Quantifying Contact Workloads in Professional Male Rugby Union by Implementing an Action Design Research Framework

A dissertation submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Master of Sport, Exercise and Health

Jessica Chittenden
17977425

2023

School of Sport and Recreation

Faculty of Health and Environmental Sciences Auckland University of Technology

Abstract

Introduction: Contact workload is an important component of the total workload in rugby union, but measurement difficulties mean it's typically not included in rugby workload assessments.

Objective: To design a system that defines and quantifies contacts during a professional rugby union game.

Design: We implemented an action design research approach to create and evaluate this system

Participants: Professional rugby union players from a Super Rugby team.

Methodology: Key contact metrics that describe contact workloads in rugby union were developed in HUDL Sportscode TM, (HUDL, V12, USA) these key contact metrics were then coded to quantify total contact workload intensity using the 10-point rate of perceived contact intensity scale (adapted from the 10-point Borg rate of perceived exertion scale) by player, position, and match. Comparisons between the contact intensities for each contact event defined by the research team were made against the actual player defined intensities for various contact events for nineteen players across six matches. The reliability of the coding methodology was examined by the researcher repeating the contact coding for a single match three times spread across four months. The consistency of the player contact intensity ratings was also examined by one player repeating their match analysis twice in the space of one week.

Conclusion: A novel time-motion methodology that identified and quantified the magnitudes of different types of contact events in professional male rugby union matches was developed and used to generate weekly match reports by the Super Rugby team. The research project found strong reliability yet, the difference between player contact intensities versus analyst contact intensities was largely significant across majority of results. This dissertation was a pilot study for the development and implementation of a novel contact intensity measurement system for rugby union. While our pilot data shows good efficacy and reliability, we recommend teams use the player defined contact intensities rather than those defined by the analyst. Finally, this novel tool became a highly valued resource for measuring match workloads alongside Global Positioning System (GPS) metrics, but we believe further research is required with a larger sample size and more trials to further assess its accuracy.

Table of Contents

List of Tables

List of Figures

Attestation of Authorship

I Jessica Chittenden hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature: Date: 26/09/23

Ethics Approval

Re: *21/299 Quantifying and Analysing Player Workloads in Professional Male Rugby Union*

Ethical approval was granted by the AUT Ethics Committee on the 13th of September 2021. The key ethical considerations that were discussed in the application ensured the design and practice of the research was ethically sound and appropriate.

Acknowledgements

Firstly, to my academic supervisors, Dr Brett Smith and Kirsten Spencer. Thank you for your time, skill and guidance. I appreciate the confidence you have given me to not only be a good academic, but also a great practitioner whose ready to enter the sport and recreation industry. I consider myself lucky to have you both apart of this journey with me, endless thanks to you both.

In addition, acknowledgements to my host organisation and industry supervisors, Troy Webber, Josh Yarnton and Sam Mulholland-Goad. Thank you for providing me with the most valuable internship experience I will never forget. Thank you for your hospitality, support and expertise over the last two years.

Finally, to my amazing family and friends. Your ongoing support, motivation and reassurance throughout this chapter of my life has pushed me to making it this far. Continued support and guidance from these important people in my life has helped me achieve this academic milestone. Please know I am forever grateful to have had you all a part of this journey with me.

I hope I made you proud, thank you.

Research Questions

1. What is contact workload in professional rugby union and why is it important?

2. Can we develop an accurate method to measure contact workload in professional rugby union?

Chapter One

Quantifying Contact Workloads in Professional Male Rugby Union by Implementing an Action Design Research Framework

Research Topic

1.1. Problem Statement

Rugby union is an elaborate game that requires multiple bouts of intensive intermittent exercise (Nicholas,1997; Thomas & Wilson, 2015; Pollard et al., 2018). The typical ball-in-play time during the 80-minute professional rugby union game ranges between 33-36 minutes (Till et al., 2023). Within this time, players are expected to engage in a variety of intense events including locomotive activity, powerful non-locomotive collisions, and strenuous isometric forces (Pollard et al., 2018). To best capture the complexity of these different types of intensive workload events in rugby union, a variety of data collection methodologies are needed to help quantify overall workload, as no single method accurately captures all these events. It is therefore important to explore unique, innovative and accurate methods that quantify all aspects of a rugby players workload. This data will assist in designing training regimes which mimic game-like and worst-case scenarios athletes could endure throughout a match. To better understand the opportunities and challenges in this space the following literature review will draw upon research that has explored the physical demands of rugby union, predominately at a professional playing level. The literature review will also provide insights around current best practice methodologies towards quantifying workloads in rugby union.

1.2. Literature Review

1.2.1. Rugby Union Workload Demands (locomotive and non-locomotive)

Due to the consistent increases in workload demands over time within the modern game, researchers suggest more robust and accurate methodologies to quantify workload is vital (Owen et al., 2015). Rugby involves a mixture of both locomotion events (e.g., running at speed) alongside recurring physical contacts events such as tackles or scrums (Owen et al., 2015).

Rugby union locomotive demands have been well documented, via a wide range of published articles. Global positioning system units (GPS), is a commonly used method for determining locomotion workload (Jones et al., 2015), but unfortunately does not provide information on other aspects of rugby workload. Roberts et al. (2008), state rugby athletes are expected to endure a mixture of both low-intensity and high-intensity bouts of running. Alongside evasive acceleration and deceleration actions throughout a match (Pollard et al., 2018).

Over half of a rugby players total movement patterns within a game is made up of non-strenuous locomotive exercise like running or jogging (Roberts et al., 2008). In comparison, periods of the game which do require sprinting only occur 31-38% of the time whilst the ball is in play (Roberts et al., 2008). Within this time though, multiple components of high speed running such as change of direction, acceleration and deceleration is essential for favourable locomotive outcomes throughout a match (Duthie et al., 2005).

Austin et al. (2011), explain an underlying expectation in rugby union is the ability to exhibit high-speed running across succinct lengths throughout the duration of a match. Commonly, rugby players are expected to produce high-speed running across 11-20 metre distances, and occasionally exceeding the distance of 30 metres (Austin et al., 2011). The locomotive demands encountered by each athlete will fluctuate across a team dependent on their respective playing position (i.e. backs and forwards) (Duthie et al., 2006).

As well as locomotive workloads a lot of contact and isometric forces occur within a rugby union match. Typically, the most familiar key performance indicators that involve contacts in rugby union include ball carries, tackles, and rucks (Fuller et al., 2007). As well as this, additional set piece complexities of the game such as scrums, lineouts and mauls exhibit some sort of contact (Fuller et al., 2007). The magnitude of impact measured across other parts of the game can fluctuate (Duthie et al., 2005), for example, support players entering a ruck or existing maul may not exert the same force, but still generate some level of contact workload. According to Reardon et al. (2017a), contact events such as mauls, rucks, scrums and tackles can have a major influence on the outcome of a game, as well as considerably contributing to one’s own individual workload throughout a match.

Quantifying non-locomotive actions are therefore crucial to understanding the complete workload of rugby players. This is even more important from a positional perspective as backs compared to forwards tend to experience multiple isometric states due to scrummaging and mauling which accumulates approximately 15% of the game (Duthie et al., 2003). Quarrie et al. (2013), support this statement and go on to link the frequent contact events experienced by forwards is often due to the more diverse positional demands required to uphold the rules and regulations of the game. Additional studies also conclude that forwards are consistently more involved in strenuous contacts throughout a game of rugby union (Pollard et al., 2018; van Rooyen et al., 2008; Deutsh et al., 2007).

According to Smart et al. (2008), forwards are at greater risk of significant muscle damage due to the increased measures of stress-related biomarkers like creatine kinase. Studies have shown a positive correlation between contact events (specifically scrums) and greater measures of creatine kinase do exist (Smart et al., 2008). Similarly, an extension of this study showed the similar biomarker results when backs were exposed to more ball carries within a game (Smart et al., 2008). Thus, it is important to develop a tool to quantify contact workload in rugby union to manage athlete workload and monitor bodily stressors that could inhibit effective sport performance. For this reason authors like Duthie et al. (2005), believe that to continually evolve our understanding of rugby union workloads, more accurate and robust workload quantification methodologies are needed.

