Workload Demands during Ball-in-Play Periods: A Comparative Study of Locomotive and Contact Metrics in Professional Male and Female Rugby Union Players.

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Abstract

Title: Workload Demands during Ball-in-Play Periods: A Comparative Study of Locomotive and Contact Metrics in Professional Male for Female Rugby Union Players.

Purpose: Rugby Union is a high collision-based sport demanding the best physical, technical, tactical and decision-making capabilities of players to influence success on the field. Various factors affect the ability of females and males to perform and meet the demands of match-play. This thesis was developed as a pilot study and employed an innovative design that examined and compared contact and workload metrics between female and male professional rugby players, aiming to explore differences in match play.

Methods: Data were collected from 60 professional male and female rugby players, from two professional 2023 New Zealand National Provincial Rugby teams. All participants wore GPS units (Apex Pro Pod, STATSport, Newry, NIR). Each match was filmed and coded using a Sportscode video analysis software package (Sportscode 12.4.3, Sportstec, Australia), where contact and GPS metrics during Ball-in-Play periods were identified and recorded throughout the match. GPS and Sportscode data for each Ball-in-Play period for each match were combined in a bespoke software package. Differences between the sexes for each metric were analysed using Welch's t-test with the level of significance set at $P<0.05$ and the magnitudes of the standardised differences were calculated using effect sizes determined by Cohen's d (Hopkins, 2009, 2017). Tests for equality of variances, normality, and the examination of outliers were conducted in IBM SPSS Statistics (Version 27) and the few metrics that failed normality testing were log-transformed.

Results: Males locomotive metrics (GPS measures) and impacts (accelerometer measures) were typically significantly greater than females showing large to moderate magnitude differences. On the other hand, contacts were often significantly higher for females with small to large magnitude differences.

Conclusion: The differences between males and females were likely a combination of genetic differences, and differences in how the respective games were played, and the males in this study typically had greater full-time professional training support and resources. Due to these differences, altering female threshold standards for specific intensive locomotion metrics to suit the physical capabilities of females, may give more of an accurate

representation of game demands. On the other hand, providing greater resources to female rugby union players for similar periods to the males may reduce the differences observed in this study.

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Abbreviations

BIP: Ball-in-play

BOP: Ball out of play

DSL: Dynamic stress load

GPS: Global positioning unit

HMLD: High metabolic load distance

HSR: High speed running

SPMET: Sprint metabolic load distance

SRPE: Session rating of perceived exertion

KPI: Key Performance Indicator

Chapter 1: Literature Review

1.1. Introduction

Rugby is a high collision field-based team sport, which comprises of an eighty-minute game that has two halves consisting of forty minutes (Duthie, Pyne, & Hooper., 2003). Participants include two teams of fifteen players on the field, including eight forwards (numbers 1-8) and seven backs (numbers 9-15). These players are rotated with the eight reserves on the bench, which substitute players onto the pitch as needed. As a contact sport, rugby is composed of high intensity efforts that vary from short bursts to sustained periods, potentially including changes in direction, collisions between players, and lower intensity movement such as walking or jogging (Owen et al., 2015; Posthumus et al., 2020). However, the intensities of these movements can vary depending on the match demands. Therefore, it is important to understand the complexities of rugby and how technologies for analysing physical demands can be used effectively and efficiently, enabling coaching staff to push players to reach peak physical performance. This review will summarise the current literature on the best practices for analysing and comparing the contact and locomotive demands in female and male professional rugby and potential gaps within the existing literature identified.

1.1.1. Physical Demands of Rugby Union

The demands of rugby have become greater over the years, as have the desired physical characteristics to be achieved (Owen et al., 2015). It is argued that to be able to meet these optimal standards, rugby players need to be built with physical attributes and ball skills that contribute to performance to excel in the sport (Nicholls et al., 2023). For this reason, training is focused on building players strength, power, agility, speed, and aerobic fitness, to enhance players physical capabilities (Quarrie & Hopkins., 2007).

In addition, Pollard et al. (2018) describes that international rugby comes with greater workload demands, requiring coaches to undertake more in-depth assessments and understand the specific requirements of players. This allows for the establishment of, better game tactics and physical standards to work on or towards. Likewise, as international rugby is ever evolving and challenging coaches to think beyond the traditional methods in how they

monitor performance, it has become critical to analyse how to achieve high levels of fitness to meet players' positional demands (Posthumus et al., 2020).

Previously, monitoring performance was primarily undertaken using simple, structured systems (Inoue et al., 2022). Thus, implementation and design of monitoring equipment has evolved and become a valuable tool to incorporate into sports teams (Nicholls et al., 2023). Technological advancement enabled the collection of large amounts of data for coaches and analysts to study, analysing internal and external workload (West et al., 2019). External load represents the physical demand experienced during matches and represents how much workload has been done, whereas internal load is the psychophysiological response between the mind and body of the athlete to that external load (Conte et al., 2022).

A monitoring system that commonly uses internal load is session rating of perceived exertion (SRPE) which helps efficiently monitor athletes' psychological responses to the training prescribed (West et al., 2019). SRPE is an inexpensive method that is mainly associated with measuring heart rate, maximum rate of oxygen consumption (V02 max), and lactate and ventilatory thresholds (Ciolac et al., 2015). Additionally, it enables coaches to see the stresses that occur during a prescribed workload, and how the individual is responding to the load. Typical measures of external load often use microelectromechanical devices like global positioning systems (GPS). These devices record measurements such as distances covered, accelerations and decelerations (Conte et al., 2022).

The significance of understanding physical demands is to enable coaches to efficiently and effectively train players to reach their peak performance, especially at an elite level (Pollard et al., 2018). Understanding the ability to utilise the most advanced tools to analyse the match demands and physiological responses, is important for coaches to capture the stimulus of their training methods, which contributes a significant part to a team's success.

1.1.2. Locomotive demands

Rugby locomotive demands are a highly valuable metric within a team, as it assesses the overall load of an individual while in training or game play (Duthie, 2006). Speed, strength,

power, and body composition are all necessary for an athlete to be successful and play an important factor in determining locomotive workload. Locomotive demands can also include low effort movements (walking, standing, jogging) and high effort movements (running and sprinting). Furthermore, Duthie (2006) describes that in matches, players are faced with the challenges of tactical manoeuvres, how well they can change direction, ball carry successfully and avoid opponents.

Locomotive demands within male rugby have been well documented across different studies. However, it is argued, that female rugby has very limited research available (Sheepy et al., 2019). The known studies that have evaluated this type of research show that with the progression of the sport, it has required players physical fitness to meet the advancement (Sheepy et al., 2019; Reardon et al., 2017).

Locomotive demands do differentiate between positions. It is known positionally that forwards receive more of the collisions and impacts, while the backs do more of the high intensity running. To elaborate, a study by Dubois et al. (2017) with elite male rugby players found that the backs covered 300-800m at high and sprinting speeds (14.4km/h and 25km/h respectively), whereas forwards covered more distance in moderate speeds zones (10-14.4km/h). This supports findings that indicate that forwards spend a notable amount of time scrummaging, rucking, and mauling which contribute to a large proportion of their game time. These events are classed 'non-locomotive' workload.

Non-locomotive workload represents demanding and critical components in a match. These components of a game are often referred to as 'intense static activity' and make up 15% of the match for the forwards (Duthie et al., 2003). Despite this, non-locomotive workload is not classed as an extensive workload with a significant impact on the match. This is because there has been no technology to justify how significant the impacts are, even though they do contribute a considerable amount to the match.

This indicates the limitations of current studies that do not mention non-locomotive workloads within their methodologies, as there is not enough scientific research to understand

the intensities of this type of workload. Technologies such as GPS can only provide information in identifying fatigued players and adapt individuals' training regime. Similarly, time motion analysis is another technology that is used for technical and tactical evaluations and is commonly done in a non-invasive way for analysing workload on the rugby field. While this analysis is important, it only provides information for practitioners and players in the development of databases, performance models used, and analysis of movements. The evidence from both these examples shows the analysis tools cannot accurately assess the intensities of these collisions that happen so frequently throughout the match.

Overall, the evidence suggests that analysing non-locomotive workloads is very valuable to understanding the full complexities of rugby, and critically, more sensitive measures are required to further expand this area of research.

1.1.3. Contact demands

As rugby is an intermittent collision sport, contact demands that happen within a rugby match are critical to the outcome of the game. These demands can differentiate between increased perceptions of effort, muscle damage, neuromuscular fatigue, and energy expenditure (Johnston et al., 2019). Contact demands can happen from tackles, rucks, mauls, and scrummaging and influence a player's ability to run quickly and their skill capability during a match. Gabbett et al. (2012) reported that if players have poorly developed speed and aerobic performance, they were more likely to sustain a contact injury compared to players with a higher aerobic capacity. This indicates that better developed physical qualities such as body mass and muscle mass can prevent injury. However, players that are required to perform multiple contacts per minute within a match sustained greater reductions in average speed across all positions. Reducing their work efficiency on field when these collisions happen, which is shown when players spend more time stationary recovering (Johnston et al., 2019).

Previously, video and time-motion analysis have been used to address the counts of the collisions that occur within a match. The technology and methodologies are effective, but the time-consuming process and the ability for human error takes away from the validity of these devices. Previous studies have shown that impact counts are as high as 858 for forwards per

match and 830 for backs (Venter et al., 2011). In contrast, when using video analysis, on average the collisions for the forwards represents 89 collisions and 24 for backs during matches (Roberts et al., 2008). Additionally, Duthie et al. (2005) concluded that when conditioning players to meet the needs of the high-level physical contact that players experience within a match, it is challenging to analyse. As mentioned above, the intense static activities like rucks and mauls as well as scrummaging all contribute to the counts of these collisions; however, technology has yet to show an accurate quantification of the force players generate when involved in contacts.

1.2. Technologies for analysing workload demands.

1.2.1. Global positioning system

GPS is a satellite positioning system. It allows for signals for geolocation for efficient movement, measurement, and tracking people. Athlete monitoring became more known in 1997 and since then, GPS has been able to manage the external training load of players during match play or training (Scott et al., 2016). GPS has become an efficient device that allows for live feedback, which for the practicality of team sports is valuable. Scott et al. (2016), explain how video motion analysis only allows for one athlete to be tracked, whereas GPS units allow for multiple athletes to be tracked at one given occasion. Prior to the introduction of GPS into sports, it was very difficult to collect accurate data on player locomotion loads, other than using video tracking and heart rate monitoring (Cunniffe et al., 2009). Recently, a large collection of studies has been published which investigate the validity and reliability of GPS units (Johnston et al., 2012). These studies have shown a variety of mixed results; however, they conclude that for best practice results using this device, it is best for athletes to wear the same GPS unit, so it shows a more accurate reading for matches and training sessions (Scott et al., 2012).

The modern GPS is built to have a lightweight and compact framework, which makes the device very suitable for team field sports. As such, the use of GPS units has become more frequent, providing valuable insight into individuals responses during not only games, but also training. As raw data can be generated from the devices, metrics can be shown such as speed, distance, high metabolic load, which can help determine locomotive workload. GPS

and monitoring technology provides an overall importance in identifying fatigued players and adapting individuals training based on their responses when using this equipment. It further exemplifies how coaches can control player management and open discussions around the data generated to make informed decisions on prescribed workload (Theodoropoulos et al., 2020).

However, there are technological and functional limitations when using GPS technology. Scott et al. (2016) highlights how the signals from the satellite can be interrupted which can result in measurement error. These interruptions may be caused by the surroundings or location where the GPS is being used such as stadiums or tall buildings. Measurement error may also be introduced by the interference of other satellites, or the positioning of the receiver relative to the satellite. These factors influence how the measurements are recorded by the receiver and will therefore influence the accuracy of the data.

A study by West et al. (2019) highlighted that there are differing naming conventions for GPS metrics between GPS providers. Teams may also use different threshold zones for specific metrics when analysing training load management. This can create barriers to data collection and the methods of understanding what to monitor. Similarly, when monitoring metrics, there are no set standards of what one team may consider being a 'highly beneficial' GPS metric, compared to another team who may consider that GPS metric as 'not important at all'. Therefore, the perceived effectiveness will also vary between teams.

The practicality of the GPS makes it a valuable tool to use among teams. While GPS technology is constantly evolving and becoming more systematic in how the device measures metrics, there are still limitations to how the device functions. However, the use of GPS has made some groundbreaking discoveries within the game of rugby and will still be regarded as an important tool in assessing workload measures.

1.2.2. Accelerometer technology

Accelerometers are a tool that is usually included within the device of the GPS worn by rugby players, that can record impact data (Stevens, 2022). This technology has been used to

evaluate athletes' accelerations and rapid changes in direction (Howe et al., 2020). Furthermore, Howe et al. (2020) describe how accelerometers are a valuable device to evaluate contact events that individuals make and specific movements of a given sport including individual movement alterations and efficiency. The use of accelerometers can aid conditioning coaches in providing more valuable information in collision-based sports through the addition of external load assessments. Accelerometers are used in conjunction with GPS technology. This is because accelerometers can detect small changes, accounting for a greater proportion of an athlete's total movement. As rugby is a high-contact collision sport with many movements that include both vertical and horizontal movements (Howe et al., 2020) this is a particularly useful tool with which to evaluate performance.

In addition to detecting subtle movements, accelerometers can be used to understand the forces generated and experienced by players. GPS has built-in triaxial accelerometers, which measure accelerations in three different axes (anterior-posterior, medial-lateral and vertical). The sum of the three axes provides a vector magnitude (g force). Therefore, accelerometer data can be used to calculate the total magnitude of force an individual experiences over a period of a given time (Paul et al., 2022).

Although the device is helpful, the lack of consistency in reporting impact zones and activity metrics has created issues in the comparisons of metrics within rugby and between team sports more generally (Cummins et al., 2013). The evidence suggests that the disadvantages found within accelerometer technologies demonstrate that more analysis of the device is required to evaluate the contact workload. This is supported by Naughton et al. (2020) who state that there is an overall lack of consistency in terms of quantifying collision intensity from microtechnology. Due to the limitations of accelerometers, the importance of pairing GPS data and manual coding of contact events is still needed to fully understand workload demands in a match (Cummins et al., 2013; Stevens, 2022).

1.2.3. Time motion analysis

Time motion analysis is a non-invasive technique that is used for technical and tactical evaluations of workload on the rugby field. Each match or training is videoed for analysis and

the counts of various locomotive and non-locomotive events are collated for analysis. This provides an objective but non-invasive method of analysing these events. This information is used to assist conditioning coaches and players in the development of performance models and analysis of movements (Roberts et al., 2008). As time-motion analysis can analyse movements that GPS and accelerometers cannot, it is a valuable tool for practitioners to analyse performance amongst teams. Before the introduction of GPS, sports coding was employed to determine and quantify periods of walking, jogging, etc., However, these metrics are now supplied by GPS. Time motion analysis now typically utilises generated video-coded events to gain insights into player and team performance.

Despite these advantages, Naughton et al. (2020) describe how time-motion analysis has been utilised across multiple studies to determine the collision intensity by estimating the associated velocity and accelerations and describing them as various types of 'contact'. However, it is noted that this process is time-consuming and limited by the subjective nature of video analysis.

As such, while time-motion analysis provides useful insights to assist in the development of contact metrics, due to its inconsistencies, this type of technology also requires further research regarding the validity of this approach.

