An Investigation into Performance Monitoring in Women's Elite Rugby Sevens, with Consideration Towards the Countermovement Jump (CMJ) Test and the GPS-Derived Metric High Metabolic Load Distance (HMLD).

by

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Abstract

This study examined the effectiveness of performance monitoring strategies in elite women's rugby sevens, by evaluating the Countermovement Jump (CMJ) test and the GPS-derived metric, High Metabolic Load Distance (HMLD). While GPS tracking is widely used to quantify athlete workload, HMLD remains underexplored in rugby sevens, despite its potential to reflect training and match intensity.

Seventeen elite female rugby sevens players (age: 26.4 ± 2.9 years; height: 167.6 ± 5.2 cm; body mass: 70.5 ± 8.9 kg) were monitored across one competitive season. CMJ performance was assessed using the Output Sports V2 Sensor, and GPS data were collected from STATSports Apex Pro technology.

Backs outperformed forwards in the CMJ (40.78 cm vs. 38.02 cm) and accumulated greater HMLD in both training (560.68 m vs. 470.17 m) and competition (263.85 m vs. 216.64 m). Significant positional differences were observed across GPS metrics. HMLD correlated most strongly with total distance ($r = 0.82$), suggesting that in rugby sevens, HMLD behaves more as a volume metric, rather than a measure of intensity. Current speed thresholds may not adequately capture the sport's intensity, highlighting the need for sport-specific interpretations. CMJ performance improved over the season, though not linearly, suggesting varying levels of fatigue and physiological adaptation. HMLD volumes reflect the fluctuations and variability in training and competitive demand across a rugby sevens season.

This study highlights the value of integrating CMJ testing with monitoring of HMLD across a competitive season in elite women's rugby sevens. The CMJ provides insight into neuromuscular function and lower-body power, whilst HMLD reflects the physical demands of training and competition. Together, they offer a comprehensive view of athlete readiness.

This research addresses the gap in the literature surrounding the application and interpretation of HMLD in women's rugby sevens, and the disparity in research in the women's game. These results contribute new insight into the use of HMLD in an elite rugby sevens environment, and emphasise that alongside CMJ testing, HMLD monitoring can bring significant value to an elite training programme. The metric has the potential to be individualised to athletes, for the most effective approaches in performance optimisation, injury prevention and return-to-play strategies.

Table of Contents

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Author Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

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1. <u>Introduction</u>

1.1. Introduction to Rugby Sevens

Rugby is one of the most popular sports worldwide, boasting an impressive 500 million fans and around 10 million players (World Rugby, 2023). Being of incredibly high intensity and close contact, the sport requires great athletic ability, whereby the athlete must tolerate large training loads in preparation for competition. Players endure repeated collisions, accelerations, decelerations and sprint efforts, whilst also withstanding minimal recovery periods, and therefore athletes undergoing these competitive demands undoubtedly possess great strength, both mentally and physically. As the sport only gains more momentum, particularly as has been shown in women's rugby in recent times (Heyward et. al, 2022), the importance of understanding the requirements of the sport and monitoring players throughout becomes increasingly more essential. This not only contributes towards maximal performance outcomes, but also in injury prevention and rehabilitation, and in monitoring player wellness.

Rugby sevens (also referred to as 'sevens'), is a variant of rugby union, and is undeniably of huge physical demand, as the players must work at maximal capacity for the duration of the game, with only seven players per team on the same sized pitch as the 15-a-side version of the sport. Games are around 14 minutes in duration, as opposed to fifteen players a side, 80-minute games in rugby union (Duthie et. al, 2003). With the pitch dimensions being the same in both 7-a-side and 15-a-side, sevens players must cover distance at higher intensities, as a result of fewer players and shorter game durations. Rugby sevens is therefore characterised by a high work-to-rest ratio, frequent high-intensity running activities and impacts, undoubtedly resulting in more pressure to influence the game and perform well throughout only a short period of time. It has been reported that throughout a match of sevens, male players are expected to cover around 1,139-1,694m of distance, with high intensity running speeds being reached between 8.4-20% of this total. Females are expected to accumulate between 1,060-1,099m of distance throughout a match, with 8.3-11.0% being at this high-intensity pace (Ball et al., 2019). Rugby union players have been found to cover a greater distance as a result of a longer match duration (4,662–7,227m), however, this distance is covered at a lower intensity on average (Hogarth et al., 2016).

