Characterizing Heart Rate Differences Across Rugby Union Competition Levels

A thesis
submitted in partial fulfilment
of the requirements for the degree
of
Master of Health, Sport and Human Performance
at
The University of Waikato
by
Nikolas Koumandarakis

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2025

Abstract

Heart rate (HR) monitoring provides insight into the demands of rugby union and may be able to help discriminate between different levels of competition. There is limited data examining the differences in physiological responses among different levels of rugby union. Rugby union athletes from different levels of competition (n=15 School, n=15 Club, n=15 Professional, and n=15 International) were included in the study. HR was measured via chest straps worn during the game with specific variables compared between levels of competition (e.g. Average (Avg) HR (bpm), and HR during worst-case scenario (WCS) periods of play (1, 2, 3, 4 and 5 minutes). Data was collected from eight matches for International, six matches for Professional and Club, and with School only able to play four due to season constraints. A one-way ANOVA revealed statistically significant differences in Avg HR across the four competition levels ($p < 0.05$). School players recorded the highest Avg HR (175 ± 10 bpm), while International players had the lowest (159 ± 9 bpm). Club and Professional teams had similar values, with no significant difference between them ($p = 0.72$). This trend was consistent across both forwards and backs. WCS HRs over rolling 1–5-minute intervals followed the same pattern, with School players consistently recording the highest values and International players the lowest. The largest WCS difference was observed at the 2-minute interval between School (191 ± 9 bpm) and International (179 ± 6 bpm) teams. Tukey post-hoc tests confirmed that School and International were significantly different from all other groups, while Club and Professional teams did not differ significantly. To the authors knowledge, this study is the first to compare heart rate metrics through different levels of competition in rugby union and is timely as the age of professional players is getting lower. Coaches should consider accurately tailor training to prepare athletes for optimal performance across different levels of competition as HR provides an accurate measure of internal load and could be more effective than the commonly used measures of external load e.g. GPS.

Key words: Internal load, external load, team sports, cardiovascular responses

Acknowledgments

First, I would like to thank my supervisor, Nicholas Gill for his unwavering support and patience throughout this project. I could not have done it without you. I would also like to thank Martyn Beaven for connecting me with Dr. Gill and setting me up for success, as well as Brett Langley for his help in research methods and ethics.

Thanks to Sean Chenery for his collaboration in creating this project and his great team at the Waikato Institute of Technology. You all helped bring this project to life and I cannot thank you enough. I would also like to say thanks to Adam Hay for inviting me into his home and assisting in the data collection. I would also like to thank Han Gan for his assistance with statistics and data analytics. Thank you to Christos Argus for his incredible work ethic and help throughout.

Thank you to the University of Waikato staff at the Student Learning Centre and the Division of Health. You kept me up to date and answered all of my questions promptly.

Finally, I would of course like to thank my family and friends for their love and support throughout my time here in New Zealand.

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HR	Heart rate
Avg	Average
Max	Maximum
Min	Minimum
WCS	Worst case scenario

Chapter One: Literature Review

The game of rugby union was created in 1823 and is now a major worldwide sport with over 6.6 million players (Duthie et al., 2003). Since becoming a professional sport in 1995, more teams, and therefore more athletes have entered the sport around the world, creating a highly competitive environment that requires players to adapt as the level of play inevitably rises each season (Duthie et. al., 2003). This competitive nature of rugby union pushes athletes to continually develop greater strength, speed, and endurance to withstand the physical demands of match play (Duthie et al., 2003). Previous analysis of matches characterizes rugby union as a multidirectional invasion game that requires intermittent high-intensity efforts including sprinting, tackling, and other sport-specific skills such as rucking and scrummaging (Jones et. al., 2016). Accordingly, players must consistently train the many aspects to prepare themselves to handle the high levels of physical load while maximizing performance and minimizing the risk of injury. It is known that the training process in sports involves systematically applying physiological and biomechanical stress to achieve specific outcomes, with results depending on training volume, intensity, and frequency all combined as total training load (McLaren et. al., 2017). Sufficient aerobic conditioning is known to support recovery and sustained performance in team sports like rugby, making it an essential component of player development (Stone & Kilding, 2009). According to a review by Bridgeman et. al. (2021) "players cover distances of between 5000 and 7000 [meters] during matches with backs covering greater HSR [high-speed running] distances while forwards are involved in more impacts, collisions and static work (e.g. mauls and scrums)" (p. 3). Measuring player load has become paramount, especially at the top levels of professional rugby, where recent changes in game rules, strategy, and average (Avg) player body composition necessitate new data on player performance (Duthie et. al., 2003). This data is necessary as it provides insights into the effectiveness of current strength and conditioning practices and allows coaches to more efficiently manage their team, ensuring maximized performance and minimized injuries. Coaches and researchers alike must pay careful attention to how much total load the players are exposed to during training and games to ensure that their training adequately prepares the athletes for elite levels of performance and longevity in the game.

By measuring player load during training and matches, coaches can accurately quantify the volume and intensity of load an individual is exposed to and how they respond. Measuring player load has become increasingly important as the game evolves. At the top levels of international and professional rugby union, changes in rules and tactical strategies have influenced player body composition, favouring larger and faster athletes, which in turn alters the physical demands of the game and necessitates updated data on player performance (Duthie et al., 2003). Physical demands in rugby league, a different code of rugby, have been shown to vary significantly by playing standard, with higher competitive levels requiring greater repeated high-intensity efforts and overall match intensity (Gabbett, 2013). While many other sports have gathered significant data on player load, there have been few studies done with rugby players, with studies varying significantly in terms of methodology, making it difficult to come to any reliable conclusions (Bridgeman & Gill, 2021; McLaren et al., 2018). Additionally, due to ongoing improvements in remote technologies such as GPS and heart rate (HR) monitors, new data collection is needed as many previous studies may be inaccurate or simply rough estimations due to outdated methods (Bridgeman et. al., 2021). There also remains a significant gap in the literature focusing on the differences in demands among different levels of competition, such as the Premiership (top tier) compared to the Championship (second tier), where changes in playing standards may alter the respective demands on the players (Cousins et. al., 2023). There remains a lack of distinction between the different levels of competition, with most existing studies focusing only on one level or team at a time. Research examining how these demands differ across competition levels remains limited and inconsistent (Olsen et al., 2023; Smart et al., 2013). This literature review aims to synthesize past findings on the measurement and application of training and performance load, as well as identify gaps and limitations where future research into the different levels of competition in rugby union can help to further the field.