Historically, quantification of non-locomotive workload has been largely omitted from research designs. Austin et al. (2011), argue contact events such as tackles and hit ups should be acknowledged within workload assessments due to the tiring nature of completing such combat-like actions. Inability to quantify contact workload is often regarded as a limitation in most locomotive workload research papers (Delaney et al., 2015; Read et al., 2019). Hence, the opportunity to implement an appropriate methodology and review system that accurately measures an individual's non-locomotive workload during trainings and games is important, so as to provide appropriate feedback to help maximise full athletic capability of professional rugby union players.

1.2.2. Tools for Measuring Contact Workload

Accelerometers

Accelerometers are a mechanism often incorporated within GPS worn by professional rugby players that record collision magnitudes, durations and frequencies experienced by an athlete. Using three different axes, accelerometers calculate the total magnitude of force an individual experiences over time (Paul et al., 2022). Accelerometers have been promoted as a means for measuring contact workload however their accuracy in doing this is highly debatable (Cummins et al., 2013). Some have proposed that with the appropriate algorithms they may be able to categorize different contact events, but a meta-analysis study conducted by Naughton et al. (2020), reported poor activity recognition. Rugby union athletes experience countless amounts of different impact zones at mixed intensities and accelerometers typically lack the ability to recognise and quantify these different contact events (Cummins et al., 2013).

Generally, accelerometer data is collated via GPS and is recorded when an instant force or hit occurs upon an athlete during a sports game (Naughton et al., 2020). In saying this, within the game of rugby union more unique rugby specific contact events such as scrums, rucks and mauls tend to apply isometric forces to the body which accelerometers struggle to record. Suggesting, accelerometer technology is ineffective when attempting to collate an athletes holistic contact workload during a rugby union game. Jones et al. (2015), summarised the same conclusion suggesting, in order to successfully quantify and analyse non-locomotive demands of the game more comprehensive methods of research is needed.

Limitations found in accelerometer technology promotes the need for more innovative and unique workflows to help quantify contact workload. Both Naughton et al. (2020) and Reardon et al. (2017b), discuss being able to evaluate the magnitude of contact as well as the count of contact events is vital towards gaining an understanding of one’s total perceived non-locomotive workload.

Time-motion Analysis

It is generally accepted that relaying feedback on athletic performance is a critical aspect within elite sporting environments for developing individuals (Hughes, 2004). Currently, GPS is a common tool used within high-performance environments for analysis of locomotive workload during both training and matches (Jones et al., 2015).

However as mentioned above, given accelerometers don't provide accurate measures of non-locomotive workload (i.e., contact load), it is therefore important that we identify other measurement tools like time-motion analysis for quantifying contact workloads which are an important aspect of rugby union. Overtime, time-motion analysis research techniques have proven to be worthy methods for analysing behaviours and motions during professional sports games (Deutsch et al., 2007; Roberts et al., 2008). Incorporating time-motion analysis to determine contact workloads is an easy, nonintrusive approach to measuring player workloads during matches and possibly training.

Duthie et al. (2005), categorised movement patterns of professional male rugby union players using time-motion analysis. Collation of game footage provided the opportunity to analyse work to rest ratios based off common movements displayed throughout a match. Compilation of such data enabled in-depth quantification of key performance indicators seen within a match. Evidently, workload differences were noticeable as Duthie et al. (2005), concluded a greater amount of high-speed running (i.e. sprints) by backs was observed, compared to forwards who most often accumulated workload by applying static contact forces throughout specific events (i.e. scrums).

Bouts of both low and high intensity workloads was observed throughout a match (i.e. walking, running, isometric workloads) in a time-motion analysis conducted by Roberts et al. (2008), on English rugby union players . They also found that forwards compared to backs accomplished longer bouts of high intensity running and, were involved in more workloads that involved static exertion (Roberts et al., 2008). Even though an extensive quantification of rugby union workloads was achieved using time-motion analysis, Roberts et al. (2008), expressed their concerns around the inability to accurately quantify the magnitude of workload of some activities (e.g., isometric activities). Hence, Roberts et al. (2008), were compelled to infer all static exertion activities were completed with the same magnitude of intensity. Suggesting, a more robust and holistic approach to quantifying contact workload is required within rugby union that may involve notational analysis techniques.

In summary, time-motion analysis interprets rugby union workload by accumulating the counts of various locomotive and non-locomotive events. Despite this, some argue the validity of such analysis can be inadequate due to the high risk of a facilitator glitch or inconsistency (Reardon et al., 2017a). Another important limitation is the inability to evaluate the magnitude of impact during contact events found within a game. This is because general contact events found within rugby union are complex in nature, demanding a mixture of strength, speed and technical skill (Duthie et al., 2003).

<u>Rating of Perceived Exertion</u>

To successfully analyse contact workload in rugby union it is imperative that the magnitude of each contact event is quantified. Time-motion analysis has introduced the ability to count contact events throughout a rugby union match. For example, both Duthie et al. (2005) and Roberts et al. (2008), completed research which only examined the counts of different types of contact events. However, we are interested in quantifying the amount of contact workload per player, similar to how the GPS quantifies the amount (and type) of locomotion workload therefore, to understand the magnitude of these different contact events in rugby union we need to introduce a system of workload quantification into our time-motion analysis methodology. One of the most common qualitative tools for quantifying workload is rate of perceived exertion (RPE).

The RPE scale (Borg, 1982), has been widely examined in research to date and enables the opportunity to collate personalised data originating from the athlete themselves. It provides sport practitioners with a more holistic ideology of the internal effort completed by athletes throughout a training period or game. Comyns and Flanagan (2013), opined that the combination of objective measures such as GPS alongside individual player RPE data will strengthen practitioners understanding of an athlete's impression of their overall workload.

The RPE scale is unique. Comyns and Flanagan (2013), conducted an in-depth analysis upon the usage of the RPE scale within a national rugby union team. The application of such measurement tool provides practitioners with a subjective understanding of an athlete's workload (Comyns & Flanagan, 2013). Clarke et al. (2013), go onto state the RPE scale is a practical and economical measurement tool that can quantify an athlete's perceived exertion throughout any given type of exercise (e.g., contact, locomotion, endurance, strength, speed, power). Hence why, it is often used to monitor training volume and intensity in high performance sport (Clarke et al., 2013).

1.2.3. Action Design Research

Action Design Research (ADR) is a methodology that blends design research with action research (Sein et al, 2011). It is considered a suitable approach to generating new knowledge from the intervention of building and evaluating an artefact in an organizational setting to address a problem (Petersson and Lundberg, 2016). Artefacts can be methods (for example feedback to players) and constructs (Heyner, March, & Park, 2004). ADR allows for innovative ideas and applied practice, so enabling rugby performance information to be effectively and efficiently fed back to players (Karmokar, 2013; Connell & Spencer, 2020). The typical design of an ADR system is; (i) problem identification, (ii) objectives of a solution, (iii) design and development, (iv) demonstration, (v) evaluation and (vi) communication (Bragge et al., 2006). ADR systems draw upon participant interaction (e.g., rugby players), as well as the system design and build focus. This dissertation aimed to develop concept generation in a rugby context through interaction between researcher and rugby organisation, it was therefore considered that ADR would be useful in guiding the study, as it allows the researcher to deliver a practical outcome for the rugby organization whilst simultaneously meeting academic standards.

1.3. Research Aims

The workload requirements of rugby union are a combination of locomotion and contact. While GPS can accurately measure locomotion the accelerometers typically included in the GPS only measures collisions which is a small part of the contact workload in a rugby match. Therefore, time-motion analysis is currently the only method available to quantify the wide range of contact workload events in rugby union, yet it's rarely used for this purpose.