1.3. Locomotion and Contact Metrics

When analysing metrics to quantify players' match movements, a variety of locomotive (GPS) and contact (Sportscode) metrics have been designed. Utilising GPS has allowed practitioners to monitor locomotive workload that previously was not accessible (Cummins et al., 2013). This has enabled performance observations across seasons, matches, and training sessions for teams. Additionally, quantifying the physiological stress experienced is highly valuable to assess what players experience when contact demands occur during a match. This has required researchers to understand the demands of the work required for each contact situation (Van Rooyen et al., 2008). Locomotion and contact metrics that were utilised in this project are explained in the following subsections:

1.3.1. Distance

The total distance metric is the total measure of how far an athlete may have run during a session and is usually measured in kilometres (STATSports Sonra, Newry, NIR). Total distance in match play is a measure to understand the locomotion demands for rugby (Cummins et al., 2013). This basic measure is analysed using GPS. However, this workload metric alone cannot measure the subtleties within this accumulated distance (e.g. accelerations, decelerations, speed zones), but it does allow for analysis regarding positional movement demands for players (Cummins et al., 2013).

1.3.2. Speed Zones (High-speed running)

High-speed running (HSR) is a commonly used threshold in rugby. HSR speed threshold has been adopted by many sports, as an indicative sign of monitoring performance. Clarke et al. (2015) describe HSR as not based on physiological measures but an indicative sign that players have reached their "high intensity" threshold in running. GPS commonly uses this metric to utilise what speed "zone" the player is in, in real-time. Speed "zones" signify what range of sprint effort a player may be in. These speeds may be between 1.0 m/s to 8.0 m/s. Zone 1 and Zone 6 represent the slowest and highest speeds respectively (Cummins et al., 2013). However, with many conflicting studies, it is challenging to comprehend what speed zone definitions are true across different studies. In terms of this study, predetermined speed zones provided by the chosen GPS provider "STATSports" have been adopted (STATSports Sonra, Newry, NIR).

1.3.3. Sprint Metabolic Zone

Sprint Metabolic Zone (SPMETS) is an intensive metric designed to analyse metabolic load that exceeds 50 W/kg by measuring the distance that is covered during match play (Koper, 2024). The speeds that output achieving such high metabolic power are speeds of >10.6m/s and accelerations of >3m/s^2 when starting from 0 m/s. STATSports GPS settings (STATSports Sonra, Newry, NIR) have specifically designed a threshold value for this zone due to the high magnitude of effort. However, due to the high magnitude of effort that is derived from this zone, only a small number of players will be able to reach this effort during a match. This

metric will only accumulate through intense accelerations and decelerations due to the high-speed requirement, as this effort cannot be continued for a great period (Koper, 2024).

1.3.4. Acceleration and Deceleration

During a match, rugby requires players to perform accelerations and decelerations of + 2 m/s/s and – 2 m/s/s respectively (STATSports Sonra, Newry, NIR). As intensive metrics, frequent movements have a high demanding metabolic cost and mechanical load on players (Harper et al., 2019). Harper et al. (2019) argue that these highly demanding movements like decelerations cause high force impact peaks and loading rates, which can subsequently lead to soft tissue injuries. As such highly demanding movements, elite rugby players have been shown to have a superior ability to maintain these movements at a higher frequency and magnitude compared to standard players (Harper et al., 2019; Duthie et al., 2006). The importance of monitoring the intensity and frequency of these movements is vital to understand the physical workload in rugby (Koper, 2024).

1.3.5. High Metabolic Load Distance

The energy cost that is associated with the intermittent nature of rugby offers insight into the physical workload analysis when performing movements (Young et al., 2020; Koper, 2024). Metabolic power is related to energy cost. This can be calculated once speed and acceleration are known (Gaudino et al., 2013). As an intensive metric, the metabolic power that 25.5 W/kg or higher, will show a high metabolic load distance (HMLD) when a player is at a traveling speed (Koper, 2024).

1.3.6. Dynamic stress load

The impacts and forces that are experienced during a match or training are enforced through ground contact and are reported as mechanical stress (Young & Coratella, 2021). Dynamic stress loads (DSL) are the weighted impacts above 2G measured from the accelerometer in the GPS (Vanrenterghem et al., 2017). DSL is a workload metric that encapsulates the mechanical stress that accumulates from a player through an accelerometer device (Beato et al., 2019). This metric is widely used and enables practitioners to measure fatigue during intermittent exercise, which is highly valuable among rugby and other team sports (Beato et

al., 2019; Koper, 2024). This is highly important when an athlete gets fatigued while playing (or training) the foot impacts and forces that are placed through the ground become heavier, causing an increase in DSL (STATSports Sonra, Newry, NIR).

1.3.7. Contact Metrics

Contact situations that are experienced during match play are executed by players. These contact events are executed with skill and precision. World Rugby has established a contact load guide that identified four pivotal aspects of contact training (World Rugby, 2019; World Rugby, 2021). These aspects of contact training are intensity (measuring the force applied in contact), density (evaluating the frequency of impacts), unpredictability (assessing the degree of control or predictability in contact situations), and volume (quantifying the amount of contact during a session) (World Rugby, 2021; Koper 2024).

Analysing these guidelines, contact metrics were classified on the amount of perceived work required for each contact event. Chittenden's (2023) modification of the Borg RPE's scale analysing the rating of perceived contact load, categorised contacts into three distinct categories; minimal, hard, and maximal (see Table 1). Chittenden's (2023) study used a player to rate their contacts during a match using the rating of perceived contact scale. There were large discrepancies between the player and the analyst who was assigned contact ratings. This shows the visual interpretation may not accurately quantify the intensity of the contacts. Chittenden (2023) utilised these discrepancies and developed contact classifications for researchers to use.

1.4. Methods of measuring physical demands in rugby matches

1.4.1. Fixed time methodology

The fixed-time methodology involves splitting the match into set epochs, such as eight-to-ten-minute epochs or segments during a full eighty-minute match. The fixed-time methodology has been utilised in examining workload and intensity over fixed periods (Jones et al. 2015). This also includes rest periods of play and ball out of play (BOP), which are not

entirely representative of actual match intensity, therefore many practitioners chose not to utilise this type of technology.

Cunningham et al. (2018) investigated two different methods for analysing peak running intensities during international rugby matches using the fixed-time methodology. The findings from Cunningham et al. (2018) concluded that the fixed-time methodology underestimated both the maximum distance covered and the high-speed running (HSR) distance of the epoch length when they split the team into their positional groups. This correlates with other literature exploring the concept. However, the study indicated that the fixed-time methodology was underestimated by 11-12%, which was consistent across all epoch durations used. The understanding of the intermittent nature of rugby workload is highly important to analyse, these peak intensities during match play are highly valuable to optimally prepare players for the demands of the match, because of how irregular the demands of rugby can be. However, fixed-time methodology lacks accuracy, as the often-unpredictable work-to-rest ratios can greatly vary during a match (Stevens, 2022).

1.4.2. Rolling epochs

Rolling epochs involve taking data from a set block of time (e.g. 5 minutes). The difference compared to a fixed-time methodology is that each interval block starts at a set interval, as opposed to when the previous interval block ended (Varley et al., 2012). The use of fixed and rolling epochs is to prepare players for the demands of the competitions and the intense period of play that cannot be determined by just analysing the average demands of a match. This is supported by Varley et al. (2012) who state that both the rolling epochs and the fixed-time methods demonstrated that the peak intensities seen in the rugby competition were a lot greater compared to the average demands reported from previous literature.

A study by Delaney et al. (2015) investigated the position and duration-specific running intensities from match-play analysis in rugby league competitions. This was achieved using a moving average method for analysing the prescription and monitoring of training. The investigation used a GPS to analyse the data across the season from 32 professional athletes. A rolling epochs method was used to obtain values that were calculated for 10 different

durations (1-10min) for each player across the entire match. The results of the study showed large differences between the 1- and 2-minute rolling epochs.

A similar study by Read et al. (2019) analysed the maximum running intensities during a rugby match. They used a rolling epoch methodology with a 0.1-second rolling mean for durations of 5 and 30 seconds, and 1, 2, 3, 4,5, and 10 minutes. Their investigation concluded that running intensities for consecutive durations decreased as the time for the epoch duration increased. The authors however acknowledge that this relationship may be due to the major differences between forwards and backs at all time durations. The correlation contributes to the findings of Delaney et al. (2015) and shows the relationship between the positional differences regarding the rolling and fixed epochs.

However, due to the nature of rugby and its infrequent bouts of play, the rolling epochs have become more favorable. This is due to the limitations of the fixed-time analysis analysing workload demands. The fixed-time analysis is subjected to periods of ball-in-play (BIP) with large durations of time and intensity levels, which overall cannot accurately quantify the whole match intensity (Jones et al. 2015).

1.4.3. Ball-in-play methodology

While both rolling epochs and fixed-time methodology analysis have been shown to provide a better understanding of the intermittent nature of rugby workload demands, both methods still lack accuracy. This is because the nature of the fixed-time intervals can vary greatly from game to game, as the most intense periods of match play may not fall within those set bouts of play. Therefore, an alternative method is BIP, which can be described as the duration of play continuing before the ball departs the pitch, or the referee discontinues the play (Pollard et al., 2018). Alternatively, BOP can be best described as when the referee blows the whistle due to an infringement or the ball has gone out of play.

Pollard et al. (2018) discusses the mean and maximal demands for BIP periods for international rugby compared to analysing whole match demands. The findings showed that both mean and maximal BIP demands for high metabolic load distance (HMLD) and high-

speed running (HSR) for backs were greater than forwards. However, forwards execute a greater number of collisions. The findings support the role of what forwards do within a match, which is to challenge for the ball. Pollard et al. (2018) reinforced how using BIP analysis can provide practitioners with an accurate interpretation of the movement and collision demands that happen within a match.

1.4.4. Positional differences

An important factor to consider is that the workload demands greatly vary between positions (Owen et al., 2015). As described by Quarrie et al. (2011), being able to compare positional roles to endorse effective grouping of players for coaching or selection purposes is a vital part in finding a successful team. Expanding on this point, the information regarding the requirements for positions also aids in assisting playing assessment during matches.

Positional differences vary within the game of rugby. Forwards typically cover more distance and have key responsibilities in the team's overall performance by influencing plays to score tries and conversions. However, they also have a defensive requirement to keep the ball out of their area and defend the ground they cover. All backs have unique attributes that contribute to their performance some of these include speed, awareness of the play, reaction time and strategic play makers. Due to positional demands, backs have more space to move compared to the forwards who are condensed with a lot of contact. Forwards provide a strong foundation for attacks in defensive dominance on the pitch. Thus, forwards require more brute strength and size to dominate in scrums, lineouts, and mauls.

The positions within the forwards demand more engagement with contact because of greater isometric movements and strain when engaging in scrummaging and mauling (Duthie et al., 2003). Forwards perform more frequent work activities for longer durations of time, whereas backs support the play and perform more high intensity bursts of movement. These findings were reinforced by those of Austin et al. (2013), whose study showed how backs cover 42% greater distance with a higher intensity of running when compared to the forwards. The high intensity bursts can happen due to the greater proximity to the opposition; backs are able to reach their maximal speed due to having greater spatial movement. Another study by Suarez-

Arrones et al. (2014) described the total physical demands encountered by rugby players and analysed if there were differences between the two positional groups, forwards, and backs. These findings were supported by the findings of Duthie et al. (2003) and Austin et al. (2013) that indicate that backs cover more total distance at a speed greater than 14.0 km/h and >20km/h than the forwards. However, the forwards were involved in a higher number of scrums and tackles than the backs.

Quarrie et al. (2011) did a cluster analysis gaining insight into the differences existing between various positional roles. A large sample size using players from international rugby matches to provide a comprehensive breakdown of the differences between the positional groups. Quarrie et al. (2011) reconfirmed the findings from the previous literature discussed above, indicating that the primary role of the forwards is to contest possession in scrums, lineouts, rucks, and tackles. Whereas backs use the possession to gain territory and score tries. Thus, forwards had greater involvement in contact events than the backs. Forwards were involved in over three and half minutes per match in, rucks, mauls, and scrums. Forwards were also involved in twenty-five scrums per match; however, previous studies have shown that the forces and physical demands during scrums varies among the forwards. Additionally, the movement patterns of the front row showed they tended to cover less distance and at lower speeds. The reasoning may be the forwards exerting themselves in the heavy static loads of the scrums and mauls, causing fatigue.

While these supporting studies are developed on forwards and backs positional data, it should be noted that the data can vary greatly depending on what players are filling the positions. Specifically, positions have certain demands, and the data retrieved from a post-match game can vary greatly depending on the physical fitness of the player within that position which is analysed during the progression of the game. For that reason, real time GPS technology has been significantly important in analysing players, positional locomotive demands and to track the match-play demands. Assisting in distinguishing whether training is giving players the physical capacity to perform for longer durations of time during match play without any decrease in performance. Furthermore, the diverse range of physical characteristics and attributes players possess exemplifies the demands of each playing position and performance differences seen within rugby. A study by Alexander et al. (2020) explains how the

characteristics, such as body mass and levels of body fat affect playing performance, and naturally leaner athletic body type would be in the back row, and muscular size for a forward would influence their playing performance in the front row.

The differences in the workload generated between forwards and backs have been well documented from the current studies available. Various studies highlight why certain positions have an increased workload rate compared to other playing positions within the team. This demonstrates why it is important to study positional differences and how to successfully condition players to meet those differing needs.

1.5. Sex Differences in Rugby Union

1.5.1. Male Rugby Union players:

Male rugby players have been well-documented over the years. The important characteristics players require have been an influencing factor for coaches and conditioning staff in picking teams and academies. However, male rugby players possess varying levels of physical capabilities and characteristics that contribute to their overall match outcomes. Physical characteristics such as height, body mass, skinfold results, and body composition such as lean mass, fat mass, and bone mass are all important variables for contributing to the success of an elite male rugby player (Posthumus et al., 2020). These physical characteristics influence the male players' capabilities on the field and their performance. Previous literature has suggested that having larger players, particularly heavier forwards and taller backs, generally leads to greater success in international matches.

Starling et al. (2023) undertook a global survey on current professional match training practices to better understand how players engage in contact. The review of the data led to the development of contact load guidelines. The contact load guidelines have influenced coaches and practitioners to manage contact load during the in-season (Starling et al. 2023). However, there were limitations to this research as the study only took data from the in-season period and did not cover the preseason, of which the requirements of contact load are likely to differentiate. Overall, the research found that objective data is necessary to measure the elements of contact and wearable devices, such as instrumented mouthguards. This is to aid in the information regarding contact workload and head acceleration exposure of contact training activities.

Furthermore, previous studies have also provided a perspective on match characteristics in male rugby with comparisons through age and playing standards. Till et al. (2023) highlighted information on collision and non-collision match characteristics. The large-scale study, which compared both male amateur and elite playing standards from different rugby nations, demonstrated that the development of age and playing standards differentiated. The frequency of scrums and tries is lower at an elite playing level but had greater BIP time. The

limitations of the analysis required further research to understand the relationships between match events and health considerations across all age and playing levels. The analysis also failed to incorporate playing positions which as previously stated, may impact the collision and non-collision match activity.

An influential factor is the financial advantages for countries that can host tournaments and what professionalism for male rugby players means in terms of large sponsorship deals and contracts (Kuchar & Martin, 2016). For instance, in October 2020, World Rugby (World Rugby, 2020) reported the benefits to the countries fortunate to gain the hosting rights for the men's Rugby World Cup. The report revealed that hosting a male Rugby World Cup produced £2.9 billion in total economic impact, enabling a positive impact for male rugby in the host country.

The depth of research has aided in the development of the male rugby game across all ages and playing levels. There is sufficient research to help aid practitioners in guiding their players to success.