Rugby

To provide a deeper understanding of load monitoring and management, one must first understand the sport of rugby, the training process, and the physical demands of the players. Firstly, rugby has multiple different codes which all contain slightly different rules such as rugby league and rugby sevens; however, this review will focus mainly on rugby union. Rugby union is played with 15 players on each side on a 100m by 68-70m grass field with the objective of invading the opposition's half with the ball and scoring a "try" in the opposition's end zone. Games are 80 minutes long and separated into two 40-minute halves by a 15-minute halftime period. Due to the variation in gameplay and the high number of players on each side, specialization in positions is a defining characteristic of rugby and one that makes load monitoring slightly more complicated than individual sports like running or swimming (Duthie et. al., 2003). The main difference in positions is between the forwards and backs. The forwards, numbers 1-8, are typically larger and stronger players who have a bigger role in terms of tackling and set-piece play such as scrums and lineouts (Duthie et al., 2003). On the other hand, the backs, numbers 9-15, are usually smaller and faster with more emphasis on skills like passing and ball running (Duthie et al., 2003). It is known that a significant difference exists between forwards and backs in terms of demand during training and matches, with forwards experiencing a greater demand in tackles and contact areas, and backs covering more distance and running at higher speeds (Cousins et. al., 2023). Among the forwards and backs groups, there are further divisions in position with high levels of specification, such as the front row (#1-3) versus the locks (4 and 5), loose forwards (6-8), inside backs (9-10), midfielder (12 and

13), and outside backs (11, 14, 15) all of which encounter different demands due to their position specific roles. This specification among positions is a defining characteristic of rugby union “when compared with a number of other team sports where homogeneity of physique and physical performance attributes are more common” (Duthie et. al., 2003, p. 975). The physical demands of rugby union vary substantially by position, reflecting differences in tactical roles and physiological requirements. Front row players are primarily involved in frequent collisions, scrummaging, and short-distance efforts, while locks also contribute heavily to set-pieces and defensive rucks. Loose forwards exhibit the highest overall workload per minute among forwards, combining frequent impacts with substantial movement. Acceleration profiles and exercise-to-recovery ratios have shown clear positional differences in rugby union, with back row forwards performing more high-intensity accelerations and front row players engaging in more static efforts, while overall workloads remain similar between roles (Lacome et al., 2014). Inside backs cover the greatest distance per minute among backs due to their dual role in attack and defence, while outside backs perform at the highest running speeds to act as strike players in attack and exploit space in the defence (Lindsay et al., 2015). Rugby matches are also separated into two playing halves, with usually a 10-minute break in the halftime like many other field-sports. Work rate declines in the second half of rugby sevens matches, reflecting fatigue from the sport’s high-intensity intermittent demands (Ball, Halaki, & Orr, 2019). Among researchers, there is a call for specificity of standards and thresholds when measuring player load to avoid over and underestimations as many studies conclude dissenting findings depending on their methodology. Furthermore, the measurement of one aspect of player load has been shown to be inadequate in measuring the true amount of load present, which has created a need for future studies with multiple different measures to avoid any more estimations. It has been shown that a combination of multiple measures for both external load and internal load provides the clearest data as to the true demands of rugby (Weaving et. al., 2014).

Wearable Technology

The rise of wearable technologies has revolutionized how both external and internal load is monitored in rugby union. Polar HR monitors and Statsports GPS systems have become standard tools for coaches and researchers seeking to identify player demands. This technology allows users to collect real-time data on both the physiological responses of athletes and the physical actions performed during matches and training sessions, bridging the gap between laboratory measurement and on-field application (Bridgeman et al., 2021).

Wearable technologies are small, lightweight, non-invasive devices worn on the chest or on the back between the shoulder blades. The device is inserted into a tight but comfortable bib worn over the shoulders and chest, with optional HR monitors across the chest at the bottom underneath the pectorals, and the GPS monitor pocket on the top of the back. These systems have advanced significantly in recent years, improving the validity and reliability of external load measurements and offering positional specificity that older video-based or observational methods lacked (Cunniffe et al., 2009). Similarly, HR monitors from manufacturers such as Polar have enabled the non-invasive and continuous collection of internal load data outside of a controlled environment such as a laboratory, thereby increasing its environmental validity to on-field sports such as rugby. Together, these technologies have given coaches and sports scientists actionable insights into players' workload and recovery needs. However, some players may find the bibs and chest straps uncomfortable or distracting during play, potentially affecting compliance or even match performance. Despite this small limitation, the widespread use of wearable technologies has contributed significantly to the understanding of rugby union's demands. The combination of GPS and HR data has become the standard in field-based research, enabling practitioners to tailor training loads to match the specific demands of competition more accurately (Bridgeman & Gill, 2021; McLaren et al., 2018).

The continued refinement and integration of multi-modal monitoring protocols make wearable technology invaluable tools in both research and practice. Their ability to simultaneously capture external actions and internal physiological responses makes them the current standard of modern load monitoring, providing the foundation for more individualized approaches to player preparation and comparison.

External Load

External load refers to "the physical workload encountered by the player (i.e., the stimulus imposed) and is often measured as exposure time (either total duration or time spent completing individual activities), speed, distance, movement volume, or movement intensity" (Fox et. al., 2018, p. 2746). These types of metrics provide valuable insight into the intensity and frequency of a player's movements and help quantify the physical load that the players undertake during training and/or games. Traditional methods of calculating external load relied on observations, such as manually timing work:rest ratios from game footage or while watching training sessions (Cunniffe et. al., 2009). One traditional method for quantifying the physical demands of rugby includes time motion analysis, through which movement, distance, velocity, and work:rest ratios can be identified by measuring time spent in different actions (Duthie et. al., 2003). Video analysis techniques to quantify external load have been a preferred method in past studies on rugby and other team sports; however, "its validity is questionable because time-motion analysis simplifies movement patterns into categories, when actual play involves a dynamic combination of tasks, skills and tactics" (Duthie et. al., 2003, p.983). Most older methods of calculating external load relied heavily on broad estimations and lacked any reliable data for the population to refer to. In recent years, due to a new rise of remote technologies such as global positioning systems (GPS), researchers have a better understanding of the individual external loads placed on players and how to more efficiently prepare for them. GPS allows for accurate measures of Avg external demands throughout a game and maximum (Max) demands over a particular time within a game, which allows for more precise data as opposed to general averages that may underestimate the true external load (Bridgeman et. al., 2021). By using satellite triangulation and Doppler shift methods, micro-GPS receivers worn by players can measure objective distance and speed calculations that were once more subjective, creating more accurate training methods that more closely relate to the demands of games (Cunniffe et. al., 2009). In addition to GPS, accelerometers (AS) have also been found to be reliable measures of impacts and collisions, an extremely important aspect of rugby that had previously been difficult to accurately calculate (Bridgeman et. al., 2021). The combination of GPS and AS data can accurately quantify the complex external demands of games as well as ensure training sessions either mimic or exceed game demands to adequately prepare players (Bridgeman et. al., 2021). By quantifying external load, coaches and managers can help tailor training programs to optimize player performance and reduce the risk of injury. However, measuring the external load by itself does not provide enough information about the response from the player. Only when paired with a measure of internal load does external load measurement become clinically relevant.

Internal Load

Internal load monitoring shows the biochemical and biomechanical stress responses within the body in response to an external load (McLaren et. al., 2017). The body's physiological response to external loads indicates the direct effects of demands on the individual and can be measured in many ways. Some common measures of internal load are HR, rate of perceived exertion (RPE), and hormonal or chemical markers. Resting, submaximal, and recovery heart rate measures are commonly used to monitor athletes' responses to training load, though their sensitivity varies across contexts (Buchheit, 2014). As with external load, measurement of internal training load can be difficult as one modality of assessment is oftentimes insufficient to identify and support the relationship between the external dose and the internal response (McLaren et. al., 2017). Over the course of a competitive season, professional rugby players can show reductions in lower body strength and power, and increases in hormonal markers of stress and fatigue, further highlighting the importance of effective load monitoring and management strategies (Argus et al., 2009). HR and its various forms have become a common measure of internal load as new remote technologies, such as wristwatches or chest straps, have opened new ways of non-invasively monitoring heart rate during training or games. It is known that "an individual's homeostatic stress response to training may reflect the magnitude of the imposed training stimulus and is hypothesized to contribute to individual variation in adaptation," with assessment of the autonomic nervous system using heart rate variability (HRV) providing the most accurate data (Flatt et. al., 2017, p.222). These new technologies provide researchers with real-time feedback on the cardiovascular responses to the demands of rugby and provide greater evidence as to the effectiveness of training. According to McLaren et. al. (2017), "measures of internal load derived from perceived exertion and heart rate show consistently positive associations with running and accelerometer-derived external loads and intensity during team-sport training and competition" (p.642) It has been shown that measures of HR are a reliable and valid measure of internal load, providing an in-depth look into the true demands of rugby. While laboratory assessments offer high reliability, field-based measures of internal load, such as HR monitoring, provide greater ecological validity and better reflect the specific demands of rugby match play (Reilly et al., 2009). By examining the strength of the relationship between external and internal load, coaches can adjust training however needed to ensure the highest levels of performance with the lowest chance for injury. Monitoring internal load using measures such as HR is a widely accepted approach to quantify athletes' responses to training and match demands, and has been associated with injury and illness risk when training loads are mismanaged (Drew & Finch, 2016). Internal load measures such as HR capture physiological strain and recovery status that are not fully explained by external load alone. Heishman et al. (2018) found that athletes with similar external loads could exhibit markedly different internal readiness and performance outcomes, highlighting the unique value of internal monitoring for identifying under-recovery and optimizing training.