Being able to accurately define and identify key workload performance indicators in rugby is essential however, given the complex nature of sport this can often be hard to do (Hughes, 2004). In addition, Hughes (2004), suggests time-motion analysis projects are largely subjective, which could be interpreted to mean that using this method to quantify contact workloads has some limitations. Yet, O'donoghue (2009), goes on to state that even though this methodology can be subjective, observations are often determined by trained professionals who are in the most optimal positions to make those necessary judgements.

In summary, post-match analysis is an essential aspect needed in the ever evolving domain of professional sport. Hence why, continued advancements in sports science is required to create better tools and methods for quantifying both locomotive and non-locomotive workloads in professional rugby union. With this in mind, the aim of this research project was to develop and validate a novel time-motion methodology that identifies and quantifies the magnitudes of different types of contact events in professional male rugby union players during matches. To achieve this goal the following four research aims were developed:

1) Development of a theoretical contact intensity rating for rugby union players across all the different match contact events.
2) Determination of the differences between this theoretical intensity measurement system compared to player-perceived contact intensities.
3) Examination of the differences between theoretical and player perceived contact intensities across the various contact events.
4) To examine the internal reliability of the contact coding methodology

The development of this research avenue will generate a greater understanding of the workload aspects of the game. It will also support rugby union teams in executing appropriate training regimes and athlete monitoring systems which will be valuable tools for not only match analytics but also development and growth of rugby union athletes.

Chapter Two

Quantifying Contact Workloads in Professional Male Rugby Union by Implementing an Action Design Research Framework

Action Design Research Framework

2.1. Methodology

2.1.1. Study Design

The research approach that was utilised throughout this study was an action design research (ADR) framework. An ADR study comprises of six key phases, these include; identification, objectives of a solution, design and development, demonstration, evaluation, and communication. In layman's terms these stages involve a wider identification of the full scope of issues related to measuring contact workload in rugby union, exploring a range of possible solutions, design and development of a research project/s to explore all or some of these possible solutions, collecting the research results, analysis and evaluation of the results and finally, critical discussion and communication of the accuracy and meaning of the findings. This is an appropriate research design as Sein et al. (2011), states ADR systems provide practical knowledge towards identifying alternative interventions that can solve important issues.

2.1.2. Participants

As it is not possible or perhaps relevant to measure the entire rugby playing population, a convenience sample of elite professional rugby players from a New Zealand Super Rugby Team was selected. The players involved in this study had all secured fulltime playing contracts during the Super Rugby season that this study was undertaken.

The non-probability sampling technique that was used to recruit participants in this research involves convenience sampling. If the participants wished to take part, they then contacted the primary researcher to give consent. A total of 19 professional rugby union players volunteered their time to the research project (n=19). Of these 19 participants, 10 participants were forwards and 9 participants were backs.

2.1.3. Ethical Clearance

Ethical approval was granted by the AUT Ethics Committee on the 13th of September 2021 (21/299 Quantifying and Analysing Player Workloads in Professional Male Rugby Union) and all participants signed the required ethics documentation before participating in this study. The key ethical considerations that were discussed in the application ensured the design and practice of the research was ethically sound and appropriate.

2.2. Action Design Research Framework

2.2.1. Problem Identification

Consultations with coaches and sports scientists from a Super Rugby Club assisted in identifying a gap in match data. At that time, match workload was largely calculated from GPS measures of locomotion actions, however, there was general agreement around the importance of also understanding non-locomotive workload. From these conversations, a breakdown of research questions was developed to help identify a problem within the organisation, namely:

- What is contact workload in professional rugby union and why is it important?
- Can we develop an accurate method to measure contact workload in professional rugby union?

2.2.2. Objectives of a Solution

Notational analysis is a methodology used within time-motion analysis. Commonly, notational analysis is used to analyse tactical movements and opposition set plays. For this research project notational analysis has been identified as a useful time-motion analysis tool to measure contact workload of individual players during matches. To help solve the above research questions, the key objectives and aims described below have been developed to help guide this ADR project.

1. To design a time-motion system which effectively defines and quantifies ~~key~~ performance indicators that measure the workload of contacts during a professional rugby union game.
2. To evaluate the action design research approach taken to create this system.

2.2.3. Design and Development

Step 1: Identification of Contact Metrics

Firstly, key metrics used to measure the various aspects of contact found in rugby union were These metrics were also defined as offensive or defensive actions and a list of these metrics is included in table 1.1.

Table 1.1

Contact Metrics

Offensive	**Defensive**
Scrum, Hard	Scrum, Hard
Scrum, Max	Scrum, Max
Lineout, Minimal	Lineout, Minimal
Lineout, Hard	Lineout, Hard
Maul, Hard	Maul, Hard
Maul, Max	Maul, Max
Hit Up, Minimal	Tackle, Minimal
Hit Up, Hard	Tackle, Hard
Attack Order of Arrival, Minimal (Ruck)	Defence Order of Arrival, Minimal (Ruck)
Attack Order of Arrival, Hard (Ruck)	Defence Order of Arrival, Hard (Ruck)

Step 2: Quantification of the workload of the contact metrics.

The researcher and a group of rugby analysts involved with the Super Rugby club in this study met to discuss how to quantify the intensity of workload for the contact metrics described in table 1.1. Eventually this group decided to use the 10-point RPE Borg scale (Borg, 1982), to quantify the intensity of each contact event. Given each of the determined RPE measures was a multiple of two it was decided to employ a five point scale instead (see table 1.2). In most cases each individual metric had more than one intensity magnitude which reflected the different intensity levels of contact for that metric that often occurred during a match which is explained in more detail in table 1.3. By using a five point scale a more simplistic analysis against contact workload and locomotive workload could be established. This would not reduce the sensitivity of the measure as player interviews were completed using the 10-point RPE scale, it was not until after this process was the data then converted into a five point scale (e.g. contact weightings of 1, 3 and 5).

Table 1.2

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

Step 3: Creation and Implementation of Code Window

A list of operational definitions was created to identify each ball-in-play contact, and its associated intensity (see table 1.3). A code window using HUDL Sportscode TM version 12.2 was then designed to record these specific contact events. The code window shown in figure one and two was used to collate the identified contact metrics and their intensities for each player, for each ball-in-play across the entirety of a match. A total of six in-season Super Rugby games were coded for this project. Routinely collected video footage of each match, from four angles publicly available via broadcast feeds from Sky Sport was captured using HUDL Sportscode software. These feeds ran through a multi-capture device and appeared on coaches and analyst's computers throughout the game. Two extra cameras were used to film additional end-on and side-on angles during each match. The side on angle was filmed using a Panasonic HC-V385 camcorder and the end on angle was filmed using a Canon Legria HFG50 digital video camera. Following every match, these additional angles were then packaged together with the four broadcast angles. Post-match, the complete video package was analysed using HUDL Sportcode software. Specifically, contacts experienced by each player were coded (clipped) with correct labels (e.g., player name, type of contact etc.). These coded contacts were then counted and multiplied by specific intensity weightings (see table 1.2).

Figure 1

Contact Code Window

Figure 1

Contact Code Window

Table 1.3

Contact metrics detailed operational definitions and weightings

Hit Up	
A hit up occurs when a 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 and hit ups can only be judged by contact with other players, not contact with the ground. Finally, as if hit ups occur as players are scoring a try they must be counted.	
Minimal (Min)	**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 the 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

A tackle is when 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. Finally, tackles must only be judged on contact with other players, not contact with ground.