The competitive layout of rugby sevens often means players must compete up to 3 times a day throughout the duration of a 2 or 3 day tournament, and so players competing at an elite level may only have a few hours of rest between each match. The requirement of players to be repeatedly competition-ready over the span of a few days is unlike other rugby codes, whereby athletes must prepare themselves both psychologically and physically at multiple points in a day (Henderson et al., 2018). With the expansion of rugby sevens worldwide resulting in its recognition as an Olympic sport, beginning in the 2016 Olympics in Rio (Lee et al., 2022), travelling to compete is often accompanied by long-haul journeys and changes in time zones. Further considerations must then be made particularly by performance staff to ensure competitive readiness and individual player well-being, as these factors affect an athlete's ability to cope with training and competition demand (Mitchell et al., 2017). Travel in elite-level sport has also been found to cause issues with sleep and recovery, and make individuals more susceptible to injury (Rossiter et al., 2022), so extra precaution is necessary when scheduling training and rest periods around competition.

1.2. Global Positioning Systems (GPS)

Both in training and in a competitive environment, the collection and analysis of data in elite sport is vital to assess performance (Clemente et al., 2019). Global Positioning Systems (GPS) allows this to be possible with astute accuracy, and can also be used in combination with other monitoring to ensure players are coping appropriately with the strain that comes with performing at an elite level (Seshadri et al., 2019). Utilising GPS monitoring in rugby specifically allows for the various elements of the game to be analysed effectively, with the validity of GPS data being very well documented and used in many team sports, as well as in individual player monitoring out with a team environment (Scott et. al, 2016).

The positional accuracy of GPS is determined by the strength of satellite signals and therefore with improved signal, the reliability of performance metrics obtained from the device is improved also. A minimum of four satellites are required to calculate the GPS unit's location, and this positional accuracy improves with a greater number of available satellites (Larsson, 2003). Using these orbiting satellites, GPS units can identify the position of the tracking device as well as the speed it is moving at, which in turn quantifies the internal load of the athlete (Scott et al., 2016). The strength of these signals is classified as the Horizontal Dilution of Precision (HDOP) value (EUSPA, 2019). The HDOP value is a measurement of how much impact the geometric distribution of surrounding satellites has on the horizontal positional accuracy of the GPS. The value therefore determines how precisely the coordinates of the unit's position can be located, and is influenced by satellite geometry. A lower Dilution of Precision (DOP) value suggests that the signal from surrounding satellites is evenly spread, and as a result, improves positional accuracy. The higher the DOP value, the weaker the satellite signal present, and therefore there is a reduced accuracy in the GPS readings (STATSports®, 2022). Detection of this signal and resultant accuracy of data can be guaranteed by switching on the GPS units outdoors and allowing appropriate time for a connection to be established, with as many satellites as possible available, before an athlete's session.

Each GPS unit determines rotation, position, and the speed of acceleration, using inertial measurement sensors (IMS), also referred to as inertial movement units (IMU), that are integrated within each pod- these being magnetometers, gyroscopes and accelerometers. Magnetometers determine both the athlete's position and direction using the Earth's magnetic field, whilst gyroscopes use the Earth's gravitational pull to detect orientation, and to sense the athlete's rotational movement. Acceleration is detected by the triaxial accelerometers integrated within the unit, capable of measuring both the magnitude and frequency of movement. This allows for the detection of motion, and can be used to record impacts (by way of decelerations), which are of particular interest in the monitoring of performance in rugby (Cummins et. al, 2013).

Using this technology, a wide expanse of data can be recorded and visualised, giving a clear representation of the player's session, including individual sprint efforts, high metabolic load distance (HMLD), maximal speed, and impacts, such as accelerations, decelerations and collisions. Data gathered by GPS can also be used in combination with wellness monitoring responses, to add further depth or context to any inferences that are made from performance metrics alone. Monitoring an athlete's psychological state can prove just as important as their physical state when considering the factors that impact performance, and should be implemented consistently within elite-level sports. Considering both physical performance metrics and an athlete's own reflection of their well-being, these data can then be used to quantify exertion in the athlete, appropriately structure training programmes, avoid injury and monitor rehabilitating players (Cummins et al., 2013). The use of GPS therefore allows for accurate data collection both remotely and when training as a team, which makes it an attractive option for tracking performance and impactful athlete monitoring.