Limitations/Future Research

Despite their advantages, the measurement of internal load has its limitations. The most obvious limitation for internal load monitoring in the current literature is differences in methodology and reporting. Differences such as equipment used, metrics collected, and even statistical analysis can make extrapolation of specific groups' results to larger populations difficult. According to a review by Bridgeman et. al. (2021), comparing results across different research studies is almost impossible due to the many present differences in methodology and reporting, with many studies not including the number of satellites that were connected as well as neglecting the horizontal dilution of position during data collection. GPS measurements are also limited due to the number of different models available, all of which may possess slightly different biases making a comparison of results unreliable. In addition, hormonal and chemical markers are highly invasive methods and often impractical for field use, while RPE, though valuable, remains subjective and prone to bias, making HR and HRV the most reliable and accessible internal load measures (Lupo et al., 2021). In terms of internal load monitoring using heart rate measures, there remain limitations as well. According to Cunniffe et. al. (2009), "it is possible that elevations in HR may have overpredicted aerobic demand because it has been suggested that changes in HR may not accurately reflect changes in energy cost occurring over short-term high-intensity activities" (p.1202). This is particularly important when measuring rugby as the sport demands many high-intensity movements requiring upper and lower body musculature, such as tackling and scrums that do not cover much distance, if any, but will display sharp increases in HR as a result. In a study measuring running demands and heart rate responses in rugby sevens players, a code of rugby that is known for its increased high-speed running distances compared to the typically slower code of rugby union, results showed that despite increased running activity in sevens rugby, Avg time spent at 90% HRmax was lower than in rugby union, with results speculated to have been affected by the high frequency of non-locomotive (low-running speed) actions such as pushing and pulling that are more present in rugby union (Suarez-Arrones et. al., 2012). Future studies should focus on accounting for these types of non-locomotive actions to more accurately measure demand. In addition, several outside factors can also artificially change HR that may affect the relationship between the observed external load and the internal response such as environmental temperature and psychological impact or emotions. In addition, there remains a gap in the literature comparing multiple levels of competition with internal load as the main measure, whereas there has been significant research done comparing levels of competition with external load.

Different Levels of Competition

Rugby union offers a clear competitive pathway through which athletes progress as they develop their physical, technical, and tactical abilities. Each level of competition presents unique challenges and demands that shape player development and performance, yet relatively few studies have comprehensively compared these levels, particularly with respect to internal load. Understanding these distinctions is critical for designing level-specific training, managing player workload, and supporting successful transitions between tiers.

At the foundation of this pathway are school-level players, typically aged ~17 years old and representing their secondary school teams. Despite its potential utility, HR monitoring is not widely adopted at lower levels of rugby, as coaches and support staff often report barriers such as time constraints, cost, and the need for immediate, practical feedback, favoring subjective monitoring tools instead (Starling & Lambert, 2018). These athletes are still in the early stages of physiological and tactical development, often displaying less efficient movement patterns, higher levels of psychological arousal, and limited exposure to structured training environments (Smart et. al., 2013). Deutsch et al. (1998) reported that elite under-19 players spent a large proportion of match time above 85% of their Max HR, indicating a high cardiovascular strain relative to their capacity. Youth rugby sevens players have been shown to sustain very high cardiovascular loads during matches, with both U15 and U19 players spending over half of match time above 90% HRmax, despite differences in running and sprinting demands between age groups (Wintershoven, Beaven, Gill, & McMaster, 2023). In junior rugby league players (~16.7 years), higher-standard teams demonstrated greater locomotor and collision demands during matches and experienced smaller performance decrements in the second half compared to lower-standard teams, highlighting the influence of competitive level on physical demands at the school age level (Gabbett, 2014). Positional differences are also apparent at the school level, with forwards typically experiencing greater internal load due to higher involvement in contact situations, while backs tend to accumulate more high-speed running but at lower overall cardiovascular strain (Cousins et al., 2023). Similarly, Smart et al. (2013) highlighted that amateur-level players tend to exhibit reduced physical and tactical proficiency compared to professional counterparts, suggesting that elevated internal load at this stage may stem from a combination of immaturity and inefficiency.

Above the school level are senior club players, who typically compete at an amateur or semi-professional level and serve as a bridge between youth development programs, such as Colleges and Universities, to professional teams. Club players often display improved fitness, skill execution, and understanding of tactical systems compared to school players, yet still fall short of the conditioning and efficiency observed at professional and international levels (Smart et al., 2013; Gabbett, 2013; Olsen et al., 2023). These findings reinforce the importance of targeted training programs at the club level to prepare players for the increased demands of professional rugby. At the club level, positional trends are likely to reflect the demands observed at higher levels such as semi-pro or professional, with forwards workload in set pieces and collisions contributing heavily to internal load and backs relying more on aerobic and high-speed running capacities. However, both internal and external load research at the club level remains sparse, creating a need for more data at this level to properly define and compare with the levels below and above it.

At the professional level, players typically demonstrate advanced physical conditioning, refined technical skills, and the ability to regulate effort effectively throughout a match (Smart et al., 2013; Olsen et al., 2023). Senior elite rugby league (NRL) matches are characterized by greater work rate, defensive efficiency, and technical execution compared to elite youth (U20) matches, with higher numbers of runs, tackles, and kicks and fewer missed tackles observed at the senior level (Woods, Robertson, Sinclair, Till, Pearce, & Leicht, 2018). Professional teams benefit from full-time strength and conditioning staff, advanced recovery protocols, and have greater experience competing under structured tactical systems. At the professional level, positional roles impose distinct internal and external demands, with backs performing more high-speed running and sprints while forwards spend more time above 85% of Max HR despite covering similar distances, reflecting the collision heavy nature of their role (McLellan, Lovell, & Gass, 2011). Strength and power profiles also differ markedly across levels of rugby union competition, with professional players demonstrating significantly greater upper and lower-body strength and power compared to semi-professional and amateur players (Argus et al., 2012).