Minimal (Min)	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. Both arms are used but only on one leg/arm.	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. 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 Order of Arrival (Attack OOA)

An attack order of arrival is when a player arrives to an offensive ruck. Rucks occur 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 and halfbacks are not coded for OOA's unless they make a clear attempt (i.e., do more than just distribute the ball)

Minimal (Min)	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.	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)

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	Can have multiple hard OOA's from the same player in one ruck (e.g., one attempt, two attempt)
Defence Order of Arrival (Defence OOA)	
A defence order of arrival is when a player arrives to a 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 players are entering an area where the ball is being played on the ground, it is classed as an OOA.	
Minimal (Min)	**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 (Lineout Off)	
Forwards set up an offensive lineout to retrieve the ball from a side line throw in. Once the ball exits the lineout, no other contacts are coded unless a maul occurs.	

Minimal (Min)	Hard
All attacking players part of the lineout who do not lift, or jump are coded with minimal contact. are coded with hard contact.	All attacking players who are part of the lineout and are lifters or jumpers
The hooker (thrower) is always coded as minimal contact.	Only forwards are coded in lineouts. No backs.
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 (Lineout Def)

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 (Min)	Hard
All defending players part of the lineout who do not lift or jump are coded with minimal contact.	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.	Only forwards are coded in lineouts. No backs.

Maul Offence (Maul Off)

A maul offence is when a rolling maul occurs on attack. Formation of a maul occurs following a lineout

Hard	Maximal (Max)
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 re-joins).

Once the ball is grounded and is distributed to the next phase a new metric occurs.	Once the ball is grounded and is distributed to the next phase a new metric occurs.

Maul Defence (Maul Def)

A maul defence occurs when a rolling maul occurs on defence. Formation of a maul occurs following a lineout. In this research project a maul defence is also classed when players attempt to hold players up in tackles.

Hard	**Maximal (Max)**
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 re-joins).

Scrum Offence (Scrum Off)

A scrum offence is when one scrum pack engages against the opposing scrum pack. In this research topic backs whom are also included in scrums for whatever reason must also be coded (i.e. player numbers down if teams carded)

Hard	**Maximal (Max)**
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 (Scrum Def)

A scrum defence is when one scrum pack engages against the opposing scrum pack. In this research topic backs whom are also included in scrums for whatever reason must also be coded (i.e. player numbers down if teams carded)

Hard	Maximal (Max)
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 This occurs even if the front row collapses because they are still experiencing contact and forces around them.

Table 1.4

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.
Ball Out of Play (BOP)	When the ref blows the whistle due to an infringement or stop in play. Side-line official's flag goes up on the side-line after a BIP kick.

Step 4: Comparison between player and coders Rating of Perceived Contact Intensity (RPCI).

The next stage was to determine the difference between the players perception of the match contact intensities they were involved in compared to the researcher who coded their match contact intensities using the procedures outlined in table 1.3. At the beginning of 2022, a group of Super Rugby players were invited to watch individual video clips of contacts they were involved in. The process involved player interviews, with a total of 3-4 players each week across six weeks of matches. In total, 19 participants completed the interviews where they were required to watch individual contact clips and verbally recite their perceived magnitude of impact for each contact they experienced during a match. Throughout the interview players had clear sight of the level of perceived contact intensity scale (adapted from Borg, 1982), found in figure 2. The interviews were conducted no later than 48 hours post-game to ensure players recollection of each contact was as clear and as fresh in their mind as possible when completing the RPCI interview. To support the justification of this methodology Scantlebury et al, (2018), study found positive correlation when validating the use of retrospective measures of session RPE.

The ratings collated from players were then compared to the original rating of perceived contact intensities generated (from figure 2) by the primary researcher (analyst). This data was used to compare the theoretically constructed contact intensities with the actual player determined contact intensities which we understand is unique.

Rating of Perceived Contact Load Scale (Chittenden, J. 2021)	
0	Rest
1	Really Light
2	Light
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really Hard
10	Maximal

Figure 2

Rating of Perceived Contact Intensity Scale

Step 5. Internal reliability of analyst and players contact intensities

To test the internal reliability of the contact coding methodology the primary researcher repeated their coding of the same match three times, first on the 27th February, second on the 26th July and finally on the 29th August. This was to examine whether the primary researcher was consistently coding the same contact intensities throughout the duration of a match.

To test the internal reliability of the level of perceived contact intensity scale the primary researcher repeated one RPCI interview twice with a randomly selected player. First on the 29th of March and the second on the 4th of April. This was to examine whether players were interpreting the rating of perceived contact intensity consistently.

Step 6. Statistical Analysis

The differences between the coders perceived intensity and the players perceived intensity for each type of contact was determined using IBM SPSS (Version 28). Descriptive statistics were calculated for all variables, and presented as mean and standard deviation.

To examine how ratings of perceived contact differed between accessor groups (analyst, player), a series of linear mixed-effect models were fit (Aim 2). The dependant variable was the perceived contact rating (1—10), while the accessor group was specified as a fixed effect. To account for the repeated measures, player was specified as a random intercept in all models. Next, position group (forwards, backs), position (fullback, halfback, hooker, lock, loose-forward, midfield, prop, wing), and contact metric (Attack OOA hard, Attack OOA min, etc…) were added as additional fixed effects (with an interaction term specified with accessor group) to examine if the difference between analyst and player ratings varied across these variables (Aim 3). For all models, estimated means (and 95% confidence intervals) were calculated for each group. Pairwise contrasts (and 95% confidence intervals) between each pair of groups were determined, and p values were adjusted for multiple comparisons using the Bonferroni correction.

To determine the reliability of the analyst ratings (Aim 4), the three repeat ratings performed by the analyst were analysed using an intraclass correlation coefficient (ICC). A two-way mixed model, single measures, absolute agreement model was specified to test intra-rater reliability. This analysis was stratified by contact metric, to obtain a reliability estimate (and 95% confidence interval) for each metric. This analysis was also repeated for the player ratings (2 x repeats).

2.2.4. Demonstration

Table 1.5

Season Summary Table

Contact Metric	Mean Count	Standard Deviation
Att OOA, Min	1.7	1.2
Att OOA, Hard	4.5	3.9
Def OOA, Min	1	0
Def OOA, Hard	2.2	1.4
Hit Up, Min	1.7	1.2
Hit Up, Hard	4.3	2.5
Tackle, Min	2	0.9
Tackle, Hard	5.9	4.2
LO Off, Min	1.6	0.5
LO Off, Hard	2.4	1.5
LO Def, Min	3.7	3.7
LO Def, Hard	2.3	1
Maul Off, Hard	1	0
Maul Off, Max	1.4	0.7
Maul Def, Hard	1	0
Maul Def, Max	1.8	1.5
Scrum Off, Hard	2.5	0.7
Scrum Off, Max	2.7	2.7
Scrum Def, Hard	1	NA
Scrum Def, Max	2.3	1.9

Table 1.5 below summarises the mean count and standard deviation of all contact metrics analysed within this action design research process.

Table 1.6

Difference between Player and Analyst contact ratings by various position groups

	Various Factors	Mean		*n*	Difference (95% CI)	p value
		Analyst	Player			
Overall		5.767	3.685	896	2.082 (1.753, 2.410)	< 0.001
Group	Backs	5.547	3.792	318	1.755 (1.227, 2.282)	< 0.001
	Forwards	5.986	3.578	578	2.408 (2.017, 2.799)	< 0.001
Position	Fullback	6.000	6.429	28	0.429 (-1.318, 2.175)	0.63
	Half-back	5.455	3.409	44	2.045 (0.652, 3.439)	0.004
	Hooker	5.500	2.688	64	2.813 (1.657, 3.968)	< 0.001
	Lock	6.087	4.467	184	1.620 (0.938, 2.301)	< 0.001
	Loose-Forward	6.000	3.152	66	2.848 (1.711, 3.986)	< 0.001
	Midfield	5.625	3.375	128	2.250 (1.433, 3.067)	< 0.001
	Prop	6.030	3.280	264	2.750 (2.181, 3.319)	< 0.001
	Wing	5.390	3.763	118	1.627 (0.776, 2.478)	< 0.001

** The player values are the averages of those provided in the interview for the specified position groups.*
** The analyst values are the average value provided by the primary coder for the specified position groups.*
** n = number of contact events overall, by group and by position.*

The player ratings of the contact intensities overall and by position were almost exclusively significantly lower than the analysts coded intensities, with the only difference to this trend being the fullback (see table 1.6).