Certain metrics that can be obtained from GPS have been identified as being of particular interest when it comes to elite-level team sports. Decelerations for example are a commonly expressed metric, in rugby specifically, as a result of high intensity, frequent movements such as these being a key characteristic to the game. Decelerations are quantified by the player essentially ‘braking’, which requires a very high degree of mechanical loading in the athlete (Dalen et al., 2016), expected to be as a result of the rate of loading and high-force impacts that are demonstrated in the sport (Verheul et al., 2019). An evident link has been identified between the degree of post-match muscle damage and decrements in neuromuscular performance capacity, with the frequency of accelerations and decelerations that are seen in elite athletes (Gastin et al., 2019). This further emphasises the importance of monitoring these movements, to help reduce the risk of injury and other performance detriments, including over and undertraining.

Despite the damage inflicted on soft-tissue structures because of repeated high intensity actions that occur over the course of a game, this impact can be better attenuated in athletes through appropriate workload monitoring. With this, athletes can be better prepared and therefore efficiently cope with frequent decelerations, as well as accelerations and collision impacts, which resultantly demonstrates optimal performance outcomes (Delves et al., 2021). In particular, accelerations and high-speed running (HSR) have been identified as actions that should be closely monitored, particularly within the intermittent high-intensity work profile connected to rugby sevens (Peeters et al., 2019). Players are required to perform hard accelerations and frequent high-speed running bouts throughout the duration of the match, which further adds to the fast-paced and intensive nature of the game.

1.3. High Metabolic Load Distance (HMLD)

A relatively novel metric, high metabolic load distance (HMLD), has since been highlighted as a key indicator when quantifying athletic performance and tolerance of load, which combines the aforementioned metrics into one. HMLD is a custom metric presented by STATSports**,** a world-renowned provider of GPS player trackers, and is commonly reported in each of their GPS devices. The metric reports the total distance an athlete travels above their metabolic power threshold of around 25.5W/kg (STATSports, 2025), and is calculated by combining the distance (m) covered by accelerations, decelerations, and high-speed running (HSR) (>5.5 m.s^{-1}) achieved in a session (Carroll, 2019). This metric is therefore used to quantify the intensity of each session, and the load that a player is experiencing throughout. It can be used to set parameters for how efficient the athlete is in tolerating this loading, to make clear inferences on training structures and the requirement of rest and recovery.

HMLD takes positional differences into consideration and presents an individualised metric for how hard the athlete is working. As HMLD measures the total distance of HSR achieved, it is expected that the positions that require more high-speed running will accumulate a larger HML distance. Specifically in rugby, those who play as a forward experience a greater degree of impact, and so accumulate less high-speed running than those who play as a back (Alonso-Aubin et al., 2021). Backs in rugby are anthropometrically shorter and lighter, and therefore demonstrate greater distances of HSR, achieving a higher volume of HMLD (Dubois et al., 2017). Furthermore, due to the nature of this code of rugby, relative HSR is expected to be higher across the team. In comparison to fifteens, it has been found that rugby sevens athletes can cover 135% more high-speed running distance per minute (Higham et al., 2012). Therefore, a greater emphasis is placed on understanding the significance of monitoring HMLD, due to its ability to quantify an athlete's high intensity load in a single metric, whilst considering positional differences. Additionally, in rugby union, strong correlations have been highlighted between HMLD and the time taken to complete rugby-specific, high-intensity running tasks (Smith et al., 2019).

It should be noted that whilst HMLD provides a measure of high-intensity workload experienced by an individual, studies investigating HMLD- or a GPS-derived, metabolic power equivalent- have suggested variability within a game and between matches, with the metric demonstrating fluctuations throughout the season. In football, significant differences in HMLD covered by players were found in training sessions during MD-2 and MD-1 in comparison to MD-5, MD-4 and MD-3 (Petrov et al., 2022). The nature of the training session can also largely explain the change in HMLD values observed, where in a study in professional rugby league, the highest volumes of HML distance were recorded on Fridays- the training day prescribed specifically for game-specific drills (Fairbank et al., 2022). Therefore, monitoring this metric on a player-by-player basis is extremely beneficial when understanding an athlete's tolerance of training load at various stages in a season, and can inform decisions on prescribing training and for injury avoidance.