1.5.2. Female Rugby Union players

Professionalism was only introduced to female rugby in 2017, with many nations supporting part and full-time training contracts (Woodhouse et al., 2022). Progression and development in female rugby have significantly contributed to the increased opportunities now available to female athletes in sport, resulting in greater participation at the professional level. However, inequalities remain within the sport, particularly regarding participation, motives, funding, and uniforms (Dane et al., 2022). The limitations can be attributed to the late growth of the sport. Woodhouse et al. (2022) state that the female game is less mature in its professional status, and player information is researched less. An outcome of this is male performance threshold standards are used as baseline metrics for female performance.

Dane et al. (2022) undertook a qualitative study of female rugby experiences to understand the views of the psychosocial determinants that influence skill development. The background

and context of the participant's involvement in rugby are integral to understanding the growth of female rugby and the challenges female athletes continue to face. The evidence shows that the first encounters of an 'organised' sport at an international level, unlike the usual academies and clear pathways from other sports or the structured development systems seen in male rugby. Because there are fewer opportunities and less support for female rugby players, they have fewer chances to develop their skills and advance in their careers. As a result, the skill levels within premier teams can vary widely, reflecting the lack of development and experience among players when compared with male premier teams. The participants in Dane et al. (2022) study described the inequalities that remain within female rugby, access to facilities, hand-me-down male uniform, quality in coaching, and support from wider staff. These examples further exemplify the challenges female rugby players still face within the sport (Dane et al., 2022).

Additionally, as mentioned above, research surrounding the female rugby game is limited, which means male performance standards are used as baseline metrics. For instance, a study by Nyman and Spriet (2022) investigated individualised speed thresholds to characterise the external demands of female rugby. High-speed running (HSR) metrics from existing male rugby research represent HSR values of 5.0 m/s. However, Nyman and Spriet (2022) reported in their study, that 65% of athletes had estimated HSR thresholds below these values. This discrepancy arises because male HSR do not accurately represent female performance. Nyman and Spriet (2022) highlight the need for more research on female athletes to provide practitioners with accurate threshold baselines, as current data is limited and does not fully represent female performance.

While the female game has grown in popularity over the years, the growth has received little regarding published studies analysing the physical and genetic capabilities of females in rugby. Lewis et al. (1986) found females typically have less hemoglobin than their male counterparts resulting in a relatively lower VO2max, in turn reducing relative intensive endurance capacity. This impacts overall rugby fitness and performance on the field, which disadvantages females. Furthermore, Dane et al. (2023) describes how evidence-based coaching frameworks such as tackling are likely based on research in men's rugby. As discussed previously, these frameworks may not accurately represent or be applicable to

female players performance in skills like tackling. Additionally, the assumption that female players train in environments like their male counterparts and already possess these skills places them at a disadvantage. As the female game evolves, relying on outdated or inaccurate frameworks can impact both player safety and overall performance. Dane et al. (2023) underscores the need for more updated frameworks that cater to the unique needs of female rugby players, emphasising the importance of establishing appropriate training targets and performance metrics for women in the sport.

1.5.3. Differences between Male and Female Rugby Union players

When analysing the differences between male and female rugby players, research clearly indicates that genetic characteristics do exist (Lewis et al., 1986). Historically, male rugby has been around for a lot longer compared to females. Therefore, it essentially meant the development of the game has progressed a lot faster. As of recently, the growth in popularity of the female game has generated more interest nationally and internationally. Participation levels have grown from youth development to senior level, there has been progress creating a clearer pathway for females into an international team.

The physical characteristics of rugby players differ. Hene et al. (2013) described that elite female rugby have reviewed anthropometric and physical performance characteristics. However, limitations were evident in this study as participants were subjected to a single fitness test to review fitness pre-season, mid-season, and postseason. The study concluded that no significant changes were made in the skinfold thickness, explosive leg power, upper body muscular strength and aerobic fitness within forwards and backs between pre- and mid-season. Hene et al. (2013) implied that the conditioning program for the players was inadequate as the players did not adapt accordingly. The study suggested that the strength and conditioning coaches should be more directly involved to improve physical conditioning, like the training structure of the male players.

It is well established that female and male rugby players have differences in their genetic characteristics (Lewis et al., 1986; Kelly et al., 2024). Genetic differences do contribute to the way players exert themselves on the field, how they approach conditioning and develop

muscle mass. Naturally, males tend to carry greater levels of testosterone (Turner et al., 2018). This affects bone density and how much muscle mass males will carry and contributes to performance. Male rugby players body types are typically broad, and heavier compared to females. However, Posthumus et al. (2020) analyses the physical characteristics of elite female rugby players and found that the differences in anthropometrics and body compositions between forwards and backs were similar for both male and female players. Despite this, Posthumus et al. (2020) reiterate the importances of understanding that females have hormone differences compared to males, especially through female's menstrual cycles. Limited research is available on the effects of measuring hormones through the adaptation of rugby training, which further implies future research is needed to understand the importance of the links between the two.

Analysis of the existing literature indicates that, while some research into female rugby exists, it remains limited in depth. Future research is needed to understand the full complexities of the game from a female perspective to further the development of effective conditioning strategies for female players.

1.6. Conclusion

Overall, rugby is an intermittent high intensity sport characterised by intensive running, contact and a diverse range of plays throughout the match, demanding a high level of physical and tactical skill from players. The important measures of performance are grouped into various key performance indicators (KPI) metrics, which are determined by GPS, accelerometer and Sportscode metrics. These KPI metrics can often include distance, contacts, DSL, HMLD, acceleration, deceleration and SPMETS. Due to the intermittent nature of rugby, analysis of workload is best determined within the BIP periods in a match rather than EPOCH measures, as this best represents the organic workloads in rugby. As GPS and accelerometers are not yet able to quantify contact metrics, that often involve isometric movements, it can only be measured via video coding of the perceived intensity of contact events. The development of the female game has highlighted a significant gap concerning female match and training standards for the various KPI metrics, which are often still based on their male counterparts. Conducting more research on relevant metrics and training

standards specific to female players should enhance performance and better prepare them for match demands.

Chapter 2: Workload Demands during Ball-in-Play Periods: A Comparative Study of Locomotive and Contact Metrics in Professional Male and Female Rugby Union Players.

2.1. Introduction

Rugby is a high intensity on field collision sport. It requires an individual to possess a high level of skill for success within a team. Research into female rugby has grown rapidly, as the sport has gained popularity among women, though it still lags the extensive documentation available for male rugby.

Both female and male players navigate the complexities of the sport including collisions between players, isometric movements such as scrummaging, mauling and rucks, higher intensity movements, such as accelerations and sprinting, and lower intensity movements, such as walking and jogging (Owen et al., 2015; Posthumus et al., 2020). The intensities of these movements can vary depending on the demands of the match. The match is divided into two halves, consisting of forty minutes per half (Duthie, Pyne, & Hooper, 2003a). A required starting 15 players will be on the field, these include eight forwards (numbers 1-8) and seven backs (numbers 9-15). The players will be rotated with the remaining 8 reserves on the bench, these players will be substituted onto the pitch when needed.

As a contact sport, rugby is composed of high-intensity efforts that vary from short to long with the potential to also include change of direction, collisions between players, and lower-intensity movement such as walking or jogging (Owen et al., 2015; Posthumus et al., 2020). The intensities of these movements can vary depending on the match demands. It is important to understand the complexities of rugby and how technologies for analysing physical workload demands can be used effectively and efficiently to enable coaching staff to support and condition players to reach peak physical performance. Previous literature has identified how these workload demands occur in a game and how intense they are, but there remains a need to improve accuracy in these assessments.

Previous literature has shown that the physical demands of rugby have increased over the years, requiring coaches to meet the progressions of the sport with new and innovative ideas to utilise technology when analysing match play. Studies analysing match play have investigated various devices such as time-motion analysis (Deutsch et al., 2007). However, time motion analysis does have limitations. As discussed in Section 1.1.2, the device is unable to utilise how plays during rugby involve dynamic movement patterns and already thought-out tactics and skills to execute these movements. Similarly, numerous studies have analysed GPS and have confirmed the device to be highly valuable for providing live feedback and data (Johnston et al., 2012). However, studies have also shown a variety of results regarding the validity and reliability of the device (Scott et al., 2016). Despite the technological advancements, there are still issues with the device and how it functions. While GPS will still be perceived differently between rugby clubs in terms of effectiveness, the device has proven to be an important tool in analysing workload measures.

Locomotive demands in rugby are highly valuable metrics in rugby for assessing the overall physical load of an individual during training or match play. However, it is noted that research to evaluate this type of rugby demand is still limited for female rugby (Sheepy et al., 2019). The use of GPS has been a well-utilised method for quantifying locomotive workload, which is often categorised into safety zones for players. However, a large amount of non-locomotive workload happens within a rugby match. Non-locomotive metrics are critical components of a match and are often referred to as 'intense static activity' (Duthie et al., 2003). GPS and time-motion analysis have not yet been able to quantify this type of static activity that occurs within a match. While time-motion analysis has previously been used to address contact demands that happen within a rugby match, the approach presents limitations in understanding the demands of contact events. These technologies can only provide information to identify fatigued players and workload on the rugby field. More nuanced data is required to fully understand player performance across all facets of gameplay and optimise training strategies.

As alluded to above, the constant documentation on male rugby players for understanding the game further is very apparent (Starling et al., 2023). The depth of knowledge of male playing capabilities and physical characteristics has influenced coaches and conditioning staff for

training strategies and recommendations (Posthumus et al., 2020; Till et al., 2023). Professional rugby for females was introduced in 2017, marking the beginning of its development as a professional sport. Therefore, the development of the game has been progressing since when it was established as a professional sport. Since then, the game has progressed but remains significantly behind male rugby, which has a much longer history and established infrastructure. This is illustrated as existing literature relating to female rugby utilises continual comparisons to the male game because of the lack of research into female rugby. Therefore, males' performance standards are used as baseline metrics for female athletes (Woodhouse et al., 2022). The limitations this creates for women's rugby are apparent, as males and females differ physically, genetically and hormonally. Thus, using men's data is not a true representation of what female workload measures would be. Further research is required to develop a greater understanding of workload measures during a female rugby match metrics during different types of play.

Therefore, this study aims to compare BIP periods during a match by evaluating the selected GPS locomotive measures and quantifying Sportscode (contact) metrics, comparing these chosen locomotive metrics for male and female professional rugby.

2.2. Methods

2.2.1. Participants

During this study GPS and Sportscode data were collected from 60 professional male and female rugby players from two professional New Zealand National Provincial Rugby teams. Ethics approval (#41 see Appendix B) was granted by the Waikato University Ethics Committee on the 4th of August 2023 and all participants signed the required ethics documentation before participating in this study. Participants were provided with information outlining the intention for the study, procedures, and potential applications that would take place during the study. All participants signed informed consent forms before the commencement of this study. Throughout the given time of this study, all participants were in full-time training and were deemed healthy individuals. Additionally, all participants were

familiarised with the data collection procedures before commencement. Participants were very familiar with the process of wearing GPS devices and having matches and training filmed as part of their regular training routine. Participants were not required to make changes to their regular competition and training for the duration of the study. Participants were grouped into the following positions for each male and female team: Forwards (props, hooker, second row, loose forwards) and backs (midfield backs, inside backs, and outside backs).

2.2.2. Procedures

During the 2023 National Provincial Rugby season, data collection was recorded across eight in-season games. All participants wore GPS units (Apex Pro Pod, STATSport, Newry, NIR) which collected data at a sampling frequency of 10 Hz (Stevens, 2022; Koper, 2024; Haakma, 2021). Before the pre-match warm-up, GPS units were activated as per the guidelines between 30-50 minutes before kick-off. Devices were then placed in a firm-fitting custom-made pocket situated between the scapulae on the back of the participant. The custom-made pockets on the playing shirts are designed to fit the GPS units as close as possible to the participant's body to minimise the chance of accidental unit movement or getting knocked out of the shirt pocket (Stevens, 2022; Koper, 2024; Haakma, 2021). Each participant used the same GPS unit for each match. This was to minimise the inter-unit variability between players. When the match concluded, all GPS units were collected and switched off. The GPS units were placed into a 16-point charging case which downloaded the GPS data files for each participant onto a computer using STATSports Sonra software (STATSports Sonra, Newry, NIR). The match was filmed using cameras from numerous angles and the footage was received from the television provider for the match or manually from team game footage (Stevens, 2022; Koper, 2024; Haakma, 2021). When this footage was gathered, the video was loaded into the Sportscode video analysis software package (Sportscode 12.4.3, Sportstec, Australia). Within the Sportscode contact timeline, timestamps were then created for the start and end of specified events. These events were as follows: Ball out of play (BOP), Ball in play (BIP) and contacts instances.

These contact events were manually coded using criteria that were set in Appendix A. The contact events were coded using a procedure developed and validated by Chittenden (2023).

This procedure has been utilised in subsequent research on match contact load in male super rugby players (Stevens et al., 2022). The full-match MP4 video file was imported into STATSports Sonra software alongside the corresponding GPS data for each given match. The video was aligned to the GPS data by adjusting the start time. This was done by opening the full match video in STATSports Sonra software and the match was played. To find the correct 'sync' time, the video is needed to match up correctly. Therefore, it is critical to search for a peak in the velocity value and corresponding peak with the player. Normally, this is represented within the first 2 minutes of when the match starts.

The timeline of the Sportscode BIP and BOP instances was imported into STATSports Sonra software as tags. The starting 15 of matches were selected under the BIP tag, the match video was opened and played. When the alignment is correct, the starting 15 players from the session group were selected, as were all BIP instances. When all are selected, the BIP label will highlight grey indicating the import of the tags can successfully occur. Drills were labelled in sequence (BIP01, BIP02, BIP03 etc.) for the entire match. GPS data was then exported as a CSV file, selecting only the corresponding BIP drills. The locomotion metrics selected for the analysis were as follows: Total distance (distance), session time, contact, high-metabolic load distance (HMLD), acceleration count (accelerations), deceleration count (decelerations), sprint-metabolic load distance (SPMET), and dynamic stress load (DSL). The metric zone analysis was done as per the methods used in STATSports Sonra software (STATSports Sonra, Newry, NIR).

The contact events were manually coded in the Sportscode software. Criteria are shown in Appendix A. The following categories of these events based on Chittenden (2023), are as follows: attack order or arrival, defence order of arrival, hit up, tackle, offensive line out, defensive lineout, maul offence, maul defence, scrum offence and scrum defence. These instances were rated one of three efforts, which referred to a weighting value of 1, 3 or 5. The weighting values were based on the 5-point scale utilised by Chittenden (2023) study (see Table 1).

Table 1. Table 1.2 from Chittenden (2023) refers to the 5-point scale weightings and different magnitudes of the workloads for each contact metric.