Table 1.7

Difference between Player and Analyst contact ratings for the contact metrics

	Various Factors	Mean		*n*	Difference (95% CI)	p value
		Analyst	Player			
Contact metric	Att OOA, Min	2.000	.409	44	1.591 (0.799, 2.383)	< 0.001
	Att OOA, Hard	6.000	3.627	151	2.373 (1.946, 2.801)	< 0.001
	Def OOA, Min	2.000	3.500	4	1.500 (-1.126, 4.126)	0.263
	Def OOA, Hard	6.000	3.172	58	2.828 (2.138, 3.517)	< 0.001
	Hit Up, Min	2.000	1.400	10	0.600 (-1.061, 2.261)	0.478
	Hit Up, Hard	6.000	4.507	137	1.493 (1.044, 1.941)	< 0.001
	Tackle, Min	2.000	1.667	24	0.333 (-0.739, 1.405)	0.542
	Tackle, Hard	6.000	4.110	200	1.890 (1.519, 2.261)	< 0.001
	LO Off, Min	2.000	.462	26	1.538 (0.509, 2.568)	0.003
	LO Off, Hard	6.000	2.750	24	3.250 (2.178, 4.322)	< 0.001
	LO Def, Min	2.000	.346	52	1.654 (0.926, 2.382)	< 0.001
	LO Def, Hard	6.000	2.556	18	1.654 (2.207, 4.682)	< 0.001
	Maul Off, Hard	6.000	4.000	6	2.000 (-0.144, 4.144)	0.067
	Maul Off, Max	10.000	4.000	28	6.000 (5.008, 6.992)	< 0.001
	Maul Def, Hard	6.000	3.250	8	2.750 (0.893, 4.607)	0.004
	Maul Def, Max	10.000	4.429	14	5.571 (4.168, 6.975)	< 0.001
	Scrum Off, Hard	6.000	7.600	10	1.600 (-0.061, 3.261)	0.059
	Scrum Off, Max	10.000	7.250	48	2.750 (1.992, 3.508)	< 0.001
	Scrum Def, Hard	6.000	8.000	2	2.000 (-1.714, 5.714)	0.291
	Scrum Def, Max	10.000	6.563	32	3.438 (2.509, 4.366)	< 0.001

**The player values are the averages of those provided in the interview for the specified contact metric*
**The analyst values are the average value provided by the primary coder for the specified contact metric*
** n = number of contact events overall, by contact metric*

The player ratings of the contact intensities by event were generally significantly lower than the analysts coded intensities, with the only differences being scrum offence and defence hard (see table 1.7).

Table 1.8

Coding Reliability (Three repeated measures by analyst)

Contact Metric	ICC (95% CI)	p value
Att OOA, Min	0.942 (0.889, 0.973)	< 0.001
Att OOA, Hard	0.994 (0.986, 0.997)	< 0.001
Def OOA, Min	0.711 (0.514, 0.853)	< 0.001
Def OOA, Hard	0.967 (0.935, 0.985)	< 0.001
Hit Up, Min	0.738 (0.537, 0.871)	< 0.001
Hit Up, Hard	0.981 (0.958, 0.992)	< 0.001
Tackle, Min	0.819 (0.642, 0.916)	< 0.001
Tackle, Hard	0.985 (0.970, 0.993)	< 0.001
LO Off, Min	0.993 (0.986, 0.997)	< 0.001
LO Off, Hard	1	.
LO Def, Min	0.979 (0.959, 0.990)	< 0.001
LO Def, Hard	1	.
Maul Off, Hard	0.397 (0.151, 0.643)	< 0.001
Maul Off, Max	1	.
Maul Def, Hard	0.682 (0.448, 0.841)	< 0.001
Maul Def, Max	1	.
Scrum Off, Hard	1	.
Scrum Off, Max	1	.
Scrum Def, Max	1	.

**The ICC value is the reliability value provided by the primary coder for the specified contact metric*

The values found in table 1.8 show very good reliability consistently across majority of contact metrics.

Table 1.9

RPC Reliability (Two repeated measures by player)

Contact Metric	ICC (95% CI)	p value
Player Z	0.851 (0.601, 0.950)	< 0.001

**The ICC value is the reliability value provided by the Rugby Player for the rating of perceived contact scale*

Table 1.9 depicts that the rating of perceived contact scale used within this project is a reliable source of information that can be used consistently over time.

2.2.5. Evaluation

As mentioned previously identifying the contact metrics in rugby and determining their intensities is important, but despite this there are currently limited studies and applied methods that address this. The reason for this is complex but primarily resides around the inability of the available technology to accurately measure contact intensity in situ. We therefore developed a novel time-motion coding methodology to identify the magnitudes of different types of contact events in professional male rugby union players during matches. From this pilot study the following insights were gained.

Firstly, a contact intensity measurement tool was developed and implemented, and the contact intensities determined by the research group were significantly higher than those determined by the players. Perhaps, one of the possible factors for this difference was that most of the experts had been away from playing the game for a while and maybe in that time the game had changed (i.e., the players regular exposure to heavy contacts had conditioned them to normalise this). The players may have scaled down the perceived contact intensity ratings during the interviews because of a sense of pride, to maintain a tough reputation, satisficing etc. While every attempt was taken to ensure the reviews were as close to the match as possible the reality was, they were typically 36–48 hours post-match to allow for the mandated time off. It is possible that this delay resulted in a change in the players true rating of the contact intensities. Ideally RPCI interviews should be conducted post-match. Interestingly during the interviews, the players examined their (and sometimes the opposition who they were coming into contact with) skill execution and technique, and these factors influenced their contact intensity rating. Furthermore, during the interviews players were often found selecting a contact intensity rating related to quality of the execution of the contact rather than purely it’s intensity rating. For example, they may have tried very hard (e.g., 10 out 10) but the execution was poor (e.g., 3 out 10) so they ranked it a three when the actual intensity was probably closer to ten (or somewhere between 3 and 10). One complication was different ratings of the same set-piece event, for example in the scrum the front row was often different to the locks who were in turn different to the loose forwards, all of whom were in the same contact event. So, while the defensive scrum provided an average intensity rating of six the players provided a wide range of perceived contact intensities due to their different roles in that scrum (e.g., the loose forwards noted they were more focussed on defending a scrum strike from the opposing team rather than inputting maximal contact workload during the scrum compared to say the front row).

Secondly given this was a pilot study we only explored the reliability of the methodology by assessing the intraclass correlations for one analyst coding the same match three times and one player ranking the contact intensities for the same match two times. The reliability tests performed show very good consistency, however further reliability assessments are necessary using more players and more analysts to gain an accurate view of the within and between player and analyst reliability of this methodology.

Despite this action design research methodology showing very good reliability, there are still some limitations to this approach. For example, visual cues that the coder is looking for to determine intensity of contact effort may differ between players. Two people doing the exact same thing may not be exerting the same amount of contact workload. How players behave at the contact event and the duration of time which they are involved in the contact event can be very different. Another limitation may be the long concentration span required to complete rating of perceived contact intensity interviews, which may have led to interviewee fatigue and inconsistency. One interesting factor is the forwards recorded a lot more contacts compared to backs similar to the study conducted by Quarrie et al. (2013). Hence, forwards completed RPCI interviews that were much longer than backs which may have led to more fatigue in this group and possibly less consistency in their responses.

Further examination needs to be undertaken to determine the validity of our contact coding system across all matches, players and events. Given there is currently no accurate contact measurement technology or methods available, it was not possible to validate our contact intensity rating methodology against actual player contact forces, contact workload and contact intensity. Despite the inability to empirically validate our methodology, our pilot work shows a hint of good reliability but more importantly this tool showed good expert face validity in that it was widely accepted by the players and coaches in the rugby team (who are arguably the experts in this area).