HMLD has also been identified as a strong indicator of high-intensity intermittent running performance involving high speed, accelerations and decelerations, all of which are composite measures of the metric. Used correctly, HMLD has the potential to tailor training and recovery to the individual and their role specific physical demands. However, practitioners should also consider the variability in the measurement of metabolic load between training and competition, with training models taking into account the variation between individuals, and expected fluctuations throughout the season. The monitoring of high metabolic load distance throughout training is essential for effective quantification of external training load (Cummins et al., 2013). Additionally, the increase in intensity and acceleration and deceleration events that accompany competition are associated with increased risk of skeletal muscle damage, and reduced neuromuscular performance (Gastin et al., 2019). Hence, failure to monitor HMLD in players can be detrimental, both to performance and to the individual.

1.4. Quantifying Effort: Current Measures and the Benefit of HMLD

Due to the intensive nature of the game of rugby sevens, there can be challenges when quantifying the effort felt each session, compared to the actual physiological output as tracked by measurable GPS metrics. This is of particular importance during competition weeks, considering the back-to-back tournament game structure, combined with external elements that impact performance and fatigue perception, such as travel and acclimatisation.

The session rating of perceived exertion (sRPE) scale is a subjective scoring method used in the quantification of internal training load, and is based on the athlete's perception of how intensive a session was. Non-invasive, quick and easy, the use of sRPE is widely used by practitioners in a variety of sports (McLaren et al., 2018). However, it's reliability is questioned due to its subjectivity, with the rating of rating of perceived exertion (RPE) being influenced by psychological factors like mood and stress (Coquart et al., 2012) and external factors, like temperature and auditory stimuli (Bishop et al., 2008; Chow and Etnier, 2017). It can therefore be difficult to effectively explain these observations in performance monitoring. However, tracked alongside the Acute:Chronic Workload Ratio (ACWR), RPE can complement its practical applications in training load management and individualised training adjustments.

The ACWR is used to provide further insight into the athlete's recent (acute) and their long term (chronic) workload. Often in team sports, the acute measurement comes from the average training load experienced in the last 7 days, and can be used as an indicator of fatigue, whereas the chronic element of this ratio represents the rolling average of an athletes training load, usually from the past 28 days (Gabbett, 2016). With the two workloads calculated as a ratio (acute load/chronic load), the ACWR gives a quantifiable framework to highlight any training load imbalances and its impact on the athlete. It is well documented that the use of the ACWR is both a beneficial tool for monitoring athlete fitness and competitive preparedness, and is also closely related to injury prevalence in many sporting disciplines. In rugby league, a high acute:chronic workload ratio was correlated with the greatest risk of injury (≥1.54) (Hulin et al., 2015). The same conclusions have been made in cricket, Gaelic football and soccer (Hulin et al., 2013; Malone et al., 2017; Fanchini et al., 2018). Whilst there appears to have been no investigation into the ACWR in rugby sevens, a pilot study by Sun and Lee (2023) presented a similar suggestion that reflects what is documented in the various other sports mentioned prior. This research proposed that in elite male rugby sevens players, those with an ACWR greater than 1.35 and lower than 0.85 should be placed in the high possibility of sports injury (HPI) grouping in their study, based on thresholds from research in rugby league.

The ACWR can be closely linked with injury occurrence, and can provide fatigue indicators and beneficial insight into workload monitoring. More so in rugby sevens, where athletes are frequently exposed to high workload, the need for close monitoring of the athlete's ACWR is of great significance. Particularly in the World Rugby Sevens Series tournament, preparation time for each event can vary greatly, and in some instances these events are scheduled in consecutive weeks. As a result, there is a greater demand placed on effective recovery, and therefore in the preparation of athletes, the ACWR can play a very important role. In comparison to what is seen in one 15-a-side Rugby Union match lasting 80 minutes, the workload over the course of the Sevens Series has been found to be significantly greater. It has been documented that starting players in a sevens team on this campaign cover around 50% more total distance, and are involved in around 40% more contact events in a tournament week than in one game of rugby fifteens (Schuster et al., 2017). With such notable increases in high intensity workload in sevens, especially during tournament weeks, there are clear benefits presented by effective use of the ACWR to ensure an athlete is not only prepared for these tournaments, but that they are robust and can withstand the intensity of an entire sevens season. Especially when considering what is known from other sport disciplines, regarding the close correlation the ACWR has to injury prevalence, this further reinforces its utility as a practical and evidence-based tool for monitoring and managing rugby sevens training load.