Contact Metric	5-point scale	10-point RPE
Attack Order of Arrival, Min	1, Minimum	2, Minimum
Attack Order of Arrival, Hard	3, Hard	6, Hard
Defence Order of Arrival, Min	1, Minimum	2, Minimum
Defence Order of Arrival, Hard	3, Hard	6, Hard
Hit Up, Min	1, Minimum	2, Minimum
Hit Up, Hard	3, Hard	6, Hard
Tackle, Min	1, Minimum	2, Minimum
Tackle, Hard	3, Hard	6, Hard
Offensive Lineout, Min	1, Minimum	2, Minimum
Offensive Lineout, Hard	3, Hard	6, Hard
Defensive Lineout, Min	1, Minimum	2, Minimum
Defensive Lineout, Hard	3, Hard	6, Hard
Maul Offence, Hard	3, Hard	6, Hard
Maul Offence, Max	5, Maximum	10, Maximum
Maul Defence, Hard	3, Hard	6, Hard
Maul Defence, Max	5, Maximum	10, Maximum
Scrum Offence, Hard	3, Hard	6, Hard
Scrum Offence, Max	5, Maximum	10, Maximum
Scrum Defence, Hard	3, Hard	6, Hard
Scrum Defence, Max	5, Maximum	10, Maximum

It is important to note however, the weighting values were selected as by-products of the Borg CR 10 RPE scale weightings and descriptors (William, 2017; Stevens, 2022; Chittenden, 2023). The events coded within Sportscode were a collection of the type of contact it displayed and the contact weighting, recorded as a weighted count. An example of this would be shown as “scrum, maximal”. The contact events were coded as two-second instances of when they occurred. The contact event timeline within Sportscode was exported as an XML file (Stevens, 2022; Haakma, 2021).

The GPS and contact data were combined with the use of Sportyweb sports analytic software (Sportyweb, version 1.0, Sportyweb Analytics). The GPS CSV files were imported according to the given week and opponent played. The contact XML file was imported separately into Sportyweb and labelled in the same way as the CSV, therefore the files can be combined successfully as the software uses the unique function to pair the files with the correct labelling upon import. The XML data was displayed on the unique function within Sportyweb which shows if the game BIPS and contacts were successfully combined. The successfully combined contact and BIP export was downloaded within Excel and a summarised pivot table was used to confirm the data was also successfully combined (Stevens, 2022; Haakma, 2021).

When using Sportyweb, it is important to note the contact Sportscode XML file that is generated from the contact tags does not have a clock time attached to the file. In this situation, the GPS data cannot be aligned. This is due to contact coding tags having no time attached to the coding and it will always start at 'zero time'. However, GPS events have a clock time associated with them due to the real-time of when these events occur. Therefore, the Sportscode contact XML game time (00:00) value will begin at the start of the original match footage (before the import into Sportyweb). Match footage as well, will always start before kick-off. To correctly align all aspects of the match, the first kick instance was the beginning of the match time (Stevens, 2022; Haakma, 2021). This means the contact Sportscode XML file had to be aligned accordingly, with the "dead time" removed. Aligning the contact Sportscode XML to the GPS CSV, the first kick instance start time in the XML file was subtracted from the original clock time of the GPS CSV file. Thus, the XML file corresponded to the true clock time for the match. Before importing into Sportyweb, the correct value was entered into the XML file to align both the GPS data and contact coding (Stevens, 2022; Haakma, 2021).

Once both the data sets were aligned accordingly, a summary CSV file was extracted from Sportyweb. This provided the contact and GPS metrics and contact and GPS metric values for each player (Stevens, 2022; Haakma, 2021). Added data, such as positions and sub-positions were manually added into the summary CSV file.

2.2.3. Data analysis

The challenge of recruiting a male and female professional rugby team in the same region (to enable the accurate collection of the complex data), who were playing in competitions of a similar level and over the same relative time of the season limited the amount of data collected. The resulting four male and four female matches reduced the statistical power which precluded complex statistical analysis. Therefore, the decision was made to determine the differences between the male and female data for contact, distance, dynamic stress load (DSL), high metabolic load distance (HMLD), decelerations, acceleration, and sprint-metabolic load distance metrics (SPMET). The metrics were analysed as averages or metrics per minute. Differences for each metric between males and females for the whole team, forwards, backs, and for each sub-position group were also examined. The player metrics analysis used four sub-positional groups. These were defined as tight forwards (front row and locks), loose forwards (flankers and number 8), inside backs (halfback, first and second five), and outside backs (remaining positions).

Preliminary analysis showed that the different physical capacities of the male and female players could result in unequal variances. Therefore, the probability of no significant difference versus a significant difference, for each metric between males and females for the whole team and by position/sub-positional group was derived using Welch's t-test with the level of significance set at $P < 0.05$. The standardised differences were also determined for each measure and the effect size was calculated using Cohen's d and the data was analysed and interpreted using the methods described in Hopkins (2009, 2017). The magnitude of the effect sizes was defined from Cohen's d as trivial (<0.2) small (0.2-0.6), moderate (0.6-1.2), and large (1.2), and very large (2-4). These same magnitudes applied to negative Cohen's d values.

Tests for equality of variances, normality, and the examination for outliers were conducted in IBM SPSS Statistics (Version 27). This study utilised Levene's test for equality of variances. Observations with unusually high or low values were examined as possible errors and further detection of possible outliers was examined via boxplot analysis and extreme z-scores (i.e., ±3.29). Normality testing was conducted by visual inspection of the Q-Q plots, the Shapiro Wilk-Test, and tests for skew and kurtosis. For metrics that did not meet the normality

assumptions, the data was log-transformed (natural log + 1) for the calculation of both Welch's t statistic and the standardised differences and then back-transformed (Ln-1) for presentation in the relevant results tables and figures. The back-transformed data generated the geometric mean and the standard deviation was expressed as an ×/÷ factor which was calculated by taking the square root of the upper standard deviation divided by the lower standard deviation. The non-transformed data was expressed as mean ± standard deviation.

For metrics that were generally significantly different between males and females, plots of the average metric per minute value for males versus females, for various BIP interval bins were plotted. The length of each BIP interval bin was determined such that each bin consisted of roughly the same number of samples. However, to ensure a clearer visual presentation, the start time and end time of each interval bin were set as a multiple of five seconds. The study lacked the statistical power to analyse the difference in the metrics for all the BIP intervals.

2.3. Results

Table 2. Statistical difference between the genders for distance (m).

	DISTANCE METRIC					
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	1205 ± 676	3285 ± 2433	0.000	P<0.05	-1.075	Moderate
Loose Forward	2021 ± 724	3024 ± 2444	0.074	NS	-0.539	Small
FORWARDS	1484 ± 788	3210 ± 2415	0.000	P<0.05	-0.904	Moderate
Inside Back	2412 ± 791	4348 ± 3349	0.018	P<0.05	-0.795	Moderate
Outside Backs	2386 ± 696	5724 ± 3857	0.000	P<0.05	-1.204	Large
BACKS	2398 ± 730	5095 ± 3648	0.000	P<0.05	-1.025	Moderate
FULL TEAM	1922 ± 884	3968 ± 3096	0.000	P<0.05	-0.866	Moderate

Generic footnote for tables 2-16: When log is transformed for analysis, the values are back-transformed geometric mean ×/÷ standard deviation as a factor, otherwise values are mean ± standard deviation. NS is non-significant (P > 0.05). Magnitudes were determined from Cohen's d.

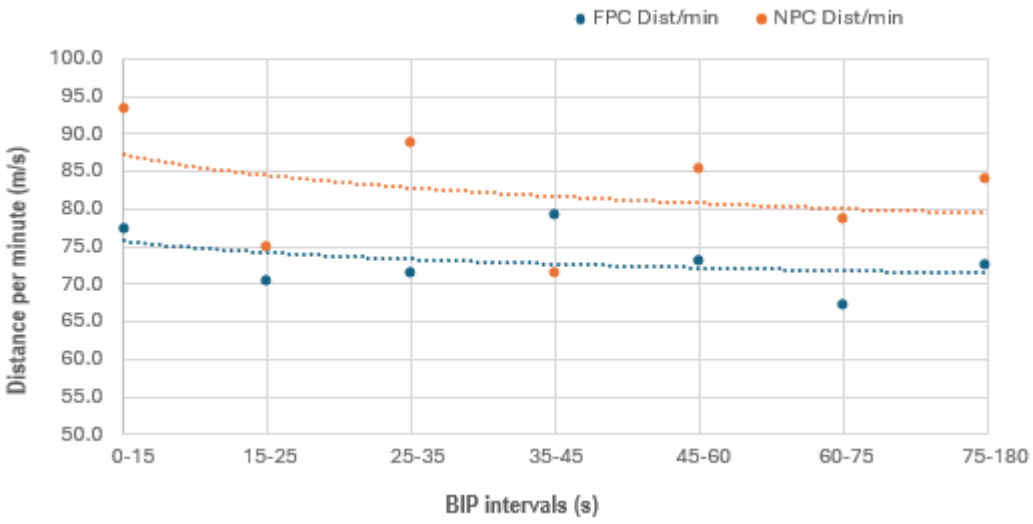
The distances covered by males were significantly greater than those of females, with a moderate to large magnitude of difference observed across all positions apart from the loose forwards (see Table 2).

Table 3. Statistical difference between the genders for distance per minute.

DISTANCE METRIC PER MINUTE						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	45 ×/÷ 2.1	57.6 ×/÷ 1.6	0.073	NS	-0.413	Small
Loose Forward	68.7 ×/÷ 1.4	56.4 ×/÷ 1.5	0.084	NS	0.532	Small
FORWARDS	52 ×/÷ 1.9	57.3 ×/÷1.6	0.220	NS	-0.175	Trivial
Inside Back	76.5 ×/÷ 1.5	70.6 ×/÷ 1.5	0.277	NS	0.211	Small
Outside Backs	72.3 ×/÷ 1.4	68.7 ×/÷ 1.6	0.351	NS	0.126	Trivial
BACKS	74.4 ×/÷ 1.4	69.5 ×/÷ 1.6	0.244	NS	0.166	Trivial
FULL TEAM	61.8 ×/÷ 1.7	61.9 ×/÷ 1.6	0.488	NS	-0.005	Trivial

The distance metric per minute results showed no significant difference between genders (see Table 3). The visual pattern of the differences across the BIP intervals shows that the males on average were usually higher than the females (see Figure 1).

Figure 1. Distance per minute for the various BIP intervals, for females (FPC) and males (NPC).



Generic footnote for Figures 1-4: Plots of the average metric per minute value for males versus females, for various BIP interval bins. The length of each BIP interval bin was determined such that each bin consisted of roughly the same number of samples. To ensure a clearer visual presentation, the start time and end time of each interval bin were set as a multiple of five seconds.

Table 4. Statistical difference between the genders for session time.

SESSION TIME METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	23.5 ± 10.2	22.7 ± 14.05	0.404	NS	0.061	Trivial
Loose Forward	32.2 ± 9.4	21.4 ± 14.1	0.013	P<0.05	0.897	Moderate
FORWARDS	26.7 ± 10.7	22.3 ± 13.9	0.052	NS	0.347	Small
Inside Back	26.5 ± 11.6	22.1 ± 13.6	0.182	NS	0.353	Small
Outside Backs	34.1 ± 8.2	26.5 ± 16.9	0.053	NS	0.584	Small
BACKS	30.4 ± 10.6	24.7 ± 15.5	0.045	P<0.05	0.447	Small
FULL TEAM	28.6 ± 10.7	23.2 ± 14.5	0.004	P<0.05	0.423	Small

The females overall (full team) had significantly greater session times than males. The magnitude of the difference was small to moderate for all loose forwards, backs and full teams (see Table 4).

Table 5. Statistical difference between the genders for HMLD.

HIGH METABOLIC LOAD DISTANCE METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	106.2 ± 79.7	556.5 ± 443.9	0.000	P<0.05	-1.296	Large
Loose Forward	336.3 ± 176.5	576.2 ± 479.3	0.044	P<0.05	-0.646	Moderate
FORWARDS	184.9 ± 162.7	562.2 ± 449.7	0.000	P<0.05	-1.053	Moderate
Inside Back	523.6 ± 258.5	986.1 ± 722.1	0.013	P<0.05	-0.853	Moderate
Outside Backs	482.2 ± 225.6	1391.8 ± 1021.4	0.001	P<0.05	-1.230	Large
BACKS	501.1 ± 238.5	1206.3 ± 907.9	0.000	P<0.05	-1.062	Moderate
FULL TEAM	336.5 ± 256.4	821.3 ± 739.5	0.000	P<0.05	-0.847	Moderate

The males HMLD were significantly greater than the females and the magnitude of the difference was moderately too large for all positions (see Table 5).

Table 6. Statistical difference between the genders for HMLD per minute.

HIGH METABOLIC LOAD DISTANCE PER MINUTE						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	4.2 ×/÷ 2	9.5 ×/÷ 1.7	0.000	P<0.05	-1.340	Large
Loose Forward	10 ×/÷ 1.5	10.7 ×/÷ 1.9	0.369	NS	-0.125	Trivial
FORWARDS	5.8 ×/÷ 2	9.8 ×/÷ 1.7	0.000	P<0.05	-0.819	Moderate
Inside Back	14.5 ×/÷ 1.6	18.9 ×/÷ 1.6	0.063	NS	-0.555	Moderate
Outside Backs	14.5 ×/÷ 1.9	16.8 ×/÷ 2.1	0.257	NS	-0.213	Small
BACKS	14.5 ×/÷ 1.7	17.7 ×/÷ 1.9	0.083	NS	-0.334	Small
FULL TEAM	9.2 ×/÷ 2.1	12.5 ×/÷ 1.9	0.005	P<0.05	-0.423	Small

The males HMLD per minute was significantly greater than for females and the magnitude of difference was moderate too large for all tight forwards, forwards and full team (see Table 6). The visual pattern for this metric across all the BIP intervals shows males were on average almost always greater than females (see Figure 2).

Figure 2. HMLD distance per minute for the various BIP intervals, for females (FPC) and males (NPC).

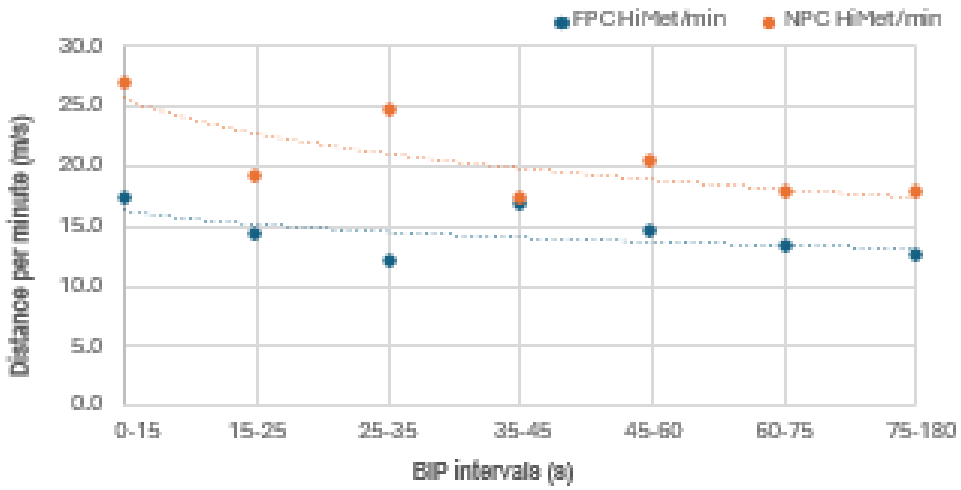


Table 7. Statistical difference between the genders for accelerations.

ACELERATIONS METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	6.5 ± 5.14	32.0 ± 29.1	0.000	P<0.05	-1.122	Moderate
Loose Forward	16.8 ± 10.9	39.3 ± 30.8	0.009	P<0.05	-0.940	Moderate
FORWARDS	10.0 ± 8.9	34.1 ± 29.5	0.000	P<0.05	-1.038	Moderate
Inside Back	21.8 ± 13.2	50.9 ± 39.8	0.006	P<0.05	-0.984	Moderate
Outside Backs	17.9 ± 10.7	60.5 ± 44.4	0.000	P<0.05	-1.318	Large
BACKS	19.7 ± 11.9	56.1 ± 42.1	0.000	P<0.05	-1.180	Moderate
FULL TEAM	14.6 ± 11.4	43.0 ± 36.5	0.000	P<0.05	-1.010	Moderate

The male accelerations were significantly greater than for females and the magnitude of difference was moderate too large (Table 7).