This time-motion system has the utility to be an effective monitoring tool for contact workload in rugby union. Practical take home implications include the ability to monitor overall player game day workloads which in turn helps inform the weekly training workload (both contact and locomotion). We would recommend using the player intensity ratings rather than the experts, as we believe the players perception to be more accurate in this instance than anyone else's. Understanding overall player workload is advantageous as it can be used to assess an individual's current condition and physical state (Gabbett et al. 2017). Additionally, long term advantages include access to more holistic individual athletic performance reports leading to a greater understanding of positional demands in rugby union. This information can in turn be used to ensure effective locomotion and contact workload periodization to encourage optimal physiological adaptions and maximize athletic potential (Windt & Gabbett, 2017).

Researchers in future should explore measuring contact workload by incorporating the duration of the contact event (i.e., rating of perceived contact intensity multiplied by time), specifically during set piece events such as scrums, mauls and rucks. This is because these contact events can experience an initial hit (impact) and then accumulate contact through continuous isometric forces which vary in length of time. In addition, an extension of this project could include a coach's perspective towards the rating of perceived contact measurement in rugby union. Likewise, continually searching for technology to measure contact workload is important. For example, the use of wearable technology that measures force (e.g., shoe sensors, shoulder pads or gloves), could prove worthy in deepening our understanding of individualised contact workload in rugby union.

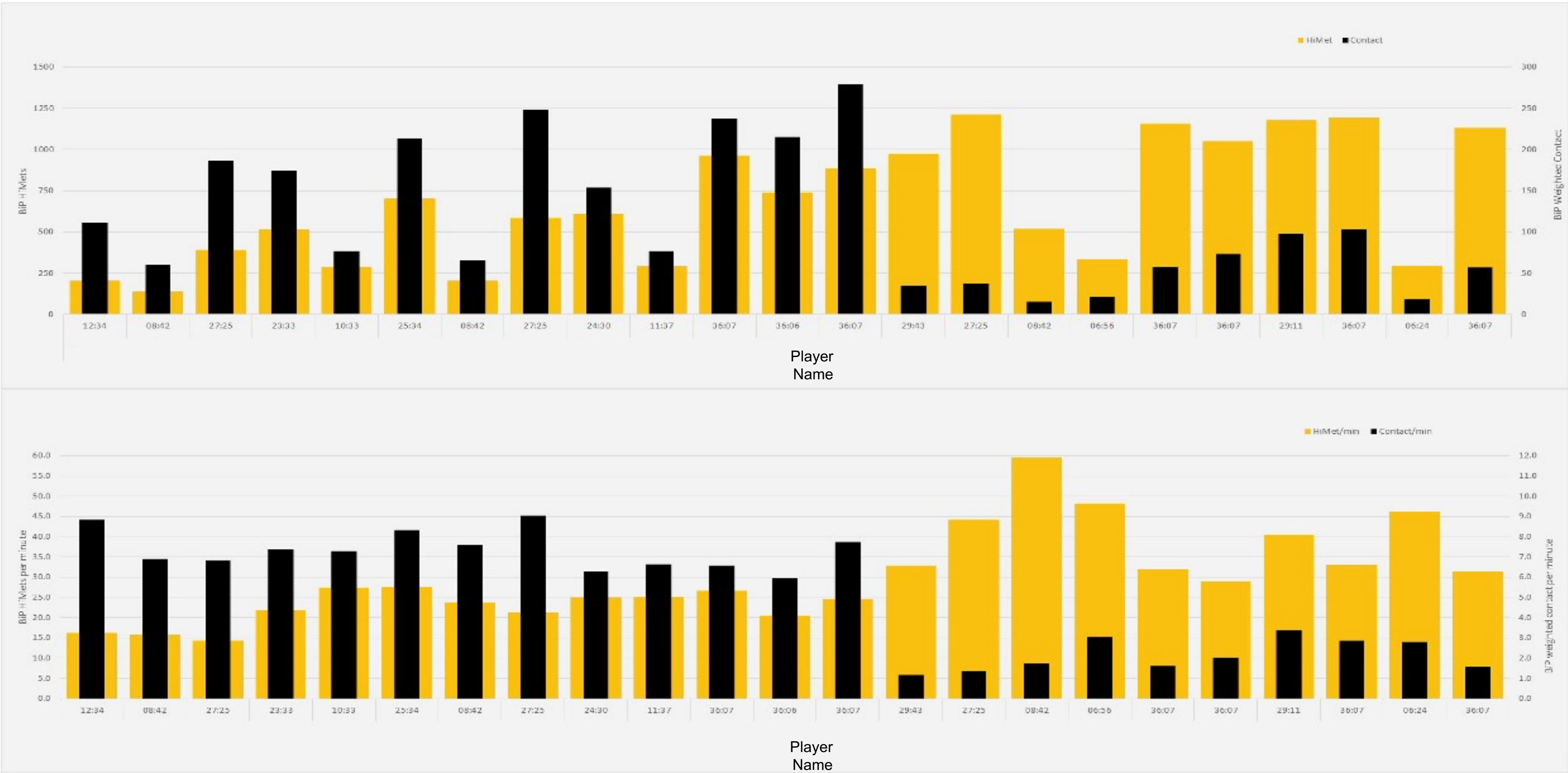
2.2.6. Communication

Due to the good reliability and team acceptance this contact workload methodology was integrated within match day reports. Throughout the 2021, 2022 and 2023 rugby season, contact workload results were communicated to the organisation which informed training interventions, player selection and finally individual player reviews. This action design research project moved from a conceptually sound project with strong pilot study reliability to a fully accepted and integrated match analysis tool. Initially we used expert ratings, now we use the player ratings to help inform the organisation around athletes in-game contact workloads. As shown in table 2.1 and figure 3 this contact workload data is now merged with other influential game day metrics such as player running load (e.g., high metabolic load).

Table 2.1 Difference between relative contact load intensity and relative running load intensity by player

Player name	BiP Time	Contact	HiMet	SpMet	Contact/min	HiMet/min	SpMet/min	CONTACT LOAD INTENSITY Total Plays	CONTACT LOAD INTENSITY Relative Trajectory	CONTACT LOAD INTENSITY Relative contact quality	RUNNING LOAD INTENSITY Total Plays	RUNNING LOAD INTENSITY Relative Trajectory	RUNNING LOAD INTENSITY Relative running quality
[redacted]	12:34	111	204	42	8.8	16.2	3.3	17	-2.30%	41%	18	-3.79%	-4%
[redacted]	08:42	60	137	16	6.9	15.7	1.8	11	0.87%	-17%	12	-6.57%	-31%
[redacted]	27:25	187	390	47	6.8	14.2	1.7	38	-2.70%	-22%	40	2.32%	-59%
[redacted]	23:33	174	515	85	7.4	21.9	3.6	31	1.01%	0%	34	1.78%	0%
[redacted]	10:33	77	289	40	7.3	27.4	3.8	13	3.92%	-13%	14	-12.17%	52%
[redacted]	25:34	213	703	143	8.3	27.5	5.6	36	0.83%	9%	38	1.04%	51%
[redacted]	08:42	66	206	35	7.6	23.7	4.0	11	-8.72%	9%	13	2.29%	-8%
[redacted]	27:25	248	585	85	9.0	21.3	3.1	38	1.26%	40%	40	-1.11%	-21%
[redacted]	24:30	154	611	117	6.3	24.9	4.8	28	0.39%	19%	37	-3.77%	-1%
[redacted]	11:37	77	292	78	6.6	25.1	6.7	11	0.47%	30%	15	-3.45%	32%
[redacted]	36:07	237	964	252	6.6	26.7	7.0	41	-0.62%	-2%	52	-1.21%	24%
[redacted]	36:06	215	738	158	6.0	20.4	4.4	44	0.44%	-29%	52	0.53%	-20%
[redacted]	36:07	279	884	190	7.7	24.5	5.3	48	-0.50%	11%	52	-0.45%	6%
[redacted]	29:43	35	975	289	1.2	32.8	9.7	9	0.32%	-29%	41	1.12%	-10%
[redacted]	27:25	37	1210	184	1.3	44.1	6.7	14	1.42%	-37%	38	-1.59%	56%
[redacted]	08:42	15	518	144	1.7	59.5	16.6	4	-8.98%	-33%	12	-6.57%	72%
[redacted]	06:56	21	334	95	3.0	48.2	13.7	5	-9.26%	-18%	10	12.33%	24%
[redacted]	36:07	58	1156	364	1.6	32.0	10.1	15	-2.73%	-21%	52	-1.70%	-17%
[redacted]	36:07	73	1049	372	2.0	29.0	10.3	18	1.32%	-19%	52	0.89%	-28%
[redacted]	29:11	98	1179	398	3.4	40.4	13.6	24	0.55%	15%	42	-1.93%	41%
[redacted]	36:07	103	1195	414	2.9	33.1	11.5	22	-0.19%	40%	52	1.16%	-17%
[redacted]	06:24	18	296	109	2.8	46.3	17.0	3	21.30%	99%	9	-11.44%	1%
[redacted]	36:07	57	1131	356	1.6	31.3	9.9	11	-1.33%	12%	52	0.55%	-26%