At the pinnacle of the pathway there are international players, the highest standard of rugby union where players represent their home country competing around the world. The Avg age for international teams is ~27 years old, making them typically 10 years older than school players. These athletes exhibit the most efficient physiological and tactical profiles, characterized by superior conditioning, strategic pacing, and composure under pressure (Olsen et al., 2023; Smart et al., 2013). At the international level, rugby union imposes significantly greater physical demands than lower professional levels, with players covering more high-speed running and sustaining higher-intensity positional workloads, particularly among forwards in contact and backs in sprinting (Quarrie, Hopkins, Anthony, & Gill, 2013). Players competing at this level also experience significantly greater collision intensity and higher collision load compared to lower professional levels (Tierney, Blake, & Delahunt, 2021). International rugby sevens matches are characterized by longer ball-in-play sequences, greater frequencies of very-high-speed running and sprints, and superior technical execution, including more effective tackles and counter rucks and fewer handling errors, compared to provincial matches (Ross, Gill, & Cronin, 2015). Olsen et al. (2023) also observed that running demands increased significantly from club to international levels, yet internal load appeared to decrease, reflecting the players' ability to meet greater external demands without proportionally increasing physiological strain. Research in touch rugby has shown that although higher-level players perform greater relative high-intensity work, their internal load is often lower than that of lower-standard players, likely due to superior fitness and pacing strategies (Beaven et al., 2014). Internal load may not increase proportionally with the greater external demands observed at elite levels of play, suggesting an improved aerobic efficiency among players (Olsen et al., 2023; Cousins et al., 2023). This highlights the importance of understanding efficiency and preparedness at the international level, as well as the need for data driven benchmarks to inform talent identification and player development programs.

Despite these insights, significant gaps in the literature remain regarding internal load differences across competition levels. Many existing studies have focused on external load measures or examined a single level of competition in isolation, making it difficult to establish clear thresholds that differentiate tiers of play (Cunniffe et al., 2009; Suarez-Arrones et al., 2012; Portillo et al., 2014; Deutsch et al., 1998; Smart et al., 2013; Gabbett, 2013; Cousins et al., 2023). This study aims to address that gap by systematically comparing internal load across School, Club, Professional, and International rugby union, providing a complete HR profile at the individual, positional, and team levels.

Chapter Two: Introduction

Rugby union is characterized by intermittent high-intensity bursts of activity, such as sprints, tackles, rucks, and scrums, performed in a multidirectional playing environment that demands both physical versatility and tactical precision (Jones et al., 2016). Training must prepare athletes for repeated bouts of sprinting, tackling, rucking, and scrummaging, each contributing to the physical stress placed on the body. This diverse training stimulus influences the overall load, which is shaped by volume, intensity, and frequency, key components of total training load (McLaren et al., 2017).

As professional rugby union continues to evolve in intensity and structure, accurate monitoring of player load has become a cornerstone of performance analysis and injury prevention strategies (Bridgeman & Gill, 2021; McLaren et al., 2018). This load data is extremely important for the sport as it can provide insights into the effectiveness of current strength and conditioning practices and allows coaches to more efficiently manage their team ensuring the highest levels of performance and lowest risk of injuries. While many other sports have gathered significant data on player load, there have been few studies done with rugby players, with studies varying significantly in terms of methodology, making it difficult to come to any reliable conclusions (Fox et al., 2018; McLaren et al., 2018; Bridgeman & Gill, 2021; Duthie et al., 2003). Additionally, with the invention and implementation and consistent advancement in technologies, such as remote HR monitors, continual data collection is needed as many previous studies may be inaccurate or simply rough estimations due to outdated methods (Bridgeman et. al., 2021). There have been many more studies focusing on external load, such as distance and acceleration, than there have been on internal load.

Most studies focus on only one level of competition at a time, or at most two, mainly around professional and international. Differences in anthropometric and physical characteristics between professional and amateur players have been clearly documented, further reinforcing the need for level-specific training and load assessment strategies (Smart et al., 2013). Previous studies such as Portillo et al. (2014) have shown that international rugby sevens players exhibit higher HR responses compared to national-level players, finding increasing internal demands at higher levels of competition. Deutsch et al. (1998) reported that elite under-19 rugby union players spent substantial portions of match time above 85% of their Max HR, indicating the high cardiovascular demands placed on youth athletes during competition. Taylor et al. (2020) found that internal-to-external load ratios were reliable indicators of fitness and fatigue in academy rugby union players, reinforcing the value of HR monitoring for individualized training and load management.

To the author's knowledge, this is the first study to examine differences in internal load across four distinct levels of rugby union competition: School, Club, Professional, and International. By measuring HR metrics including Avg HR, Max HR, Min HR, and WCS across 1–5 minute intervals, this study aims to characterize the HR profiles unique to each level of competition by individual, positional group, and by team. The classification of these demands will assist players in tailoring their training for optimal performance at their current level and in preparing for progression to higher levels.

Chapter Three: Methods

This study used a cross-sectional comparative design to analyse differences in internal load, measured via HR, among rugby union players across four levels of competition: School, Club, Professional, and International. HR data was collected during official matches to provide insight into the physiological demands at each level. Each team contributed data from the starting 15 players only from each game measured due to constraints. All players were registered, actively participating in their respective competitions, and free of any medical conditions that could influence cardiovascular function. Players were excluded if they had a history of heart conditions, injuries that limited full match participation, or were taking medications known to affect heart rate.

Participants were recruited through their teams in collaboration with coaching and support staff, with research study information distributed via email or direct meetings. Informed consent was obtained prior to data collection, and each participant was provided a detailed information sheet and consent form outlining the study's purpose, procedures, risks, benefits, and their right to withdraw at any time. Ethical approval was granted by the Wintec Human Ethics Research Group, and further approved by the University of Waikato Human Research Ethics Committee (HREC).

HR data was collected using Polar HR monitors worn on the chest under players' jerseys in GPS vests. Measurements included Avg HR, Max HR, Min HR and WCS values calculated across 1–5 minute rolling intervals. Participants in the International team were tracked across 8 games, Professional and Club recording 6 games each, and School with 4 games. All players raw HR data was trimmed for periods of stoppages with only active time-on-field included in the final analysis. Data was extracted using the Polar mobile application Statsport, processed in Microsoft Excel, and analyzed in Minitab.

Statistical Analysis

All statistical analyses were conducted using Excel and Minitab software. Descriptive statistics (mean ± standard deviation) were calculated for all HR variables: Avg HR, Max HR, Min HR, and WCS values over rolling intervals of 1 to 5 minutes. All obvious malfunctions of equipment, identified by large gaps of missing or repeated data in the raw HR data files, were immediately discarded from the final analysis. All raw HR data files were analysed individually, then combined into a summary sheet to combine all individuals into their respective teams and positional groups. Further analysis was then conducted on the larger summary sheets to make broader comparisons between teams.

To identify statistically significant differences in HR metrics across the four levels of competition (International, Professional, Club, and School) a one-way analysis of variance (ANOVA) was employed. ANOVA is a statistical method used to compare the means of two or more independent groups and determine if at least one group's means differ significantly from the others. This approach allowed for the assessment and comparison of internal load variation between competition levels. ANOVA is appropriate for comparing means across more than two independent groups and is commonly used in sport science research to evaluate between-group variability (McLaren et al., 2018).

When significant differences were detected by ANOVA, Tukey's Honestly Significant Difference (HSD) post-hoc test was used to identify which specific group comparisons were significantly different. This method adjusts for the increased risk of Type I error when making multiple comparisons and is widely used in physiological and training load research (Weaving et al., 2014). Post-hoc grouping results were interpreted based on overlap in confidence intervals and group membership patterns (A, B, C, or D), which allowed for the identification of statistically similar groups versus significantly different ones.

Outliers greater than ±3 standard deviations from the mean were excluded prior to analysis to reduce the influence of extreme values, as per standard practice in training load studies (McLaren et al., 2018). Although normality and homogeneity of variance were assessed using graphical summaries in Minitab, the results of these assumption checks were not reported, and variance was assumed equal for all groups. The threshold for statistical significance was set at $p < .05$.