Table 8. Statistical difference between the genders for accelerations per minute.

ACELERATIONS METRIC PER MINUTE						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	0.5 ×/÷ 1.8	0.6 ×/÷ 1.6	0.185	NS	-0.262	Small
Loose Forward	0.5 ×/÷ 1.6	0.8 ×/÷ 1.7	0.033	P<0.05	-0.711	Moderate
FORWARDS	0.5 ×/÷ 1.8	0.6 ×/÷ 1.6	0.041	P<0.05	-0.388	Small
Inside Back	0.6 ×/÷ 1.6	0.9 ×/÷ 1.7	0.026	P<0.05	-0.719	Moderate
Outside Backs	0.6 ×/÷ 1.6	0.8 ×/÷ 1.6	0.014	P<0.05	-0.738	Moderate
BACKS	0.6 ×/÷ 1.6	0.9 ×/÷ 1.6	0.002	P<0.05	-0.734	Moderate
FULL TEAM	0.5 ×/÷ 1.7	0.7 ×/÷ 1.7	0.001	P<0.05	-0.494	Small

The male accelerations per minute were greater than females and the magnitude was small to moderate for all positions, apart from tight forwards which shows no significance between genders (Table 8).

Figure 4. Rest ratio in work to rest ratio assuming work value is 1, for females (FPC) and males (NPC).

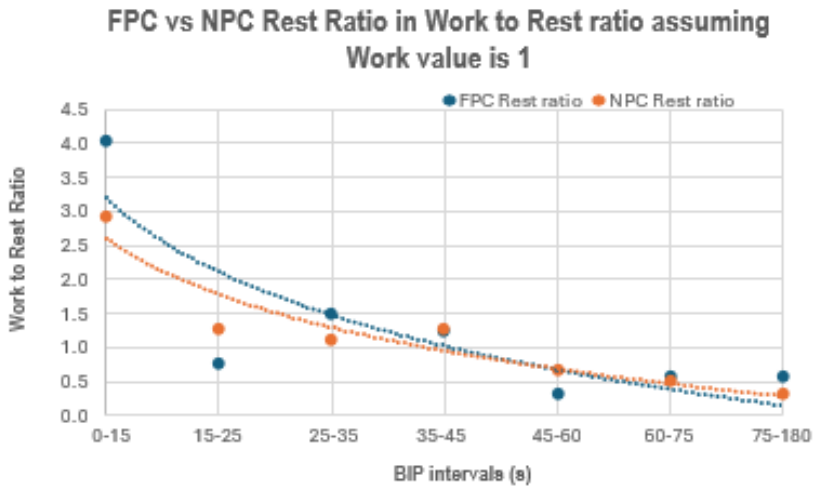
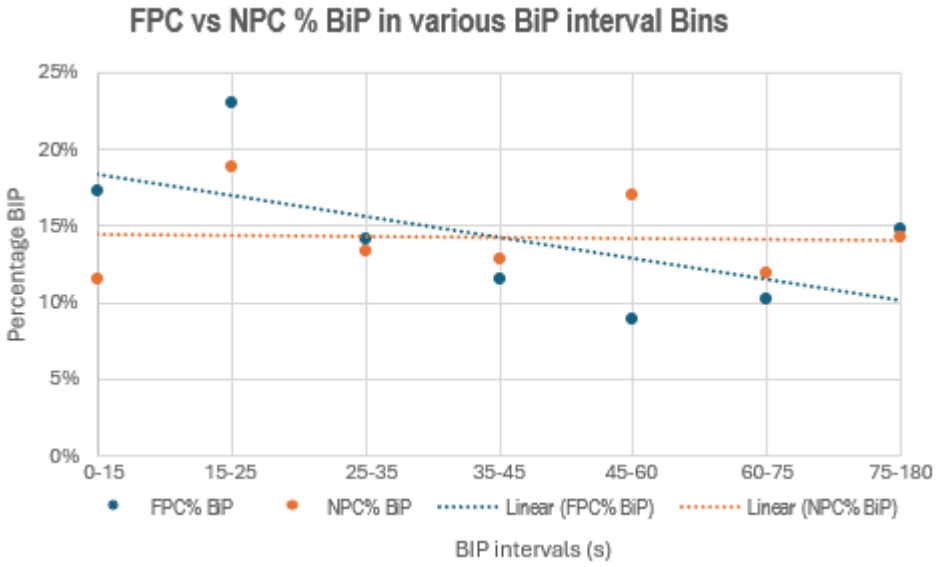


Figure 3. Percentages of BIP's in various BIP interval BINS, for females (FPC) and males (NPC).



The fitted curves in Figure 2 of the work to rest ratio shows a decrease in distance per minute with increasing BIP intervals. However, the average value for each BIP interval shows some anomalies that don't fit the curve, particularly with the men's data. Although it was intended for each BIP interval to include an equal number of BIP samples, correcting the BIP timeframes to the closest multiple of five seconds (for better visual reference) created some unequal distribution (see Figure 3).

Table 9. Statistical difference between the genders for contact.

CONTACT METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	75.2 ± 37.7	69.6 ± 43.1	0.318	NS	0.138	Trivial
Loose Forward	91.1 ± 46.1	76.5 ± 44.7	0.201	NS	0.321	Small
FORWARDS	82.0 ± 41.7	71.8 ± 43.2	0.151	NS	0.240	Small
Inside Back	41.8 ± 45.2	21.4 ± 20.2	0.108	NS	0.583	Small
Outside Backs	13.6 ± 8.5	21.1 ± 10.6	0.012	P<0.05	-0.777	Moderate
BACKS	23.0 ± 29.4	21.2 ± 14.3	0.381	NS	0.078	Trivial
FULL TEAM	54.8 ± 46.8	51.0 ± 42.4	0.311	NS	0.086	Trivial

The male contacts were greater than the females to a moderate magnitude for outside backs only. However, all other positions had no significant differences (see Table 9).

Table 10. Statistical differences between the genders for contact per minute.

CONTACT METRIC PER MINUTE						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	3.3 ×/÷ 1.8	1.5 ×/÷ 2	0.000	P<0.05	1.202	Large
Loose Forward	3.1 ×/÷ 2	2 ×/÷ 1.8	0.074	NS	0.629	Moderate
FORWARDS	3.2 ×/÷ 1.9	1.6 ×/÷ 1.9	0.000	P<0.05	1.006	Moderate
Inside Back	1.1 ×/÷ 2.7	0.8 ×/÷ 2.2	0.243	NS	0.322	Small
Outside Backs	0.5 ×/÷ 1.8	0.7 ×/÷ 1.8	0.046	P<0.05	-0.578	Small
BACKS	0.7 ×/÷ 2.4	0.7 ×/÷ 1.9	0.389	NS	-0.076	Trivial
FULL TEAM	1.6 ×/÷ 2.5	1.2 ×/÷ 2	0.044	P<0.05	0.327	Small

The female contacts per minute were significantly greater than the males and the magnitude of difference was small too large for all tight forwards, forwards and full team. The male's contacts per minute was greater than females for outside backs and had a small magnitude of difference (see Table 10).

Table 11. Statistical difference between the genders for dynamic stress load.

DYNAMIC STRESS LOAD METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	31.4 ×/÷ 2	148.5 ×/÷ 3.2	0.000	P<0.05	-1.514	Large
Loose Forward	69.9 ×/÷ 2	90 ×/÷ 2.5	0.196	NS	-0.312	Small
FORWARDS	41.9 ×/÷ 2.2	127 ×/÷ 3.1	0.000	P<0.05	-1.089	Moderate
Inside Back	69.8 ×/÷ 1.7	150 ×/÷ 3.7	0.019	P<0.05	-0.761	Moderate
Outside Backs	78.9 ×/÷ 1.6	185.4 ×/÷ 2.5	0.000	P<0.05	-1.171	Moderate
BACKS	74.3 ×/÷ 1.7	165.5 ×/÷ 3.1	0.000	P<0.05	-0.909	Moderate
FULL TEAM	55.6 ×/÷ 2.1	141.2 ×/÷ 3.1	0.000	P<0.05	-0.954	Moderate

The males dynamic stress load was greater than the females with a moderate to large magnitude of difference for all positions apart from the loose forwards (see Table 11).

Table 12. Statistical difference between the genders for dynamic stress load per minute.

DYNAMIC STRESS LOAD METRIC PER MINUTE						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	1.4 ×/÷ 1.8	3.6 ×/÷ 2	0.000	P<0.05	-1.232	Large
Loose Forward	2.1 ×/÷ 1.5	2.4 ×/÷ 1.7	0.267	NS	-0.233	Small
FORWARDS	1.7 ×/÷ 1.7	3.2 ×/÷ 2	0.000	P<0.05	-0.944	Moderate
Inside Back	2.2 ×/÷ 1.6	3.5 ×/÷ 1.6	0.011	P<0.05	-0.857	Moderate
Outside Backs	2.5 ×/÷ 1.7	2.8 ×/÷ 1.7	0.321	NS	-0.152	Trivial
BACKS	2.4 ×/÷ 1.7	3.1 ×/÷ 1.7	0.031	P<0.05	-0.452	Small
FULL TEAM	2 ×/÷ 1.7	3.1 ×/÷ 1.9	0.000	P<0.05	-0.715	Moderate

The males dynamic stress load per minute was greater than females and had small to large magnitudes of difference for all tight forwards, forwards, inside backs, backs and full team (see Table 12).

Table 13. Statistical difference between the genders for decelerations.

DECELERATIONS METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	8.7 ×/÷ 2.4	26.2 ×/÷ 2.7	0.000	P<0.05	-1.145	Moderate
Loose Forward	17.5 ×/÷ 2.3	24.7 ×/÷ 3.3	0.188	NS	-0.322	Small
FORWARDS	9 ×/÷ 2.5	23.2 ×/÷ 2.9	0.000	P<0.05	-0.879	Moderate
Inside Back	21.4 ×/÷ 2.2	38.6 ×/÷ 2.6	0.034	P<0.05	-0.663	Moderate
Outside Backs	22.8 ×/÷ 1.7	52.9 ×/÷ 2.6	0.001	P<0.05	-1.061	Moderate
BACKS	21 ×/÷ 1.9	41.2 ×/÷ 2.5	0.000	P<0.05	-0.648	Moderate
FULL TEAM	14 ×/÷ 2.4	29.2 ×/÷ 2.8	0.000	P<0.05	-0.704	Moderate

The male decelerations were greater than females and had a moderate magnitude of difference for all positions except for loose forwards (see Table 13).

Table 14. Statistical difference between the genders for decelerations per minute.

DECELERATIONS PER MINUTE METRIC						
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	0.5 ×/÷ 1.8	0.6 ×/÷ 1.6	0.037	P<0.05	-0.495	Small
Loose Forward	0.6 ×/÷ 1.7	0.8 ×/÷ 1.8	0.099	NS	-0.491	Small
FORWARDS	0.5 ×/÷ 1.8	0.7 ×/÷ 1.7	0.016	P<0.05	-0.468	Small
Inside Back	0.7 ×/÷ 1.7	1 ×/÷ 2.2	0.144	NS	-0.398	Small
Outside Backs	0.7 ×/÷ 1.6	0.9 ×/÷ 1.8	0.177	NS	-0.305	Small
BACKS	0.7 ×/÷ 1.7	0.9 ×/÷ 2	0.075	NS	-0.354	Small
FULL TEAM	0.6 ×/÷ 1.7	0.8 ×/÷ 1.8	0.012	P<0.05	-0.357	Small

The male decelerations per minute were greater than females and had a small magnitude of difference for tight forwards, all forwards and full team (see Table 14).

Table 15. Statistical difference between the genders for SPMET.

	SPMET METRIC					
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	8.4 ± 8.4	101.9 ± 89.9	0.000	P<0.05	-1.338	Large
Loose Forward	55.8 ± 41.1	144.5 ± 119.5	0.007	P<0.05	-0.963	Moderate
FORWARDS	24.6 ± 33.4	114.2 ± 100.1	0.000	P<0.05	-1.131	Moderate
Inside Back	83.9 ± 61.2	253.1 ± 201.9	0.002	P<0.05	-1.134	Moderate
Outside Backs	91.2 ± 60.4	428.2 ± 331.0	0.000	P<0.05	-1.416	Large
BACKS	87.9 ± 60.0	348.1 ± 289.5	0.000	P<0.05	-1.245	Large
FULL TEAM	54.9 ± 57.3	208.3 ± 228.9	0.000	P<0.05	-0.885	Moderate

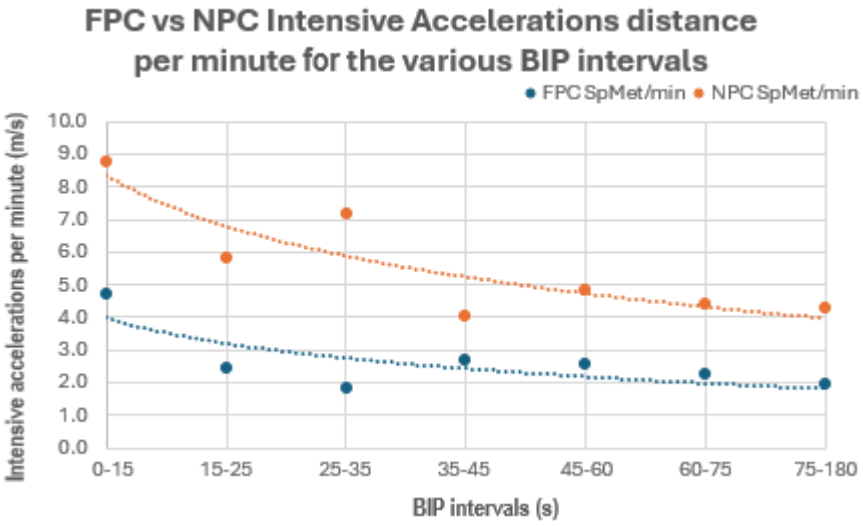
The males SPMET were greater than females and had a moderate to large magnitude of difference for all positions (see Table 15).

Table 16. Statistical difference between the genders for SPMET per minute.

	SPMET METRIC PER MINUTE					
	Women	Men		Significance	Standardised difference	Magnitude
	Average	Average	P value			
Tight Forward	0.6 ×/÷ 1.9	1.7 ×/÷ 1.9	0.000	P<0.05	-1.363	Large
Loose Forward	1.6 ×/÷ 2	2.8 ×/÷ 1.8	0.018	P<0.05	-0.837	Moderate
FORWARDS	0.9 ×/÷ 2.1	1.9 ×/÷ 1.9	0.000	P<0.05	-0.966	Moderate
Inside Back	2.3 ×/÷ 1.9	4.3 ×/÷ 1.4	0.002	P<0.05	-1.163	Moderate
Outside Backs	2.4 ×/÷ 1.8	5.2 ×/÷ 2.2	0.002	P<0.05	-1.016	Moderate
BACKS	2.4 ×/÷ 1.9	4.7 ×/÷ 1.9	0.000	P<0.05	-1.064	Moderate
FULL TEAM	1.5 ×/÷ 2.2	2.9 ×/÷ 2.1	0.000	P<0.05	-0.731	Moderate

The male SPMETs per minute were greater than females and had a moderate to large magnitude of difference for all positions (see Table 16). The visual pattern for this metric across all the BIP intervals shows males were on average always greater than females (see Figure 4).