Key:
relative contact load quality = average weighted contact per minute for each player relative to the remaining forwards or backs. Anything above zero is above average which is good
relative running load quality = similar to above but for HiMets per minutes. Anything above zero (green) means player is above average which is good.
Relative trajectory = average change in relative contact or relative running load intensity over the period of the match
Arguably a good player will have a high relative contact quality and won't drop off much throughout their time on the field (i.e., two green numbers in both contact and running).
Please note, you should check the BiP time (2nd column) as those playing small BiP minutes should arguably have different values and patterns than those playing big minutes. Also it is possible for players to have BiP periods where they were involved in no contacts, hence the difference between total plays.



The above graph presents the total HiMets and the total weighted contact for the Ball in Play (BiP) periods during the match, this graph shows total locomotion and contact work. The below graph presents the average HiMets per minute (HiMet/min) and Weighted contact per minutes (Contact/min) for the BiP periods during the match, this graph shows average intensity of running and contact work. Both bar graphs include each player's BiP time.

Figure 3

Running and Weighted Contact Load Match Day Report

Conclusion

To conclude we developed and examined the accuracy of a novel time-motion methodology that identified and quantified the magnitudes of different types of contact events in professional male rugby union matches. Our pilot work found strong reliability yet, the difference between player contact intensities versus analyst contact intensities was largely significant across the majority of contact events. We therefore recommend that the player contact intensities are employed in any similar contact intensity coding system.

Greater insight around the complete physical workload experienced in this instance contact and locomotion in professional rugby union, can benefit athletic performance. Tee et al. (2016), educates readers about the importance of training specificity, thus quantifying all aspects of workload in rugby union helps create game specific trainings that can greatly enhance a team's development and preparation towards a match. The more resources applied to achieving this, the greater the chance of success.

References

Austin, D. J., Gabbett, T. J., & Jenkins, D. J. (2011). Repeated high-intensity exercise in a professional rugby league. *J Strength Cond Res*, *25*(7), 1898–1904. https://doi.org/10.1519/JSC.0b013e3181e83a5b

Borg, G. A. (1982). Psychophysical bases of percieved exertion. *Medicine and science in sports and exercise*, 14(5), 377–381. https://doi.org/10.1249/00005768-198205000-00012

Bragge, J. Gengler, C. Hui, W. Peffers, K. Rossi, M. Tuunanen, T. & Virtanen, V. (2006). *The DSR process: A model for producing and presenting information systems research.* International Conference on DSR in Information Systems and Technology DESRIST.

Clarke, N., Farthing, J. P., Norris, S. R., Arnold, B. E., & Lanovaz, J. L. (2013). Quantification of training load in Canadian football: application of session-RPE in collision-based team sports. *The Journal of Strength & Conditioning Research*, *27*(8), 2198–2205. DOI: 10.1519/JSC.0b013e31827e1334

Comyns, T., & Flanagan, E. P. (2013). Applications of the session rating of perceived exertion system in professional rugby union. *Strength & Conditioning Journal*, 35(6), 78–85. DOI: 10.1519/SSC.0000000000000015

Connell, G., & Spencer, K. (2020). A player effectiveness analysis system in elite football using an action design research framework. *South African Journal for Research in Sport, Physical 123 Education and Recreation*, 42(3), 1-10. Retrieved from: https://www.ajol.info/index.php/sajrs/article/view/202658

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

Delaney, J. A., Scott, T. J., Thornton, H. R., Bennett, K. J., Gay, D., Duthie, G. M., & Dascombe, B. J. (2015). Establishing Duration-Specific Running Intensities From Match-Play Analysis in Rugby League. *Int J Sports Physiol Perform*, *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

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Med*, *33*(13), 973–991. https://doi.org/10.2165/00007256200333130- 00003

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

Duthie, G. M. (2006). A framework for the physical development of elite rugby union players. *Int J Sports Physiol Perform, 1*(1), 2–13. https://doi.org/10.1123/ijspp.1.1.2

Fuller, C. W., Brooks, J. H., Cancea, R. J., Hall, J., & Kemp, S. P. (2007). Contact events in rugby union and their propensity to cause injury. *British journal of sports medicine*, *41*(12), 862–867. http://dx.doi.org/10.1136/bjsm.2007.037499

Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2011). Physcial collisions and injury in professional rugby league match-play. *Journal of Science and Medicine in Sport, 14*(3), 210–215. DOI: 10.1016/j.jsams.2011.01.002

Hevner, A., March, S., & Park, J. (2004). Design Science in Information Systems research. *Management Information Systems Quarterly*, 28 (1), 75-105.

Hughes, M. (2004). Notational analysis-a mathematical perspective. *International Journal of Performance Analysis in Sport, 4*(2), 97–139. https://doi.org/10.1080/24748668.2004.11868308

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. *Eur J Sport Sci*, *15*(6), 488–496. https://doi.org/10.1080/17461391.2015.1010106

Karmokar, S. (2013). *Improving Website design process of SME's: A design science perspective*. Thesis submitted for: Doctor of Philosophy, Auckland University of Technology.
Retrieved from: http://aut.researchgateway.ac.nz/handle/10292/5786

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 Med Open*, *6*(1), 6. https://doi.org/10.1186/s40798-019-0233-9

Nicholas, C. W. (1997). Anthropometric and physiological characteristics of rugby union football players. *Sports Medicine*, *23*, 375–396. https://doi.org/10.2165/00007256-199723060-00004

O'donoghue, P. (2009). *Research methods for sports performance analysis.* Routledge

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. *J Sports Sci*, *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 Med Open*, *8*(1), 12. https://doi.org/10.1186/s40798-021-00398-4

Petersson, A.M., & Lundberg, J. (2016). Applying action design research (ADR) to develop concept generation and selection methods. *Procedia CIRP*, *50*, 222–227. https://doi.org/10.1016/j.procir.2016.05.024.

Scantlebury, S., Till, K., Sawczuk, T., Phibbs, P., & Jones, B. (2018). Validity of Retrospective Session Rating of Perceived Exertion to Quantify Training Load in youth Athletes. *Journal of strength and conditioning research*, *32*(7), 1975–1980. https://doi.org/10.1519/JSC.0000000000002099

Sein M, Henfridsson O, Purao S, Rossi M, Lindgren R. Action design research. MIS Q 2011;35:37-56.