Chapter Four: Results and Discussion

Descriptive statistics (mean and standard deviation), one-way ANOVA tests with Tukey post-hoc comparisons, and box-and-whisker plots were used to examine differences in Avg HR and the WCS at intervals of 1-5 minutes across four levels of competition: International, Professional, Club, and School. All WCS data was calculated from rolling Avgs at each time interval (1-5 minutes) from the raw game data, with the highest value recorded as the Max or "worst" for each respective time-period. Analyses for both Avg HR and WCS were conducted using raw game data for all players across all matches played (8 International, 6 Professional and Club, 4 School) measuring HR (bpm) every 0.1 second for each player's total time-on-field. Comparisons were made between the four teams using all players group (playing position #1-15), as well as for Forwards (1-8), Backs (9-15), Front Row (1-3), Locks (4-5), Loose Forwards (6-8), Inside Backs (9-10), Midfielders (12-13), and Outside Backs (11, 14-15).

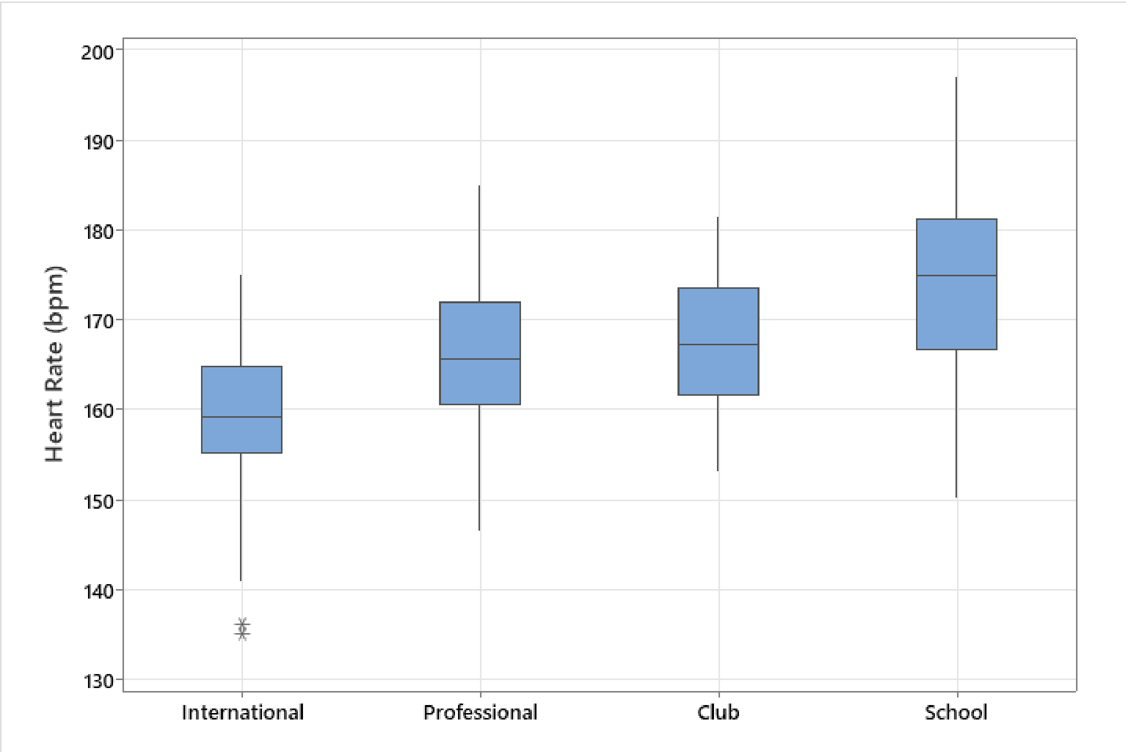
Table 1 *Mean (± SD) average heart rate (bpm) for all players (n=297), forwards (n=162), and backs (n=135) across four competition levels of rugby union*

Team	All Players	Forwards	Backs
International	159 ± 9*	161 ± 7*	156 ± 9*
Professional	166 ± 8	168 ± 8	164 ± 8
Club	167 ± 7	169 ± 6	166 ± 8
School	175 ± 10*	175 ± 12*	174 ± 8*

*Significantly different from all other groups (p<.05)
Note. values represent the mean of the Avg HR found across all games played by each competition level (8 International, 6 Professional and Club, 4 School)

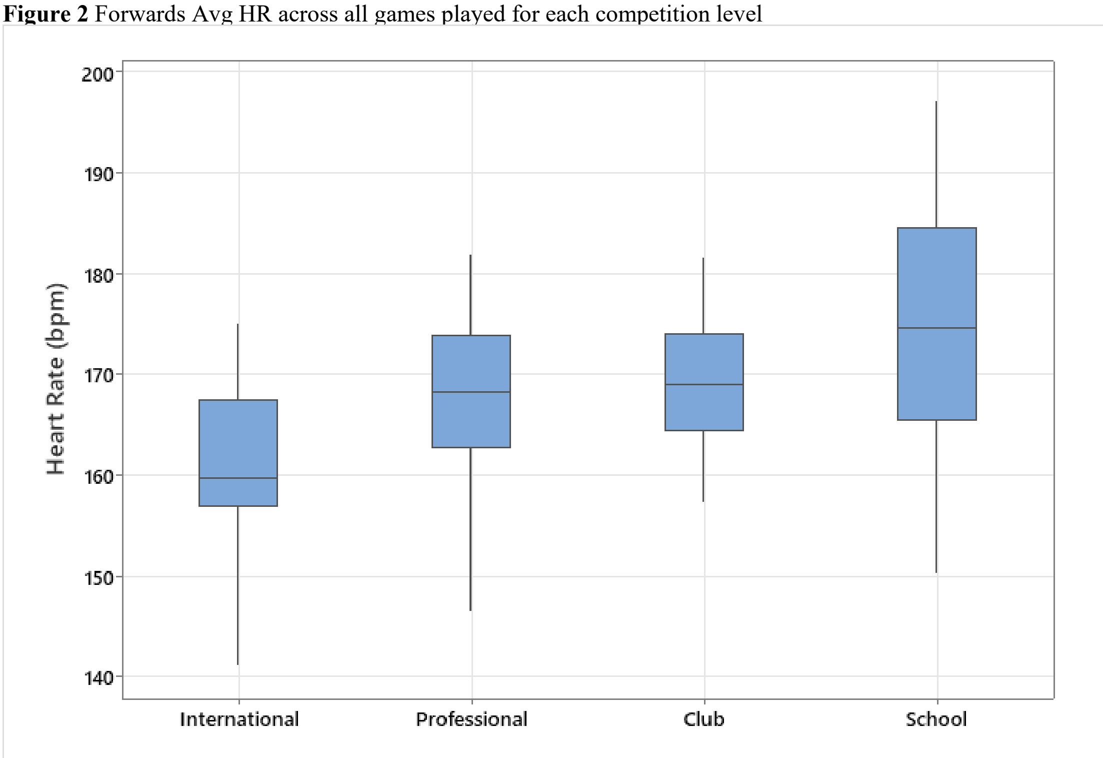
Avg HR was highest in the School players (175 ± 10 bpm) and lowest in the International players (159 ± 9 bpm), with a difference of 16 bpm, or 10% higher in School players ($p < .05$). This trend was consistent when comparing forwards and backs, with School players in both positional groups displaying higher Avg HR compared to all other levels. Club and Professional players recorded similar values, differing by only 1–2 bpm, which was not statistically significant. These findings highlight a progressive decrease in Avg HR as the level of competition increases.