Figure 4. Intensive accelerations distance per minute for the various BIP intervals, for females (FPC) and males (NPC).



2.4. Discussion

To our knowledge, this is the first study that has compared locomotion and contact workload demands in both female and male professional rugby 15's players at a similar level of competition during BIP periods. Therefore, it is difficult to compare the results of this study to others.

Interestingly, the distances covered by males were significantly greater than those by females by a large to moderate degree for inside backs, outside backs, and the full team for distance. However, there were no significant differences between genders for loose forwards, tight forwards and all forwards. Despite this, visually (see Figure 1) there appears to be a substantial difference in distance for the forwards (see Table 2). However, the large variation in the distances resulted in there being no significant differences. It is possible with more match data; this seemingly large difference could become significant.

One possible explanation of the significant differences in distance between genders for some positions could be attributed to various factors including better fitness levels and both greater mechanical work capacity and efficiency. These differences are likely a combination of genetic differences (Turner et al., 2018), differences in how the respective games are played, less training resources for the females, and our observation that males in this study typically had greater full-time professional training support from an earlier age (Brown et al., 2023).

Expanding on this point, during visual sports coding it was observed that female players rarely used the full width of the field. This is possibly due to differences in skill levels and physical capacity. Whereas males often utilised the full width of the field when passing and thus, for the same BIP intervals they appeared to travel greater distances. Possible explanations for these differences in play have been mentioned above e.g., greater resources from an earlier age and genetic differences.

Suarez-Arrones et al. (2014) analysed movement and intensity patterns in female rugby players during a full match, GPS monitoring during an international test showed, players travelled 5,820m. Overall, greater distance was performed by the backs than forwards (6,356

vs. 5,498m, $p = 0.010$). Similarly, Cunniffe et al. (2009) and Coughlan et al. (2011) found that full match distance during a men's rugby match was between 6,427 m and 7,002 m for forwards and backs respectively. In comparison the total distances for the male and female players in this study seem to be a lot lower than the above studies (see Table 2). Possible reasons for this are numerous, with the most pertinent being that this study only examined BIP workloads. It is possible that a substantial amount of workload is accumulated in the BOP period which might include warm up, half time and warm down periods. This may explain the differences between this study and others. Further reasons for any differences include the level of competition and players, different styles of play, different tactical approaches, different substitution methods, the state of the field, variations in the rules and their interpretations, and environmental conditions.

Although male players travelled greater distances than females, the distances per minute were not significantly different. These results show that even though both genders' locomotive movements are at the same intensity (i.e., distance per minute), females are not travelling as far as men during BIP periods. On average females compared had a significantly greater match BIP time, similar match BIP distance per minute values, but overall, significantly lower match BIP total distance. This anomaly is presumably related to the complexity of the analysis undertaken with a small sample size. Despite this deviation, the benefits of adding more in-depth research on female rugby players, counterbalances the small to moderate limitations this pilot study may have had.

There is a limitation to distance per minute as a measure of intensity; this metric is calculated from the total distance per BIP divided by the total time per BIP for each player. It is possible that both players can move the same distance, yet one may sprint intensely and then rest until the BIP finishes, while the other jogs the identical distance finishing at the end of the BIP. Thus, the intensity of effort for the sprinter will be higher than their jogging compatriot, yet the distance per minute will be identical. Distance is often considered an important metric in rugby (Duthie et al., 2003) but rugby is not played at a constant speed. Therefore, average speed and total distance metrics do not reflect rugby locomotion. Rugby typically involves intermittent, often unpredictable, intensive movement patterns, requiring changes of direction, accelerations and decelerations (Polglaze et al., 2016; Cummins et al., 2013).

High metabolic load (HMLD), intensive accelerations (SPMETS), accelerations and decelerations have all been introduced previously and are considered measures of intensive rugby locomotion workload (Harper et al., 2019; Duthie et al., 2006; Gaudino et al., 2013). Overwhelmingly, the males in this study generated significantly higher volumes (metric values) and intensities (metric/min values) than females across all these important intensive locomotion metrics. These intensive metrics are associated with high metabolic load and mechanical stress, and the reasons for the males having greater metric values than the females for their corresponding positions are multi-faceted (World Rugby, 2009; Howe et al., 2003). The development of the energy systems (Anaerobic, Aerobic and ATP-CP) throughout the different training periods of the season, likely differed between genders. This is because the male professional season is substantially longer compared to that for the females in this study, potentially leading to greater conditioning (NZ Rugby, 2024). There are also genetic physiological differences between the genders with males having substantially greater muscle mass, allowing them to generate a greater force and therefore greater intensive locomotion values (Kelly et al., 2024). Additionally, as discussed in Section 1.5.2 and 1.5.3 training programs for female rugby players are generally based on methods and standards generated from research and practical experience with male rugby players. This may not enable females to reach their full potential (Heather et al., 2021). Further exploration into the relevance of these specific intensive locomotion metrics for females is required.

HMLD equates to distance where workload is greater than 25.5 W/kg which is equivalent to a speed greater than 5.5 m/s or an acceleration of 2 m/s/s from a standing start, or some combination of speed and acceleration where metabolic load exceeds 25.5 W/kg (Polglaze et al., 2016). Speed greater than 5.5 m/s is typically termed ‘High Speed Running’ and accelerations greater than 2 m/s/s are considered intensive acceleration, this metric combines two measures of intensive workload. Thus, HMLD provides the benefit of being able to measure the distance covered for intensive workloads that combine both velocity and acceleration, which is important in rugby where accelerations usually occur when the players are already moving (Polglaze et al., 2016; Koper, 2024).

SPMETS or intensive acceleration equates to distance where workload is greater than 50 W/kg which is equivalent to a speed greater than ~10.6 m/s or an acceleration of 3 m/s/s from a standing start, or some combination of speed and acceleration where W/kg exceeds 50W/kg. It is uncommon for rugby players to run greater than 10.6 m/s, but they do accumulate heavy accelerations greater than 3 m/s/s. This metric is currently not that common in research literature. However, this metric was selected because it is used as a KPI for intensive locomotion workload by the teams in this study. SPMETS provides a more accurate measure of the distance of very intensive locomotion by combining both very intensive acceleration with high velocity values, which is not adequately accounted for by the traditional acceleration count metric.

Accelerations and decelerations of + 2 m/s/s and – 2 m/s/s respectively (Harper et al., 2019; STATSports Sonra, Newry, NIR) are both highly important metrics for rugby. As mentioned above, these metrics may not reflect the work of accelerations and decelerations in rugby given that most of these events occur when the athlete is already moving and are recorded as a count rather than distance (or time) which limiting the ability to measure the volume of intensive work.

If the lower values for the intensive metrics for females found in this study is the global standard, then one could argue that it is important to gain a greater understanding of why females are not reaching the same levels as males. These differences may solely be due to biological gender differences. Turner et al. (2018) found that despite training to develop muscle mass, female testosterone concentrations are ten times less compared to males. This reduced testosterone level, limits the ability to build muscle, strength and power, which are all important requirements for intensive work in rugby. Furthermore, Lewis et al. (1986) found that females typically have less hemoglobin than their male counterparts resulting in a relatively lower VO2max which in turn reduces relative intensive endurance capacity i.e., rugby fitness. This raises the important question of whether females should be trying to attain the same threshold standards in these intensive locomotion metrics as males.

Presently, there are no specific threshold zones across any of the intensive locomotion metrics described above for females, so they utilise the same threshold standards as males.

Suggestions have been made by Suarez-Arrones et al. (2014), Bradley et al. (2020), and STATSports (STATSports Sonra, Newry, NIR) that altering the thresholds to suit the physical capabilities of females will provide a more accurate representation of game demands for these metrics. Establishing female-specific standards for these intensive locomotion metrics may allow females to reach their full capabilities in training and matches but further research is required in this area.

On the other hand, it may be that female players could reach the same if not similar standards in these intensive locomotion metrics as males despite the biological gender differences if they had the same training resources, expert support, and professional training time. Therefore, resourcing best practice training interventions to develop strength, power, speed and endurance conditioning for female rugby players may narrow the gap in the intensive locomotion metrics between the two teams in this study (Dane et al., 2022).

GPS-derived impacts are measured from accelerometer-generated accelerations and decelerations typically involving collisions such as ground impacts or tackles. In rugby, this metric is not considered to be an accurate measure of contact events because many rugby contacts involve pushing and pulling with low impacts (Trewartha et al., 2015). To measure contact employed by Chittenden's (2023) modification of the Borg RPE's scale, a unique system analysing the rating of perceived contact load. The contacts were categorised into three distinct categories, minimal, hard, and maximal (see Table 1). Chittenden's (2023) scale of rating of perceived contact load is associated with relative perceived contact intensities (weighting factors) determined by male super rugby players for various contact events (see Appendix A for more detail).

Dynamic Stress Load (DSL) is the weighted impact above 2G measured from the accelerometer in the GPS (Vanrenterghem et al., 2017). DSL is a good indication of fatigue, as when the athlete gets fatigued while playing (or training), the foot impacts and forces that are placed through the ground become heavier causing an increase in DSL (STATSports Sonra, Newry, NIR).

Male rugby players should typically have greater DSL compared to females in the same positions doing the same activities due to the genetic characteristics; larger body mass and greater power (Turner et al., 2018). As seen in Tables 11 and 12, males have greater DSL than females which suggests males produce greater forces and impacts during a match. However, in this study, there were no differences in the volume of contact between the genders. Despite this, it was observed that in many positions the contact intensity (contact per minute) was greater for females than males (see Table 10). While this could be seen as an anomaly, these two metrics measure different measures i.e., DSL measures absolute accelerometer-derived impact forces while contacts are event-specific externally coded perceived contact loads. Therefore, this study indicates that female players are involved in more perceived intensive contact events per minute, but the associated impact forces may be lower. For example, in one BIP a 100kg male player may generate three maximal force tackles with a total of 3000 Newtons (N), while in the same BIP, a 50kg female player may generate five maximal force tackles with a 2500 N total. In absolute terms, the male has generated a greater force (3000 N vs 2500 N) and force per minute (intensity), but the female has done more relative work (5 maximal tackles vs 3 maximal tackles).

Considering the above, it is notable that in some instances the females were involved in more weighted contacts per minute than the males. This may be due to the aforementioned females playing in a more condensed space than the males which may result in more contacts per minute over the same distance. If this pattern occurs across all female rugby players, then perhaps more contact conditioning per minute within training for female players would be beneficial (Dane et al., 2022). It could be argued that coded contacts don't provide value, however, contact intensity is relative to the player, and thus understanding each player's "perceived" contact load is valuable. It would be useful to repeat Chittenden's (2023) study with female rugby players to ascertain whether there are differences in perceived contact load for different contact events about the male super rugby team in this study.

An interesting finding was that as the duration of the BIP increased, decreases occurred in both the work-to-rest ratio and intensity of most key intensive locomotion metrics e.g., HMLD per minute and SPMET per minute reduced with increased BIP duration. It would be useful to explore this further to gain a greater understanding of the intensities and work-to-

rest ratios and their worst-case scenarios for both genders to help inform best-match-specific training interventions.

A limitation of the current study was only one male and female team was analysed for four matches in the season. Consequently, the results reflect the strategic and conditioning practices of these teams for that specific season and do not account for broader trends. Therefore, researchers in the future should examine similar effects within multiple seasons and teams. The acknowledgment of the limitations in the accuracy of the footage received for the female matches. The female video footage was received via the team, with the video resolution being relatively poor and camera angles being limited compared to the male television footage. This may have influenced the quality of the female Sportscode contact coding. Researchers in the future should look to improve the video resolution of the female match footage, to improve the accuracy of the Sportscode contact coding.

2.5. Conclusion

This study examined data from two professional female and male rugby teams over the duration of their season. Contact and locomotive workload metrics were analysed during four matches for each team. To our knowledge, this is the first study to compare locomotion and contact metrics during match BIP periods for a male versus female professional rugby team of relatively similar levels. The analysis consistently showed that males had significantly greater intensive locomotion metrics, with large to moderate differences across all positions. Although males generally experienced higher impacts, females interestingly had a higher number of contacts per minute. The differences found between males and females in this study were likely a combination of genetic differences, differences in how the respective games are played, fewer training resources for female players from an early age, and our observation that males in this study typically had greater full-time professional training support. Due to these differences, altering female threshold standards may better suit the physical capabilities of females and based on updated metrics, provide a more accurate representation of game demands. Establishing female-specific threshold standards for all locomotion and contact metrics analysed should allow females a better opportunity to reach their full capabilities in both training and matches. On the other hand, with greater resourcing, it may be possible for females to achieve close to the male metric threshold

standards. Further exploration into this important area is necessary for the development of the female game.

References

Akenhead, R., & Nassis, G. (2016). Training Load and Player Monitoring in High-Level Football: Current Practice and Perceptions. *International Journal of Sports Physiology and Performance*, *11*(5), 587–593. https://doi.org/10.1123/ijspp.2015-0331

Alexander, J., Rhodes, D. D., Birdsall, D., & Selfe, P. J. (2020). COMPARISON OF CRYOTHERAPY MODALITY APPLICATION OVER THE ANTERIOR THIGH ACROSS RUGBY UNION POSITIONS; A CROSSOVER RANDOMIZED CONTROLLED TRIAL. *International Journal of Sports Physical Therapy*, *15*(2), 210–220. https://doi.org/10.26603/ijspt20200210

Austin, D., Gabbett, T., & Jenkins, D. (2011). The physical demands of Super 14 rugby union. *Journal of Science and Medicine in Sport*, *14*(3), 259–263. https://doi.org/10.1016/j.jsams.2011.01.003

Beato, M., De Keijzer, K. L., Carty, B., & Connor, M. (2019). Monitoring Fatigue During Intermittent Exercise with Accelerometer-Derived Metrics. *Frontiers in Physiology*, *10*, 780–780. https://doi.org/10.3389/fphys.2019.00780

Bradley, E. J., Board, L., Hogg, B., & Archer, D. T. (2020). Quantification of Movement Characteristics in Women's English Premier Elite Domestic Rugby Union. *Journal of Human Kinetics*, *72*(1), 185–194. https://doi.org/10.2478/hukin-2019-0104

Brown, N., Williams, G. K. R., Stodter, A., McNarry, M. A., Roldan-Reoyo, O., Mackintosh, K. A., Moore, I. S., & Williams, E. M. P. (2023). A Global Women's Rugby Union Web-Based Survey. *International Journal of Environmental Research and Public Health*, *20*(8), 5475-. https://doi.org/10.3390/ijerph20085475

Chittenden, J. (2023) Quantifying Contact Workloads in Professional Male Rugby Union by Implementing an Action Design Framework (Publication No. 17977425) [Masters Dissertation, Auckland University] https://openrepository.aut.ac.nz/server/api/core/bitstreams/bedc0e8a-f4df-4a1c-9fca-304c12b7d93d/content

Reardon, C., Tobin, D. P., Tierney, P., & Delahunt, E. (2017). Collision count in rugby union: A comparison of micro-technology and video analysis methods. *Journal of Sports Sciences*, *35*(20), 2028–2034. https://doi.org/10.1080/02640414.2016.1252051

Ciolac, E. G., Mantuani, S. S., Neiva, C. M., Verardi, C., Pessôa-Filho, D. M., & Pimenta, L. (2015). Rating of perceived exertion as a tool for prescribing and self-regulating interval training: a pilot study. *Biology of Sport*, *32*(2), 103–108. https://doi.org/10.5604/20831862.1134312

Clarke, A. C., Anson, J., & Pyne, D. (2015). Physiologically based GPS speed zones for evaluating running demands in Women's Rugby Sevens. *Journal of Sports Sciences*, *33*(11), 1101–1108. https://doi.org/10.1080/02640414.2014.988740