However, whilst the calculations of the ACWR often uses an athlete's sRPE to combine subjective and objective elements of a session, it fails to account for metric load parameters, and due to its subjectivity, other external factors such as motivation and mood may impact the scoring validity. In order to combat the concerns surrounding the use of sRPE, and particularly when considering the unique requirements and intensive nature of rugby sevens, a more specific approach to this concept is required (Impellizzeri et al., 2020). With this knowledge, Marshall et al., (2024) discussed the concept of using $ACWR_{HMLD}$ with the addition of personal endurance performance (EP) to investigate tolerance of training load and its relationship to non-contact injuries. EP was measured using submaximal treadmill protocols and lactate threshold (LT) testing. It was suggested that combining the ACWR with a measure of metabolic power (HMLD) when monitoring intensity can link imbalances of external workload with identification of players at high risk of injury. This study found that, when estimating injury risk, the chronic component of an athlete's ACWR was the most suitable parameter to use, and that combined with HMLD, this presents a more objective and reliable assessment of internal training load than sRPE.

Whilst this research was done in soccer, the application of this specified approach which also combines the use of HMLD is of significant interest in rugby sevens. Especially considering the nuances of a sevens athlete's physical profile and the game itself, small individual differences across the team can have significant influence in gameplay and overall performance outcomes. Furthermore, at an elite level of rugby sevens, the ability to endure frequent high-intensity bouts of running, accelerations, decelerations and collisions is essential for overall performance outcomes. Given the demands of the game, and additionally considering the short recovery periods, small squad sizes and a condensed competition format, there is a significant degree of stress imposed on sevens athletes. The integration of HMLD within this approach can further enhance individual performance monitoring and workload tolerance. Hence, implementing a highly specific and effective load monitoring strategy in rugby sevens is critical, and the use of HMLD can contribute to this.

This further emphasises the advanced utility of HMLD in workload monitoring and its extensive benefit to practitioners, particularly when current measures of workload quantification such as sRPE and the ACWR alone can be subjective, influenced by external factors, and lack specificity to match play and the actual work done by the athlete. The metric evidently offers a range of meaningful insights, however not enough research exists on the metric, and more specifically in the context of rugby sevens. Expanding on the knowledge that currently exists around the application of HMLD can contribute to a more comprehensive examination of training load, especially in a sport as demanding as sevens. With increasing understanding around the metric, competitive teams can develop a more individualised approach to monitoring athlete workload and preparedness, which can minimise injury risk, ensure player availability, and enhance overall performance outcomes.

1.5. The Countermovement Jump (CMJ) Test

In combination with these data, monitoring throughout both training and competition is essential for athletic development, and can provide a strong indication of an athlete's physical state. Whilst GPS analysis can inform decisions regarding player load, and thus performance, to a high degree of accuracy, consistently testing the athlete gives a clear indication of any accumulation of fatigue, potential underlying injury, or have positive inferences towards improved athleticism and performance peaks.

The CMJ test is a vertical jump test that measures an athlete's explosive power and lower body capacities (McMahon et al., 2018), whereby the athlete squats quickly to an appropriate depth, and then performs an explosive jump as high as possible. The CMJ test is repeated a minimum of three times so that an average score can be obtained. Performance in this test is usually reported using the athletes jump height (cm), which is accurately measured by flight time, described as the duration of time the participant is in the air without contact with the ground (Dias et al., 2011). The Reactive Strength Index (RSI) (jump height (m) / ground contact time (s)) is also a frequently used calculation from recorded jump height, providing an assessment of how quick an athlete can transition from an eccentric position to a concentric contraction. The RSI is an indicator of explosive performance capacity through reactive strength, which is vital particularly in sports like rugby sevens, and is one of many measures that can be utilised from the CMJ test. The jumps can be performed with the hands placed on hips; however, performance has been shown to have improvements of around 10% with the added momentum of an arm swing (Cheng et al., 2008). Whilst there are reasonings for both methods of the test, it is found that to remove any variation in the jumps, testing an athlete with their hands on their hips is the gold standard practice for the countermovement jump test.

This method of testing is of huge benefit to performance staff, as it can be performed quickly, and athletes can be easily familiarised with its protocol (McMahon et al., 2018). The gold standard equipment that is used for CMJ testing is by jumping on a force platform, as they can offer an array of insights that are useful for performance staff, including any limb force asymmetries that could indicate neuromuscular imbalances and an increased susceptibility to injury in an athlete. However, with further developments in sports technology, devices have been created such as velocity-based training (VBT) sensors, with built-in accelerometers, magnetometers, gyroscopes and Bluetooth (Output Sports, 2023). Devices such as these are easily transportable, and allow for testing to be completed anywhere, whether that might be pitch side or in the gym. The testing data are then stored on the device for future analysis, and is extremely beneficial for season long assessments and to understand responses to variations in training load. Furthermore, jump height has been identified as a strong indicator of neuromuscular performance and lower limb power (Claudino et al., 2017), which is of undeniable importance when considering the repetitive explosive and volume demands of rugby sevens.