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. *J Sci Med Sport*, *21*(10), 1090–1094. https://doi.org/10.1016/j.jsams.2018.02.015

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. DOI: http://dx.doi.org/10.1016/j.jsams.2012.08.005

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

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

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

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

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. (2011). Action design research. *MIS quarterly*, 37–56. https://doi.org/10.2307/23043488

Smart, D. J., Gill, N. D., Beaven, C. M., Cook, C. J., & Blazevich, A. J. (2008). The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *Br J Sports Med*, *42*(3), 198–201. https://doi.org/10.1136/bjsm.2007.040162

Tee, J. C., Lambert, M. I., & Coopoo, Y. (2016). GPS comparison of training activities and game demands of professional rugby union. *International Journal of Sports Science & Coaching, 11*(2), 200–211. DOI: https://doi.org/10.1177/1747954116637153

Thomas, G. L., & Wilson, M. R. (2015). Playing by the rules: a developmentally appropriate introduction to rugby union. *International Journal of Sports Science & Coaching*, *10*(2-3), 413–423. https://doi.org/10.1260/1747-9541.10.2-3.413

Till, K., Hendricks, S., Scantlebury, S., Dalton-Barron, N., Gill, N., den Hollander, S., ... & 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*, 1–15. DOI: 10.1080/17461391.2022.2160938

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

Windt, J., & Gabbett, T. J. (2017). How do training and competition workloads relate to injury? The workload-injury aetiology model. *British journal of sports medicine, 51*(5), 428–435. http://dx.doi.org/10.1136/bjsports-2016-096040

Appendices

Appendix A: Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:
20th July 2021

Project Title
Quantifying and Analysing Player Workloads in Professional Male Rugby Union

An Invitation:

Kia Ora.
You have been invited to participate in an integral research project that will contribute to the development of Rugby Union. Respectively, the [redacted] have declared support in undertaking this research project within their organisation.

This project is being undertaken by Jessica Chittenden from the faculty of Sport and Recreation at Auckland University of Technology (AUT), in the hope of completing a Masters in Sport, Exercise and Health.

Participation in this project will include completing a short online form. As a participant of this project if you chose to accept you may withdraw at any time. All data collected and analysed within this project will remain anonymous. It is important to note, participation in this project would be greatly appreciated however, it is voluntary, and no consequences will be given if you chose not to participate.

What is the purpose of this research?
This research is being undertaken in conjunction with AUT. We aim to firstly, develop a system for determining an athletes contact workload during a Rugby Union match. Having done this, the project also aims to then quantify the total locomotion workload provided by global positioning system (GPS) metrics alongside the newly developed contact workload metrics. Allowing a holistic analysis upon an individual's complete physical performance during a Rugby Union match. The findings of this research will be used for academic publications and evolve into a worthy source of sport science information within a high-performance environment.

How was I identified and why am I being invited to participate in this research?
You responded to a poster that was advertised within the [redacted] organisation. As a 2022 contracted Rugby player your weekly commitment an effort you provide is valuable information that we hope to include within this research project.

How do I agree to participate in this research?
Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible. Please fill out the provided consent form and return a signed copy to Jessica Chittenden.

What will happen in this research?

Two sources of routinely collected game day data will be accessed for this research. Firstly, the high metabolic rate (HiMets) GPS data collected at each game will be accessed. Secondly, from the routinely collected video footage (Sky broadcast and club end-on/side-on angles) of every game, each collision will be clipped as a separate piece of video. Each clipped video will then be used to determine the level of perceived contact within that collision.

If you chose to participate in this research project, the following will be required.
Watch video clips of collisions in which you are involved (approximately 15 minutes).
Complete a short (10 minutes) interview to rate the magnitude of impact of each collision using the level of perceived contact scale (LPC).
These ratings will then be collated with GPS collision data to improve our understanding of the magnitude of impact players experience during different contacts.

What are the discomforts and risks?
There should be no level of discomfort or risk when partaking in this project. Player welfare will be priority and involvement in this project will be simple. However, if the participant is feeling uncomfortable, they can withdraw from the project at any time.

How will these discomforts and risks be alleviated?
During the online form you will not be forced to answer any questions that may cause discomfort or distress. As a player you also have the ability to stop answering the online form at any time. To help mitigate any potential worries or issues before completing the online form, participants are welcome to email the primary researcher stating their concerns.

What are the benefits?
Participants:
- Contribute to the development of game day analytics that if successful may be adopted and applied to aid their future training programmes.
- Ability to monitor player workloads and weekly training schedules.
- Access to more holistic individual athletic performance reports.
- Greater understanding of positional demands in Rugby Union.

Organisations and Community:
- Enhanced coaching opportunities for both clubs.
- Player development can enhance with more research and resources.

Researcher:
- Understanding of trends and patterns relating to contact loads for individual Rugby Union positions.
- Opportunity for expansion into similar topic areas.
- Impact towards development programmes and grassroots knowledge.
- The primary researcher is seeking a Masters of Sport, Exercise and Health qualification.

How will my privacy be protected?
Participant's privacy will be of priority throughout the duration of the project. To respect the privacy of all participants, data published will be de-identified and aggregated. To protect player identity results will be referred to by positional status (e.g. lock, halfback, prop etc.). In addition, to offer more confidentiality team names will not be used within this project. Any queries or concerns are welcomed to be addressed to the primary researcher as they arrive.

What are the costs of participating in this research?

No monetary requirements are needed to be involved in this study. However, as a participant you may potentially need to provide 10-minutes of your time one training week to complete rating of percieved contact interview.

What opportunity do I have to consider this invitation?
Three weeks is the allocated amount of time to consider partaking in this research project. If you chose to partake, please return a signed copy of a consent form to Jessica Chittenden (primary researcher).

Will I receive feedback on the results of this research?
Participants will be able to receive feedback on these results. A full season report and summary will be completed for each player participating in this project.

What do I do if I have concerns about this research?
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,
Name: Associate Professor Kirsten Spencer
Email: kirsten.spencer@aut.ac.nz
Phone: + 64 (0)921 9999 Ext 7239
Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, ethics@aut.ac.nz , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?
Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:
Name: Jessica Chittenden
Email: jess.chittenden99@gmail.com
Phone: 027 496 8000
Project Supervisor Contact Details:
Name: Associate Professor Kirsten Spencer
Email: kirsten.spencer@aut.ac.nz
Phone: + 64 (0)921 9999 Ext 7239
Approved by the Auckland University of Technology Ethics Committee on type the date final ethics approval was granted, AUTEC Reference number type the reference number.

Appendix B: Participant Consent Form

Consent Form

Project title: Quantifying and Analysing Player Workloads in Professional Male Rugby Union

The objective is to quantify the total locomotion workload provided by global positioning units (GPS) metrics alongside the newly developed contact workload metrics. Allowing a holistic analysis upon an individual's complete physical performance during a Rugby Union match.

Project Supervisor: Associate Professor Kirsten Spencer

Researcher: Jessica Chittenden

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 20th July 2021
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way. However, once the findings have been produced, removal of my data may not be possible.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I agree to take part in this research.
- ○ I agree that the primary researcher can have access to routinely collected video capture of in-season games.
- ○ I agree that the primary researcher can have access to GPS performance data in-season games.
- ○ I wish to receive a summary of the research findings (please tick one):
  Yes○ No○

Participant's signature:

....……

Participant's name:

....……

Participant's Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Note: The Participant should retain a copy of this form.

Appendix C: Ethics Approval

13 September 2021
Kirsten Spencer
Faculty of Health and Environmental Sciences

Dear Kirsten

Re Ethics Application: **21/299 Quantifying and Analysing Player Workloads in Professional Male Rugby Union**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 13 September 2024.

Non-Standard Conditions of Approval

1. In the Consent Form provide yes and no tick boxes for agreeing to access routine data.
2. Please send through the translations when available.
3.

Non-standard conditions must be completed before commencing your study.
Nonstandard conditions do not need to be reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.
For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee
Cc: jess.chittenden99@gmail.com