Figure 1 Whole team Avg HR across all games played for each competition level



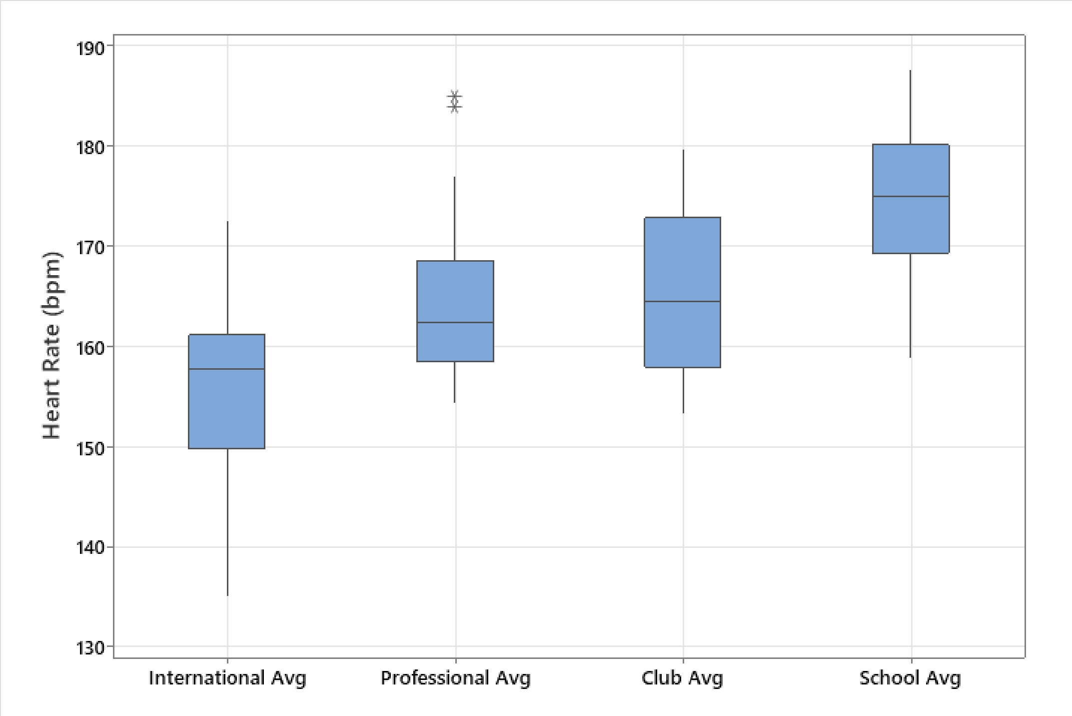
Among forwards, Avg HR was highest in School players (175 ± 12 bpm) and lowest in International players (161 ± 7 bpm), a difference of 14 bpm. This pattern was consistent with the whole team group, with School forwards significantly higher and International forwards significantly lower than all other levels (p<.05). Club (169 ± 6 bpm) and Professional (168 ± 8 bpm) forwards recorded similar values, with no significant difference between them.

Figure 2 Forwards Avg HR across all games played for each competition level



Among Backs, Avg HR was highest in School players (174 ± 8 bpm) and lowest in International players (156 ± 9 bpm), a difference of 18 bpm. Professional (164 ± 8 bpm) and Club (166 ± 8 bpm) Backs recorded intermediate values, with no significant difference between them. As with the Forwards, School Backs were significantly higher and International Backs significantly lower than all other levels ($p<.05$).

Figure 3 Backs Avg HR across all games played for each competition level



Positional group analysis identified that School players recorded the highest Avg HR across all positions, while International players recorded the lowest. The largest absolute difference was observed in the Front Row, where School players averaged 181 ± 10 bpm compared to 159 ± 8 bpm in International players, a 22 bpm (≈14%) difference. Similarly, Inside Backs and Midfielders showed large differences of 26 bpm (179 ± 7 bpm vs 153 ± 6 bpm) and 19 bpm (178 ± 4 bpm vs 159 ± 3 bpm), respectively. These three positions also displayed the greatest increases in Avg HR at the School level. Professional and Club players showed similar values across all positions, differing by no more than 2–3 bpm, with no significant differences detected between them.

Table 2 *Mean (± SD) average heart rate (bpm) for all positional groups across four levels of rugby union competition*

Team	Front Row	Locks	Loose FWD	Inside back	Midfield	Outside back
International	159 ± 8*	162 ± 5	162 ± 8	153 ± 6*	159 ± 3	157 ± 15
Professional	170 ± 7	166 ± 7	167 ± 10	165 ± 11	164 ± 7	164 ± 5
Club	170 ± 8	169 ± 5	168 ± 6	172 ± 5	162 ± 5	163 ± 8
School	181 ± 10*	172 ± 15	171 ± 10	179 ± 7	178 ± 4*	168 ± 6

*Significantly different from all other groups (p<.05)

A similar trend to Avg HR was observed across all WCS intervals (1-5 minutes), with the International team consistently recording the lowest values and the School team the highest. The largest difference found was between the International (179 ± 6) and School (191 ± 9) teams in the WCS-2 minutes interval with a difference of 12 bpm. Professional and Club teams showed similar WCS values across all intervals, with no significant differences found. Tukey post-hoc tests confirmed this pattern, with School grouped in **A**, Professional and Club both in **B**, and International in **C** for all WCS intervals ($p < 0.05$), indicating significant differences between all groups except Professional and Club.

Table 3 *Mean (± SD) Worst-Case Scenario Heart Rates (bpm) Over 1–5 Minute Intervals Across Four Competition Levels (International, Professional, Club, and School)*

WCS (min)	International	Professional	Club	School
1	183 ± 5*	187 ± 7	189 ± 7	194 ± 8*
2	179 ± 6*	184 ± 7	186 ± 7	191 ± 9*
3	177 ± 7*	182 ± 7	182 ± 7	188 ± 10*
4	175 ± 7*	180 ± 7	181 ± 7	186 ± 9*
5	174 ± 7*	178 ± 7	179 ± 7	185 ± 10*

*Significantly different from all other groups (p<.05)

Analysis of Avg HR across first and second halves showed a consistent decrease from the first to the second half at all competition levels. School players recorded the highest HR in both halves (176 ± 11 bpm first half; 173 ± 10 bpm second half), while International players recorded the lowest (161 ± 9 bpm; 157 ± 9 bpm). The largest absolute decrease between halves was observed in Club players, who dropped by 6 bpm from first (170 ± 8 bpm) to second half (164 ± 8 bpm). International and School players were significantly different from all other groups in both halves ($p < .05$), while no significant differences were observed between Club and Professional players.

Table 4 *Mean (± SD) average heart rate (bpm) for 1st and 2nd halves across four levels of rugby union competition*

Team	1st Half	2nd Half
International	161 ± 9*	157 ± 9*
Professional	167 ± 9	165 ± 8
Club	170 ± 8	164 ± 8
School	176 ± 11*	173 ± 10*

*Significantly different from all other groups (p<.05)

Note. values represent the mean of the Avg HR found across all games played, separated by playing half, by each competition level (8 International, 6 Professional and Club, 4 School)

Discussion

This study aimed to identify and examine differences in internal load, measured via HR metrics, across four levels of rugby union competition: International, Professional, Club, and School. The results revealed a clear and statistically significant downward trend in Avg HR and all WCS values from the School to the International level. These findings highlight how the physiological demands of rugby union differ across tiers of competition and underscore the importance of tailoring training programs to the specific level at which athletes compete.