Conte, D., Arruda, A. F. S., Clemente, F. M., Castillo, D., Kamarauskas, P., & Guerriero, A. (2022). Assessing the Relationship Between External and Internal Match Loads in

Elite Women's Rugby Sevens. *International Journal of Sports Physiology and Performance*, *17*(4), 634–639. https://doi.org/10.1123/ijspp.2021-0097

Coughlan, G., Green, B., Pook, P., Toolan, E., & O'Connor, S. (2011). The relationship between physical game demands and injury rehabilitation in international rugby union: a global positioning system analysis. *British Journal of Sports Medicine*, *45*(4), 323–323. https://doi.org/10.1136/bjsm.2011.084038.37

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global Positioning Systems (GPS) and Microtechnology Sensors in Team Sports: A Systematic Review. *Sports Medicine (Auckland)*, *43*(10), 1025–1042. https://doi.org/10.1007/s40279-013-0069-2

Cunniffe, B., Proctor, W., Baker, J. S., & Davies, B. (2009). An Evaluation of the Physiological Demands of Elite Rugby Union Using Global Positioning System Tracking Software. *Journal of Strength and Conditioning Research*, *23*(4), 1195–1203. https://doi.org/10.1519/JSC.0b013e3181a3928b

Cunningham, D. J., Shearer, D. A., Carter, N., Drawer, S., Pollard, B., Bennett, M., Eager, R., Cook, C. J., Farrell, J., Russell, M., & Kilduff, L. P. (2018). Assessing worst case scenarios in movement demands derived from global positioning systems during international rugby union matches: Rolling averages versus fixed length epochs. *PloS One*, *13*(4), e0195197–e0195197. https://doi.org/10.1371/journal.pone.0195197

Dane, K., Foley, G., Hendricks, S., & Wilson, F. (2023). "It's always the bare minimum" - A qualitative study of players' experiences of tackle coaching in women's rugby union. *Journal of Science and Medicine in Sport*, *26*(2), 149–155. https://doi.org/10.1016/j.jsams.2023.01.002

Delaney, J. A., Scott, T. J., Thornton, H. R., Bennett, K. J. M., Gay, D., Duthie, G. M., & Dascombe, B. J. (2015). Establishing duration-specific running intensities from match-play analysis in rugby league. *International Journal of Sports Physiology and Performance*, *10*(6), 725–731. https://doi.org/10.1123/ijspp.2015-0092

Deutsch, M. U., Kearney, G. A., & Rehrer, N. J. (2007). Time - motion analysis of professional rugby union players during match-play. *Journal of Sports Sciences*, *25*(4), 461–472. https://doi.org/10.1080/02640410600631298

Dubois, R., Paillard, T., Lyons, M., McGrath, D., Maurelli, O., & Prioux, J. (2017). Running and metabolic demands of elite rugby union assessed using traditional, metabolic power, and heart rate monitoring methods. *Journal of Sports Science & Medicine*, *16*(1), 84–92.

Duthie, G. M., Pyne, D. B., Marsh, D. J., & Hooper, S. L. (2006). Sprint patterns in rugby union players during competition. *Journal of Strength and Conditioning Research*, *20*(1), 208–214. https://doi.org/10.1519/R-16784.1

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

Duthie, G., Pyne, D., & Hooper, S. (2005). Time motion analysis of 2001 and 2002 super 12 rugby. *Journal of Sports Sciences*, *23*(5), 523–530. https://doi.org/10.1080/02640410410001730188

Gabbett, T. J., Ullah, S., & Finch, C. F. (2012). Identifying risk factors for contact injury in professional rugby league players – Application of a frailty model for recurrent injury. *Journal of Science and Medicine in Sport, 15*(6), 496–504. https://doi.org/10.1016/j.jsams.2012.03.017

Gaudino, P., Iaia, F. M., Strudwick, A. J., Hawkins, R. D., Alberti, G., Atkinson, G., & Gregson, W. (2015). Factors influencing perception of effort (session rating of perceived exertion) during elite soccer training. *International Journal of Sports Physiology and Performance*, *10*(7), 860–864. https://doi.org/10.1123/ijspp.2014-0518

Haakma, M. L. (2021). Exploring and analysing the notion of worst-case scenario in professional rugby union [Master's thesis, The University of Waikato]. The University of Waikato Research Commons.

Harper, D. J., Carling, C., & Kiely, J. (2019). High-Intensity Acceleration and Deceleration Demands in Elite Team Sports Competitive Match Play: A Systematic Review and Meta-Analysis of Observational Studies. *Sports Medicine (Auckland)*, *49*(12), 1923–1947. https://doi.org/10.1007/s40279-019-01170-1

Heather, A. K., Thorpe, H., Ogilvie, M., Sims, S. T., Beable, S., Milsom, S., Schofield, K. L., Coleman, L., & Hamilton, B. (2021). Biological and Socio-Cultural Factors Have the Potential to Influence the Health and Performance of Elite Female Athletes: A Cross-Sectional Survey of 219 Elite Female Athletes in Aotearoa New Zealand. *Frontiers in Sports and Active Living*, *3*, 601420–601420. https://doi.org/10.3389/fspor.2021.601420

Hene, N., & Bassett, S. (2013). Changes in the physical fitness of elite women's rugby union players over a competition season. *South African Journal of Sports Medicine*, *25*(2), 47–50. https://doi.org/10.7196/SAJSM.371

Hopkins, W. G. (2019). A spreadsheet for Bayesian posterior compatibility intervals and magnitude-based decisions. *Sportscience*, *23*, 5–7.

Hopkins, W. G. (2020). Magnitude-Based Decisions as Hypothesis Tests. Sportscience, 24, 1-20.

Hopkins, W. G. (2022). Replacing statistical significance and non-significance with better approaches to sampling uncertainty. *Frontiers in Physiology*, *13*, 962132–962132. https://doi.org/10.3389/fphys.2022.962132

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278

Howe, S. T., Aughey, R. J., Hopkins, W. G., Cavanagh, B. P., & Stewart, A. M. (2020). Sensitivity, reliability and construct validity of GPS and accelerometers for

quantifying peak periods of rugby competition. *PloS One*, *15*(7), e0236024–e0236024. https://doi.org/10.1371/journal.pone.0236024

Johnston, R. J., Watsford, M. L., Pine, M. J., Spurrs, R. W., Murphy, A. J., & Pruyn, E. C. (2012). The Validity and Reliability of 5-hZ Global Positioning System Units to Measure Team Sport Movement Demands. *Journal of Strength and Conditioning Research*, *26*(3), 758–765. https://doi.org/10.1519/JSC.0b013e318225f161

Jones, M. R., West, D. J., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2015). Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. *European Journal of Sport Science*, *15*(6), 488–496. https://doi.org/10.1080/17461391.2015.1010106

Kelly, A. L., Coutinho, D., Radnor, J. M., Burke, K., Barrell, D., Jackson, D., & Brustio, P. R. (2024). Disentangling Gender and Relative Age Effects in Women's and Girls' Rugby Union. *Journal of Functional Morphology and Kinesiology*, *9*(2), 61-. https://doi.org/10.3390/jfmk9020061

Koper, B. (2024). Exploring 'Ball-in-Play' Locomotion and Contact Workload in Super Rugby. [Unpublished Doctoral of Philosophy]. University of Otago.

Kuchar, R., & Martin, A. (2016). The Comparison of Competitive Balance between Super Rugby (Sanzar) and English Premiership Rugby: A Case Study from 1996-2014 Season or Not Attractive – No People – No Money. *International Journal of Entrepreneurial Knowledge*, *4*(1), 112–129. https://doi.org/10.1515/ijek-2016-0009

Naughton, M., Jones, B., Hendricks, S., King, D., Murphy, A., & Cummins, C. (2020). Quantifying the Collision Dose in Rugby League: A Systematic Review, Meta-analysis, and Critical Analysis. *Sports Medicine - Open*, *6*(1). https://doi.org/10.1186/s40798-019-0233-9

New Zealand Rugby. (2024). *Bunnings Warehouse NPC Rugby.* https://www.nzrugby.co.nz/teams-and-competitions/national/bunnings-warehouse-npc

Nicholls, M., Coetzee, D., Schall, R., & Kraak, W. (2024). Analysing match-related performance indicators in Super Rugby Competitions: A study of the 2017–2019 seasons. *International Journal of Sports Science & Coaching*, *19*(3), 1066–1081. https://doi.org/10.1177/17479541231198211

Nyman, D. L. E., & Spriet, L. L. (2022). External Training Demands in Women's Varsity Rugby Union Players Quantified by Wearable Microtechnology With Individualized Speed Thresholds. *Journal of Strength and Conditioning Research*, *36*(11), 3151–3158. https://doi.org/10.1519/JSC.0000000000004084

Owen, S. M., Venter, R. E., du Toit, S., & Kraak, W. J. (2015). Acceleratory match-play demands of a Super Rugby team over a competitive season. *Journal of Sports Sciences*, *33*(19), 2061–2069. https://doi.org/10.1080/02640414.2015.1028086

Paul, L., Naughton, M., Jones, B., Davidow, D., Patel, A., Lambert, M., & Hendricks, S. (2022). Quantifying Collision Frequency and Intensity in Rugby Union and Rugby

Sevens: A Systematic Review. *Sports Medicine - Open*, *8*(1). https://doi.org/10.1186/s40798-021-00398-4

Polglaze, T., Dawson, B., & Peeling, P. (2016). Gold Standard or Fool's Gold? The Efficacy of Displacement Variables as Indicators of Energy Expenditure in Team Sports. *Sports Medicine (Auckland)*, *46*(5), 657–670. https://doi.org/10.1007/s40279-015-0449-x

Pollard, B. T., Turner, A. N., Eager, R., Cunningham, D. J., Cook, C. J., Hogben, P., & Kilduff, L. P. (2018). The ball in play demands of international rugby union. *Journal of Science and Medicine in Sport*, *21*(10), 1090–1094. https://doi.org/10.1016/j.jsams.2018.02.015

Lewis, D. A., Kamon, E., & Hodgson, J. L. (1986). Physiological Differences Between Genders Implications for Sports Conditioning. *Sports Medicine (Auckland)*, *3*(5), 357–369. https://doi.org/10.2165/00007256-198603050-00005

Posthumus, L., Macgregor, C., Winwood, P., Tout, J., Morton, L., Driller, M., & Gill, N. (2020). The physical characteristics of elite female rugby union players. *International Journal of Environmental Research and Public Health*, *17*(18), 1–10. https://doi.org/10.3390/ijerph17186457

Quarrie, K. L., Hopkins, W. G., Anthony, M. J., & Gill, N. D. (2013). Positional demands of international rugby union: Evaluation of player actions and movements. *Journal of Science and Medicine in Sport*, *16*(4), 353–359. https://doi.org/10.1016/j.jsams.2012.08.005

Read, D. B., Till, K., Beasley, G., Clarkson, M., Heyworth, R., Lee, J., Weakley, J. J. S., Phibbs, P. J., Roe, G. A. B., Darrall-Jones, J., & Jones, B. (2019). Maximum running intensities during English academy rugby union match-play. *Science and Medicine in Football*, *3*(1), 43–49. https://doi.org/10.1080/24733938.2018.1464660

Reardon, C., Tobin, D. P., Tierney, P., & Delahunt, E. (2017). The worst case scenario: Locomotor and collision demands of the longest periods of gameplay in professional rugby union. *PloS One*, *12*(5), e0177072–e0177072. https://doi.org/10.1371/journal.pone.0177072

Reardon, C., Tobin, D. P., Tierney, P., & Delahunt, E. (2017). Collision count in rugby union: A comparison of micro-technology and video analysis methods. *Journal of Sports Sciences*, *35*(20), 2028–2034. https://doi.org/10.1080/02640414.2016.1252051

Rennie, G., Dalton-Barron, N., McLaren, S. J., Weaving, D., Hunwicks, R., Barnes, C., Emmonds, S., Frost, B., & Jones, B. (2020). Locomotor and collision characteristics by phases of play during the 2017 rugby league World Cup. *Science and Medicine in Football*, *4*(3), 225–232. https://doi.org/10.1080/24733938.2019.1694167

Johnston, R. D., Weaving, D., Hulin, B. T., Till, K., Jones, B., & Duthie, G. (2019). Peak movement and collision demands of professional rugby league competition. *Journal of Sports Sciences*, *37*(18), 2144–2151. https://doi.org/10.1080/02640414.2019.1622882

ROBERTS, S. P., TREWARTHA, G., HIGGITT, R. J., EL-ABD, J., & STOKES, K. A. (2008). The physical demands of elite English rugby union: Science and Rugby Union. *Journal of Sports Sciences*, *26*(8), 825–833.

Scott, M. T. U., Scott, T. J., & Kelly, V. G. (2016). The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *Journal of Strength and Conditioning Research*, *30*(5), 1470–1490. https://doi.org/10.1519/JSC.0000000000001221

Starling, L., Tucker, R., Ken Quarrie, Schmidt, J., Omar Hassanien, Smith, C., Sharron Flahive, Morris, C., Lancaster, S., Stephen Mellalieu, Curran, O., Gill, N., Wesley Clarke, Phil Davies, Harrington, M., & Falvey, É. (2023). The World Rugby and International Rugby Players Contact Load Guidelines: From conception to implementation and the future. *South African Journal of Sports Medicine*, *35*(1). https://doi.org/10.17159/2078-516X/2023/v35i1a16376

Stevens, L. J. (2022). *Offence vs defence: Quantifying workload demands in professional Rugby Union*. The University of Waikato.

