play whilst maximising possession; in addition to training and developing speed and recruiting players with these qualities. By having superior speed and skills relative to your opposition you will be able to create attacking mismatches multiple times throughout the match.
- Defensive work should also be prioritised as our findings show that 'Missed Tackles' are negatively associated with match outcome.
- Tactically coaches can create game plans to expose their opponent's weakness, whilst playing to their team's strengths. This might be as simple as assigning your best defensive player to mark their best ball carrier; or designing game tactics whereby your fast players can exploit the opposition.

Future Research

- Future research can examine the first vs second half, to observe if there is any decay in GPS or performance indicators over the duration of the match.
- Future studies should analyse the data in smaller time intervals. Whether that be 15-minute intervals to provide 4 periods of a match or utilising a rolling minute approach. Utilising the rolling minute approach can identify the most intense periods of a match, which may provide more accuracy on the peak relative mismatches that can impact match outcome.
- Examine the differences between positions, and starters and interchange players.
- Examine the specific occasions when points were scored to determine what mismatches in data occurred when the points were scored.

- Larger sample sizes should be used to allow for accuracy when drawing conclusions from research, and to allow for a positional analysis. As the NRLW competition expands to include more teams, the movements activity profiles and key performance indicators have the potential to change.
- A larger range of GPS and performance indicators metrics can be analysed in the future to determine if there are more metrics that can significantly impact match outcome.
- Should analyse performance indicators collectively, like the Parmar et al (2018) study, by grouping performance indicators together to provide better insight into the relationship between performance indicators and successful outcomes.
- The impact of contextual factors such as weather, temperature, time, and location, on match outcome.
- Different analysis techniques could be utilised such as the game style approach, which involves analysing game tactics, and collective team behaviour, to see how these may impact performance indicators, GPS data, and match outcome.
- Future research could analyse males and female rugby league to determine if there are any gender specific relative differences.

Chapter Six – Conclusion

This study was the first to examine performance indicators in women's rugby league, and identify which GPS and performance indicators metrics, relative to your opposition, could explain points scored and match outcome. The metrics analysed were 'All Running Metres', 'Tackles', 'Missed Tackles', 'Line Breaks', 'Average Speed', 'Average High Speed', 'Average Sprinting Speed', and 'Acceleration'. The performance indicators were analysed for a full match and the GPS metrics were analysed for the full match and half by half. This data was analysed further utilising three different approaches. The first approach analysed the absolute sum of metrics against the total points each team scored. The second approach analysed the absolute sum of metrics against the relative points difference between teams. The third approach analysed the metrics relative to the opposition (% difference between teams) against the relative points difference between teams.

'All Running Metres' was significant in both the absolute and relative analysis, with the relative analysis finding 'All Running Metres' to be more influential than in the absolute analysis; indicating that having higher 'All Running Metres' relative to your opposition is more important than total 'All Running metres'. 'Average Sprinting Speed' was significant in both the absolute and relative analysis and was found to be more influential in the relative analysis than the absolute analysis. This highlights the importance of having the ability to sprint, and sprint more relatively to your opposition. 'Average High Speed' was significant in the half by half relative analysis. The findings indicate a positive relationship between running at higher speeds, relative to the opposition, and points scoring and match outcome. 'Accelerations' were negatively associated with match outcome and found to be significant only in the absolute analysis conducted half by half. This finding is difficult to explain as it is impossible to determine if accelerations are performed more by defensive teams, or if games that exhibit high numbers of accelerations are occurring in low scoring games. Finally, although not significant, ‘Tackles’ and ‘Missed Tackles’ were associated with negative match outcomes. This is a by-product of not having attacking possession from which to score, as well as ‘Missed Tackles’ leading to potential points scoring opportunities for the opposition.

Our findings confirm those of previous research for a few reasons. First that higher ‘All Running Metres’, as a product of ball possession, separates successful and unsuccessful teams. Second that teams who cover more high-speed distance than their opposition are more likely to have a positive match outcome; and third, that ‘Tackles’ and ‘Missed Tackles’ were associated with negative match outcomes. There were contradicting findings including ‘Accelerations’ being negatively associated with match performance; and ‘High Speed’ running being a significant predictor of match outcome. Future research may look to examine why these discrepancies occurred.

This project identified the technical and physical qualities related to points scoring and match outcome in elite women’s rugby league. With this information coaches and athletes in women’s rugby league can design training programs to optimise player performance; devise game tactics to exploit the opposition; and use the data to aid in talent identification and player recruitment of athletes who exhibit qualities that will contribute positively to points scoring and match outcome.

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