Key findings indicated clear and statistically significant differences across levels, with School players consistently exhibiting higher Avg and WCS HR responses compared to their higher-level counterparts. Club and Professional teams displayed similar values, while International players recorded the lowest HR values across all metrics. These findings support the observed trend that internal load decreases as the level of competition increases, suggesting a progressive adaptation in physiological efficiency (Olsen et al., 2023; Smart et al., 2013).

The most important result was the elevated Avg HR in school players compared to all other groups. This may be attributed to several factors. Firstly, the younger age of school-level players is likely a primary driver of this difference. Age is known to influence max HR, and younger athletes also tend to have less accumulated time in structured training environments, limiting their cardiovascular development and game-specific fitness adaptations. Secondly, players at lower competitive levels typically have reduced cardiovascular fitness and less experience managing match intensity, leading to higher relative HR responses (Deutsch et al., 1998). The combination of physiological immaturity and limited exposure to high-level tactical systems likely amplifies internal load at the school level. The high HR responses observed in the school level players may reflect their lower biological maturity, which has been shown to increase internal load responses and reduce intensity management compared to more mature peers (García-Ceberino et al., 2024). School players likely experience elevated physiological strain during matches due to age related differences in physical development, technical efficiency, and tactical awareness (Wintershoven et al., 2023). Adolescent rugby training does not adequately replicate the high-intensity demands of match play, particularly in terms of sprinting and high-speed efforts (Hartwig et al., 2011). The elevated HRs observed in the school level players may reflect inefficiencies in their technical and tactical performance, similar to findings in professional rugby league where less-successful teams demonstrated higher physical output but poorer technical execution compared to more successful teams (Kempton et al., 2017). Psychological arousal and emotional stress may also contribute to increased internal load in these environments, particularly when athletes face unfamiliar opponents or elevated competitive stakes. In contrast, international players exhibited the lowest Avg HR and most compact HR distributions. These findings may reflect similar trends observed in other rugby codes, where higher-level players sustain greater external demands yet report lower internal load due to superior repeated-sprint ability and tactical pacing (Beaven et al., 2014).

Positional analysis also showed a consistent downward trend in Avg HR for both forwards and backs across each level of competition, aligning with the broader full-team results of this study. However, positional differences remained evident, with forwards recording slightly higher Avg HR and WCS values than backs at all levels. These differences likely stem from the higher contact demands and sustained effort requirements typical of forward play (e.g., rucking, scrummaging, mauling). Conversely, backs generally engage in more intermittent high-speed efforts with longer periods of lower intensity. Despite these distinctions, both groups exhibited the same pattern of progressively lower HR values at higher levels of play, indicating shared physiological adaptations regardless of position. The lack of clear HR differences between positional groups in this study, despite their distinct physical roles, is consistent with findings in international rugby sevens where backs performed more high-intensity movements and covered greater distances than forwards, yet exhibited similar HR responses (Higham et al., 2016). This suggests that internal load, as measured by HR, may not fully reflect the external work performed by different positions.

The WCS data adds to internal load analysis by capturing the most intensive match periods over 1–5 minute rolling intervals. The results identified that peak cardiovascular demands follow the same inverse pattern observed in Avg HR data. School players recorded the highest peak values across all WCS intervals, while international players recorded the lowest. Lower level players may operate closer to their maximal capacity during high load periods such as WCS compared to more elite players (Olsen et al., 2023). This supports the need for conditioning strategies that target high-intensity bursts, particularly at developmental levels where players may lack the fitness to manage repeated efforts (Stone & Kilding, 2009).

No statistically significant difference was found between club and professional players in either Avg HR or WCS metrics. HR responses during match play may not fully reflect differences in technical and tactical proficiency, as novice (≤1 year national/international competition) and experienced rugby players (≥5 years) have been shown to exhibit similar internal loads during small-sided games despite clear disparities in skill execution (Vaz, Leite, João, Gonçalves, & Sampaio, 2012). These findings are consistent with Atkins (2006), who reported no significant difference in intermittent recovery test performance between professional and semi-professional rugby league players, suggesting that internal load measures may not always scale linearly with playing standard. The results from this study may also reflect similarities in training practices, match tempo, and tactical approaches, especially where club teams are closely aligned with professional systems. In addition, senior club and professional players may be closer in age when compared to the large gap present between school age (~17) and international (~27). Similar ages among competition levels could support the similarities in HR response we observed between club and professional levels; however, no ages were collected prior to data collection so estimations will be used. As well as similar ages, these teams often share coaching staff, physical preparation models, and weekly scheduling, which may explain the physiological resemblance. While individual capacities can differ, consistent team-wide load management and strategic frameworks may result in similar internal load profiles.

From a practical standpoint, this study offers relevant applications for coaches, strength and conditioning professionals, and talent recruiters. Avg HR thresholds for each level provide a foundation for level-specific training design. School-level athletes preparing for elite play may benefit from aerobic conditioning and WCS-specific drills to simulate peak match demands and the intermittent nature of rugby union. These thresholds can also support talent identification processes, where internal load profiles serve as potential indicators of readiness. With individual, positional, and team-level HR profiles now identified, practitioners can assess readiness not just by absolute load, but relative to contextual norms across competition levels. This can support promotion decisions, monitor underprepared players, and create structured development benchmarks for both athletes and teams.

While this study presents a clear profile of internal load differences and accurate comparison across groups, several limitations must be acknowledged. This study did not collect anthropometric or physical performance data, which have been shown to distinguish players of different competitive levels, with international players demonstrating superior strength, power, speed, and aerobic capacity compared to provincial players (Ross, Gill, & Cronin, 2015). HR responses can also be influenced by psychological stress, environmental conditions, and hydration status. HR is influenced not only by training and match demands but also by environmental, psychological, and lifestyle factors, which can confound its interpretation as a measure of internal load in team sports (Schneider, Meyer, & Gabriel, 2018). Future research may benefit from adopting more holistic and context-sensitive approaches, as advocated by Colomer et al. (2020), to better capture the complexity of rugby performance. These factors were not controlled in this study and could have contributed to variability in the data, especially during high-intensity phases influencing the WCS recorded. In addition, the exclusion of players beyond the starting 15 reduces generalizability across full squads of 23 players. The starting 15 provides us with a strong look into the team as a whole with the best players typically being picked in the starting lineup who best represent their respective position; however, any substitutions were not measured, which may have affected our results. Time differences between first and second half were greatly affected by this, making comparisons across time difficult to accurately assess due to the high amount of variation in playing time across positions, especially when comparing forwards to backs as forwards typically use the majority of the substitutions during a typical match. In addition, HR monitors, though shown to be reliable, may underestimate short, anaerobic high-intensity efforts and non-locomotive demands such as scrummaging (Cunniffe et al., 2009; Dubois et al., 2017). Additionally, the lack of GPS or accelerometery data further limits interpretation of the internal-external load relationship (Bridgeman & Gill, 2021).

Future research should consider combining internal and external metrics to build a more complete picture of match load (McLaren et al., 2018). Internal load measures such as heart rate are widely used to quantify physiological responses in team sports; however, they capture only part of the overall demands and should ideally be complemented with external load metrics to provide a more comprehensive assessment of match load (Conte et al., 2022). Longitudinal studies that track athletes across transitions (e.g., school to club to professional) would also improve understanding of physiological development as an athlete age and progresses through the performance pathway (Olsen et al., 2023). Including varying game contexts (seasonal phase, opposition quality) would also help broaden generalizability and ensure research reflects the full spectrum of competitive rugby.