Suarez-Arrones, L., Arenas, C., López, G., Requena, B., Terrill, O., & Mendez-Villanueva, A. (2014). Positional differences in match running performance and physical collisions in men rugby sevens. *International Journal of Sports Physiology and Performance*, *9*(2), 316–323. https://doi.org/10.1123/IJSPP.2013-0069

Till, K., Hendricks, S., Scantlebury, S., Dalton-Barron, N., Gill, N., den Hollander, S., Kemp, S., Kilding, A. E., Lambert, M., Mackreth, P., O'Reilly, J., Owen, C., Spencer, K., Stokes, K., Tee, J., Tucker, R., Vaz, L., Weaving, D., & Jones, B. (2023). A global perspective on collision and non-collision match characteristics in male rugby union: Comparisons by age and playing standard. *European Journal of Sport Science*, *23*(7), 1131–1145. https://doi.org/10.1080/17461391.2022.2160938

Trewartha, G., Preatoni, E., England, M. E., & Stokes, K. A. (2015). Injury and biomechanical perspectives on the rugby scrum: a review of the literature. *British Journal of Sports Medicine*, *49*(7), 425–433. https://doi.org/10.1136/bjsports-2013-092972

Turner, A. (2018). *Routledge Handbook of Strength and Conditioning: Sport-specific Programming for High Performance* (1st ed.). Routledge. https://doi.org/10.4324/9781315542393

Van Rooyen, M., Rock, K., Prim, S., & Lambert, M. (2008). The quantification of contacts with impact during professional rugby matches. *International Journal of Performance Analysis in Sport*, *8*(1), 113–126. https://doi.org/10.1080/24748668.2008.11868427

Varley, M. C., Elias, G. P., & Aughey, R. J. (2012). Current match-analysis techniques' underestimation of intense periods of high-velocity running. *International Journal of Sports Physiology and Performance*, *7*(2), 183–185. https://doi.org/10.1123/ijspp.7.2.183

Venter, R. E., Opperman, E., & Opperman, S. (2011). The use of global positioning system (gps) tracking devices to assess movement demands and impacts in under-19 rugby union match play. African Journal for Physical Health Education, Recreation And Dance, 17(1), 1–8. doi:10.4314/ajpherd.v17i1.65242

Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. *Sports Medicine (Auckland)*, *47*(11), 2135–2142. https://doi.org/10.1007/s40279-017-0714-2

West, S. W., Williams, S., Kemp, S. P. T., Cross, M. J., & Stokes, K. A. (2019). Athlete monitoring in rugby union: Is heterogeneity in data capture holding us back? *Sports (Basel)*, *7*(5), 98-. https://doi.org/10.3390/sports7050098

Williams, N. (2017). The Borg Rating of Perceived Exertion (RPE) scale. *Occupational Medicine (Oxford)*, *67*(5), 404–405. https://doi.org/10.1093/occmed/kqx063

Woodhouse, L. N., Bennett, M., Tallent, J., Patterson, S. D., & Waldron, M. (2023). The relationship between physical characteristics and match collision performance among elite international female rugby union players. *European Journal of Sport Science*, *23*(9), 1849–1858. https://doi.org/10.1080/17461391.2022.2144765

Woodhouse, L. N., Tallent, J., Patterson, S. D., & Waldron, M. (2022). International female rugby union players' anthropometric and physical performance characteristics: A five-year longitudinal analysis by individual positional groups. *Journal of Sports Sciences*, *40*(4), 370–378. https://doi.org/10.1080/02640414.2021.1993656

World Rugby. (2019). *Laws of the game rugby union*. https://www.world.rugby/the-game/laws/law/5

World Rugby. (2020). *An open game: The story of how rugby union turned professional*. https://www.world.rugby/news/582543

World Rugby. (2021). *Contact load Guideline*. https://resources.world.rugby/worldrugby/document/2021/09/22/d2bd955b-1a87-438d-805b-398e3e099752/210806-Contact-Load-guidelines-final-for-website-.pdf

Young, D., & Coratella, G. (2021). Acceleration, Deceleration and Dynamic Stress Load in Elite Hurling: A Between-Quarter and Between-Position Comparison. *Sports (Basel)*, *9*(1), 10-. https://doi.org/10.3390/sports9010010

Appendices

Appendix A: Contact and event coding criteria

Contact Coding Manual (Chittenden, J. 2021)

Hit Up

When the player is carrying the ball into contact. The player will either disrupt the defensive line or travel with intent to engage the opposition.
In offensive play if the player experiences a contact without being in possession of the ball within camera shot, this is classed as a hit up.
Any contention for an aerial ball is classed as a hit up.
Only judge by contact with other players, not contact with ground.
As they score a try, hit ups can be counted.

Minimal	*Hard*
• Minimal attempt to contact from opposition • One or two hands may touch but not impede travelling speed or create stoppage • Ankle or shank tap • Scrape through a tackle at speed having minimal contact with the opposition. • Minimal aerial collision with another player • Can be more than one hard hit up or a combination of hit ups in one run (if there are no opposition players within a one-meter radius after the first hit up). • Attempt of a leg tackle with only one arm by the opposition. • Player slips at speed with minimal contact to opposition.	• Is when players are tackled and end up on the ground. • Loses significant momentum in contact, ending up in a one-on-one wrestle while driving forwards or backwards during the carry • Fends are classed as hard-hit ups • Full body contact from a tackle (knees up) • Full body aerial collision – consider contact with ground • Can be more than one hard hit up or a combination of hit ups in one run (if there are no opposition players within a one-meter radius after the first hit up). • If there is a minimal contact of the legs closely followed by an upper body full wrap tackle, then code it as one hard. • Brought down by a two-handed wrap tackle anywhere on the body if they are grounded • If the offensive player is facing backwards to an incoming hit.

Tackle

The attacking ball carrier is brought to ground by the opposition.
In defensive play if the player experiences a contact without being in possession of the ball within camera shot, this is classed as a tackle.
Only judge by contact with other players, not contact with ground.

Minimal	*Hard*
• Missed tackle • One or two hands only touches the opposition player (does not create a backwards force). • If a leg tackle is made with only one arm. • Shirt tackles are minimal tackles.	• Making a tackle and the opposition ends up on the ground. • The attacking player loses significant momentum moving forward and collides harshly with the surrounding players. • Leg tackles (2 legs) are classed as hard if both arms are used. • Full body wrap arounds are hard tackles.
• Both arms are used but only on one leg/arm.	• If they end up getting dragged down by a two arm one leg tackle but, made shoulder or torso contact beforehand it is a hard tackle.

Attack OOA

Order of arrival to the offensive ruck. Ruck occurs after the tackled player has been brought to the ground.
Players can arrive at the ruck and position themselves in a way they are about to get contacted but may not experience contact therefore, it will be a minimal ruck arrival.
If the player is entering an area where the ball is being played on the ground it is classed as an OOA.
Box kick blocking is included
Halfbacks are not coded for OOA's unless they make a clear attempt (i.e. do more than just distribute the ball)

Minimal	*Hard*
• Minimal is making minimal contact while at the ruck. • A hand may be on the ruck but no clear intent to enter the ruck for a clean out has been made. • Players can be in impact positions but do not experience any contact (bracing). • Box kick guards are classified as minimal OOA's • If a player arrives and it is originally a minimal contact but then a hard contact, the hard contact overrides the minimal • Halfbacks are not included for minimal OOA arrivals. • Shirt pulling is minimal contact	• Hard is when an attacking player arrives at the ruck and makes collision or major impact to other players. • Clean outs • Makes big impact (disrupts the ruck) • Can have multiple hard OOA's from the same player in one ruck (e.g., one attempt, two attempt)

Defence OOA

Order of arrival to the defensive ruck. Ruck occurs after the tackled player has been brought to the ground.
Players can arrive at the ruck and position themselves in a way they are about to get contacted but may not experience contact therefore it will be a minimal ruck arrival.
If they are entering an area where the ball is being played on the ground it is classed as an OOA.

Minimal	*Hard*
• Minimal is making minimal contact while at the ruck. • Players may attempt to engage the ruck but choose to abandon the intention. • Shirt pulling is minimal contact. • If the defending player gets pushed away by the opposition or they push them • Attempt at blocking a box kick • Contact with ruck but no major force to move players is generated • Gets caught up standing in the middle of the ruck	• Hard is when a defending player arrives at the ruck and makes collision or major impact to other players. • Clean outs • Makes big impact (disrupts the ruck). • Can have multiple hard OOA's from the same player in one ruck (e.g., one hit, two hit).

Lineout Offence	
Forwards set up an offensive line out to retrieve the ball. Once the ball exits the lineout, no other contacts are coded unless a maul occurs.	
Minimal	*Hard*
• All attacking players part of the lineout who do not lift, or jump are coded with minimal contact. • The hooker (thrower) is always coded as minimal contact. • Only forwards are coded in lineouts. No backs.	• All attacking players who are part of the lineout and are lifters or jumpers are coded with hard contact. • Only forwards are coded in lineouts. No backs. • Attacking players who lift and jump to retrieve the ball safely after kick-off. Once they are grounded the jumper does not get coded for a hit up. However, if the lifters attempt to engage in the ruck once grounded this is coded separately as an Attacking OOA.
Lineout Defence	
Forwards set up a defensive lineout to contest the opposition throw and lineout. Once the ball exits the lineout, no other contacts are coded unless a maul occurs.	
Minimal	*Hard*
• All defending players part of the lineout who do not lift or jump are coded with minimal contact. • Only forwards are coded in lineouts. No backs.	• All defending players who are part of the lineout and are lifters or jumpers are coded with hard contact. • Only forwards are coded in lineouts. No backs.
Maul Offence	
When a rolling maul occurs Formation of a maul occurs following a lineout	
Hard	*Maximal*
• When the defensive players involved in a maul remains in contact for three seconds or less (brief inclusion). • When a defensive player takes one hit at the maul (like a OOA action but hitting a maul rather than a ruck). • Once the ball is grounded and is distributed to the next phase a new metric occurs.	• Maximal is when the defensive players involved in the maul drives forward and remains in contact for three or more seconds. • If a player re-enters the maul (multiple rejoins). • Once the ball is grounded and is distributed to the next phase a new metric occurs.
Maul Defence	
When a rolling maul occurs Formation of a maul occurs following a lineout When players attempt to hold players up in tackles	
Hard	*Maximal*
• When the defensive players involved in a maul remains in contact for three seconds or less (brief inclusion).	• Maximal is when the defensive players involved in the maul drives forward and remains in contact for three or more seconds.
• When a defensive player takes one hit at the maul (like a OOA action but hitting a maul rather than a ruck).	• If a player re-enters the maul (multiple rejoins).
Scrum Offence	
When one scrum pack engages against the opposing scrum pack. Code backs if included (player numbers down if teams carded)	
Hard	*Maximal*
• If the ball exits the scrum in under 3 seconds (from when the ref says set) the scrum is classified as hard work.	• If the ball exits the scrum after 3 seconds (from when the ref says set) the scrum is classified as hard work. • This occurs even if the front row collapses because they are still experiencing contact and forces around them.
Scrum Defence	
When one scrum pack engages against the opposing scrum pack. Code backs if included (player numbers down if teams carded)	
Hard	*Maximal*
• If the ball exits the scrum in under 3 seconds (from when the ref says set) the scrum is classified as hard work.	• If the ball exits the scrum after 3 seconds (from when the ref says set) the scrum is classified as hard work. • This occurs even if the front row collapses because they are still experiencing contact and forces around them.

Ball in Play Criteria	
Kicks	The first BIP of the match is when the ball hits the players boot at kick off. Penalty kicks are excluded from BIP, unless it hits the crossbar and stays in play. BOP starts when the ball hits the players boot for fulltime or halftime kicks
Scrums	If the ball goes into the scrum and it results in a penalty, free kick or successful exit code it as a BIP. If the scrum is reset, it will stay as a BOP (even if the ball goes into the scrum).
Lineouts	The frame where the hooker's elbow has flexion for lineout throws is the start of a BIP lineout. If a lineout throw is not straight or the lines aren't straight, then this will count as a BOP.
Quick Taps	If a quick tap is taken it counts as "play on." Therefore, the BIP continues, and no BOP occurs. If there is an extremely large stoppage in play (>10 sec) before the quick tap there can be a BOP.
BOP	When the ref blows the whistle due to an infringement or stop in play. Sideline officials flag goes up on the sideline after a BIP kick.

Appendix B: Ethics Approval

The University of Waikato
Private Bag 3105
Hamilton, New Zealand, 3240
0800 WAIKATO (924 528)

HECS Human Ethics Committee
Brett Langley
Telephone +64 77 838 4060
Hecs-ethics@waikato.ac.nz

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

4 August 2023

Chantal MacDonald
Brett Smith

Re: HECS Ethics Approval of Application HREC(HECS)2023#41 "Quantifying contact and running demands in Men and Women's semi-professional rugby players."

Dear Chantal:

Thank you for submitting your amended application HREC(HECS)2023#41 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruitment of approximately 46 male and female Rugby Union NPC and FPC players (aged 18-40 years old) for a study that investigates player contact and running demands during game time.
- Analyse GPS data and Sportscode data that is collected for participants during every game over the season to quantify the pattern of Ball-in-Play durations, workloads, and work to rest ratios during game time.
- Participants are not required to do anything different from the normal training and playing activities and schedules for this study. Rather, the study will use data that is routinely collected.
- Participants can withdraw from the study and have all data removed at any time during data collection and up until one week after data collection has been completed

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

Brett Langley, PhD
Chairperson
HECS Human Ethics Committee
University of Waikato

Appendix C: Information sheet

The University of Waikato, Te Huataki Waiora School of Health.

Information sheet: [Rugby club] Rugby Union players

Research project Title:

Quantifying contact and running demands in Men and Women's semi-professional rugby players.

Researchers:
Chantal MacDonald
Health, Sport, and Human Performance Masters Student
Ph: +64 21 2985681
Email: chantalmacdonald12@gmail.com

Dr Brett Smith
Te Huataki Waiora School of Health
University of Waikato
Private Bag 3105
Hamilton
Ph: (07) 8384466 ext 7863
Fax: (07) 8384555
Mob: +64 21 627 863
Email: brett@waikato.ac.nz

Experiment Purpose:
This research project seeks to explore determine the pattern of Ball-in-Play (BiP) durations, workloads, and work to rest ratios for semi-professional men and women's rugby teams.

Procedure:
Player's GPS data and Sportscode data will be collected during every game over the season, as per normal team protocol. GPS metrics and Sportscode metrics will be analysed to determine best practice training standards, by positions and duration of BiP to help the team structure and monitor training load to safely optimise rugby specific conditioning.

Confidentiality:
Confidentiality and participant anonymity will be strictly maintained. Individual participants will not be named, and neither will the teams, however, in some cases, player positions relating to certain findings may be mentioned, and it will be mentioned that both men and women's semi-professional squads compete in the New Zealand NPC and FPC competition. It should however be noted that while every effort is made to ensure confidentiality, this cannot be guaranteed.

Likelihood of Discomfort:
The normal matches are rigorous and involve a number of discomforts and some potential risks. The [Rugby club] Rugby Union seeks to minimise these discomforts and risks through a comprehensive safety plan, associated monitoring procedures, and employment of specialist medical personnel who are present during every training session and match. This project does not require the players to do anything more or different than what is normally required by the team for training and matches.

Researcher
Chantal MacDonald (Master's student researcher) can be contacted by email at chantalmacdonald12@gmail.com, or by phone +64212985681 regarding this project.

In addition, Dr Brett Smith (supervisor) can also be contacted by phone 021 628963 or by email brett@waikato.ac.nz regarding this project.

Resolution of any disputes:

This research project has been approved by the Human Research Ethics Committee of the University of Waikato under HREC(HECS)2023#41. For any questions or concerns related to ethical issues associated with this research project please contact the Chair of the Committee, email hecs-ethics@waikato.ac.nz, postal address, University of Waikato, Te Whare Wananga o Waikato, Private Bag 3105, Hamilton 3240.

Results

A Master's thesis will be completed from this research by the end of 2024. A copy of this thesis, generated from this study will be available after this date which can be obtained by contacting the researcher, it will also be sent to the [Rugby club] Rugby Union upon completion.

Your rights as a participant

As a participant, you have the right to ask any question about the study at any time (before, during, and after). Your participation is also completely voluntary, and you have the right to withdraw from the study, and have all data removed, at any time during data collection and up until one week after data collection has been completed. If you have further questions concerning matters related to this research, please contact the researcher, supervisor or the research committee of the Te Huataki Waiora School of Health, University of Waikato.

Appendix D: Research consent form

The University of Waikato, Te Huataki Waiora School of Health.

Research Consent Form: [Rugby club] Rugby Union players

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask the researcher or research supervisor. Please take the time to read this form carefully and to understand any accompanying information.

Research project:

Quantifying contact and running demands in Men and Women's semi-professional rugby players.

Name of researcher: Chantal MacDonald

Name of supervisor: Dr Brett Smith

By signing below, I acknowledge that I have received an information sheet about this research project or have had the study explained to me by the researcher's supervisor. I have had the chance to ask any questions and discuss my participation with other people. Any questions have been answered to my satisfaction.

I agree to allow my data to be included in this research project thesis and I have the right to withdraw from the study, and have all data removed, at any time during data collection and up until one week after data collection has been completed. If I have any concerns about this project, I can contact the researcher or the Head of Te Huataki Waiora School of Health.

Participant's name: _____

Signature: _____ **Date:** _____