Chapter Five: Conclusion

This study characterized HR differences between four levels of rugby union competition by examining HR responses, specifically Avg HR, Max HR, and WCS HR values. A clear and statistically significant downward trend was found from school to international level players across all key metrics. These results suggest that internal load is not uniform across levels of rugby union competition and that players competing at higher levels may experience reduced cardiovascular strain, likely due to improved aerobic conditioning, tactical control, and game management. In contrast, players at lower levels exhibit higher HR responses, possibly due to both physiological immaturity and limited tactical and physical preparation.

By providing HR profiles for each level and positional group, this study offers practical insight for coaches, strength and conditioning staff, and performance analysts. School-level players, who showed the highest Avg and peak HR responses, may benefit from more targeted aerobic development and progressive exposure to high-intensity game scenarios to better prepare for advancement into higher competition levels. Conversely, the consistent values observed among club and professional teams suggest shared physiological characteristics that may guide talent pathway expectations. These findings may also contribute to recruitment or talent identification systems by offering HR-based benchmarks to assess physical readiness.

While HR monitoring provides a reliable and non-invasive way to assess internal load, it doesn't fully capture the complexity of rugby demands. Internal load is also influenced by external factors, such as emotional stress, environmental temperature, and hydration. Subjective indicators like RPE can offer real-time perceptual data to complement objective measures, especially when evaluating recovery and fatigue trends.

This study contributes to the growing body of literature examining internal load across the rugby union performance pathway. It reinforces the need for specific training strategies based on competition levels and provides new data for conditioning practices and player development models.

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Appendices

Note: All appendices list names and locations in direct collaboration with the creation and execution of this thesis and has been approved by both respective institutions.

Waikato Institute of Technology
Research Office
B Block, Tristram Street,
Hamilton 3240, New Zealand

Private Bag 3036, Waikato Mail Centre
Telephone +64 7 834 8800
Email research@wintec.ac.nz
www.wintec.ac.nz

Appendix A:

14 June 2024

Centre for Sport Science and Human Performance

Sean Chenery

Kia ora Sean,

HUMAN ETHICS RESEARCH APPLICATION

Approval reference: WTFE01100424-A

Title: Comparative running demands of rugby union players during match play: A comparison of age groups and playing levels

Thank you for submitting your Full Ethics application which was considered by the Chairperson of the Human Ethics in Research Group (HERG) on 14 June 2024.

I am pleased to inform you that ethics approval has been granted for this amendment. This approval is granted up to 30 June 2026, or until the project is completed, whichever comes first.

The Human Ethics in Research Group wishes you every success with this project.

Ngā mihi,

A Pilkington

p.p. Gillian Spry

Chairperson – Wintec Human Ethics in Research Group

Appendix B:
Comparative running demands of rugby union players during match play: A comparison of age groups and playing levels.

Primary Researcher: Sean Chenery

Primary Supervisor: Frans Van Der Merwe

External Supervisor: Christos Argus

External Supervisor: Nicolas Gill

This research aims to contrast and compare the match-based running demands of rugby union players from different age groups and playing levels in New Zealand. A secondary purpose is to establish normative data that may be used as part of a long-term athletic plan to optimally train rugby union players in the future.

Participants are expected to wear a GPS unit throughout the duration of the rugby union game. This GPS unit will be located on their upper back between their shoulder blades. The GPS will sit in a fitted slot on the provided GPS sports vest. The athlete is to continue with the game play as normal as the GPS will not impact/inhibit participant movement.

Duration of this study will be across six rugby games for each allocated team/athlete – Duration of game time will vary depending on the athlete.

The data will be collected via a GPS unit, located in a wearable bib worn under the teams playing kit. This GPS unit will gather specific metrics necessary for this study. This data will be uploaded to the GPS database and then transferred to an Excel spreadsheet for safe keeping.

The data collected via GPS will be analysed and compared against the other teams/levels and positional groups involved in this study. A one-way analysis of variance (one-way ANOVA) will be implemented to assess the differences between age groups and positional groupings. A further Bonferroni post hoc test will be applied to the data where significant main effects are observed to determine the significant differences across the analyses.

This study is not compulsory for the participant. However, participation is in this study would be beneficial for the study itself and greatly apricated by the staff involved.

Participants can withdraw from participating in this research. This can be accomplished either verbally to the primary researched or in writing via email (see contact details below).

No participant names will be included nor gathered during the entire process of this study. Specific team details too will be anonymous and untraceable to ensure total participant privacy. Collected data will be separated and analysed by specific positional groups.

Participants will not receive any incentives for participating in this research study due to the number of participants involved as well as no funding provided.

Results from this research study will not be made available until the completion of analysis and formal article. However, once this is complete the results will be available and accessible via the article.

Participants who require further details/enquires can contact the primary supervisor via email (see contact details below.

Name of Researcher/s: Sean Chenery **Contact Details**: seanchenery@hotmail.com

Date: 01/05/2024

Appendix C:

Comparative running demands of rugby union players during match play: A comparison of age groups and playing levels.

Participant Consent Form

(one copy to be retained by the Research Participant and one copy to be retained by Researcher)

I………………………………………………………… (participant's name) consent to being a participant in the above named research project, and I attest to the following:

1. I have been fully informed of the purpose and aims of this project.
2. I understand the nature of my participation.
3. I understand the benefits that may be derived from this project.
4. I understand that I may review my contributions at any time without penalty.
5. I understand that I will be treated respectfully, fairly, and honestly by the researcher/s, and I agree to treat the other participants in the same way.
6. I understand that I will be offered the opportunity to debrief during, or at the conclusion of this project.
7. I have been informed of any potential harmful consequences to me by taking part in this project.
8. I understand that I may withdraw from the project at any time (without any penalties)
9. I understand that my anonymity and privacy are guaranteed, except where I consent to waive them.
10. I understand that information gathered from me will be treated with confidentiality, except where I consent to waive that confidentiality.
11. I agree to maintain the anonymity and privacy of other participants, and the confidentiality of the information they contribute.

12. I understand that information gathered may be used for publication. i.e. journal, conference.

Primary Positional Group: (circle one)

Front Row Lock Loosie Inside Back Midfield Back Outside Back

Body Weight (kg): ____________ **Body Height (cm): ________________**

Participant………………………………………………………… Date……………

Researcher: Sean Chenery Date: 18th June

Supervisor: Frans van der Merwe Date: 18th June

Supervisor: Christos Argus Date: 18th June

Supervisor: Nic Gill Date: 18th June

Appendix D:

NEW ZEALAND RUGBY

7th August 2024

Dr Christos Argus
By Email: christosa@chiefs.co.nz

Medicine and Science Advisory Panel Decision Letter

Re. Principal Researcher: Sean Chenery
Study Title: Comparative running and heart rate demands of rugby union players during match play: A comparison of age groups and playing levels

Dear Christos,

I am pleased to inform you that the Medicine and Science Advisory Panel (MSAP) for New Zealand Rugby (NZR) has reviewed your proposal submitted 30th May 2024 and would like to provide its approval for the above proposed study.

At the conclusion of your study please provide MSAP with a report of your findings. This report will be passed along to relevant parties in NZR to ensure that this research is disseminated across the organisation.

If you require anything further or if we can be of assistance, please contact us via email msap@nzrugby.co.nz.

Kind regards,

Lauren Richardson
Medical Projects Lead

On behalf of the Medicine and Science Advisory Panel