1.6. The Benefit of Both

In any team environment, but particularly in an elite set up, monitoring training load and preparedness of an athlete is essential. In the fast paced, high-performance world of rugby sevens, competitive schedules are incredibly dense, and in some instances take place one week after another. Athletes must therefore show positive adaptations to training load, which fluctuates frequently throughout the duration of the sevens competitive cycle, whilst avoiding over or undertraining, to remain robust for the physically demanding requirements of training and tournament blocks. There is an undeniable need for practitioners to have reliable strategies in place to assess the athlete’s internal and external responses to workload, to inform training prescription, mitigate injury risk, and ultimately improve performance outcomes. Incorporating the widely used and heavily evidenced countermovement jump test, alongside tracking high metabolic load distance, is a combination that will provide practitioners with a thorough evaluation of the athlete's physical status throughout the season.

The CMJ provides a variety of different measures, such as jump height and peak power, and is widely accepted and frequently used across numerous sporting disciplines. Hence, it has earned its reputation as a valuable tool in the consistent measurement of an athlete’s neuromuscular function and lower-limb power. Through regular CMJ testing, indications of fatigue or insufficient recovery in response to training load can be highlighted through performance decrements (Wu et al., 2019). Meta-analysis conducted by Claudino et al., (2017) investigated the countermovement jump test and its ability to monitor neuromuscular status. It was found that across the 151 papers included in the study, whereby the majority (60%) of the subjects involved were athletes, CMJ ability was aligned to the successful monitoring of neuromuscular status, and the effects of fatigue on performance. Similarly, the analysis found that supercompensation effects following a training intervention could be effectively assessed through a range of CMJ performance variables, including peak power, peak velocity, and peak force. This evidence establishes clear support for the use of the CMJ in performance monitoring and the assessment of neuromuscular status in athletes. Additionally, this meta-analysis evidenced that the practicality and reliability of the test is emphasised across a range of sporting disciplines, including rugby union, soccer, basketball, judo and water polo.

In rugby-specific literature, research has found that in youth rugby players, the CMJ was sensitive to the detection of post-match fatigue, and the same was found when detecting accumulated fatigue across a seven-week period (Oliver et al., 2015). In elite female rugby sevens athletes specifically, it has been found that intensified training subsequently altered CMJ mechanics and resulted in decreased CMJ performance outputs (Gathercole et al., 2015). This further provides evidence for the benefit of the CMJ test, particularly in its application to an elite level of womens rugby sevens, and its ability to highlight performance decrements and accumulated fatigue. Hence, with longitudinal assessment of CMJ performance in athletes, the test can then provide practitioners with an evidence base that guides positive training adaptations, and can further contribute towards recovery strategies and fatigue management. However, although the use of CMJ test does present many beneficial insights, these are not entirely representative of the technical on-field requirements that are unique to rugby sevens. Hence, there is also a requirement to monitor pitch-based efforts, using metrics that are more specific to rugby specific demands.

Tracking HMLD offers substantial insight into the training load element of this assessment. The HMLD metric combines high-speed running, acceleration and deceleration distance into one measure, making session and game intensity easily quantifiable. Whilst this metric is still relatively new, its basis is grounded in the validated measures of performance from GPS-derived metrics. The high-intensity actions that are represented by HMLD- high speed running, accelerations and decelerations- have been significantly associated to subsequent markers of fatigue and impacts on performance (Varley et al., 2017; Peeters et al., 2019). Research in women's rugby sevens has found that a high number of deceleration events in particular is a key predictor of athlete load and variance in session rating of perceived exertion (sRPE) (Epp-Stobbe et al., 2024). In rugby union, HMLD has been identified as a valid measure for monitoring intensive and intermittent running load, reporting strong correlations between the metric and the time taken to complete short (10 m and 20 m) and long (20 m, 40 m and 60 m) maximal out and back rugby shuttle runs ($r = 0.85$ and $r = 0.87$, respectively) (Smith et al., 2019). This supports the efficacy of HMLD in monitoring power output and workload, especially in sports characterised by high-speed running demands, accelerations and decelerations- movements that encapsulate the high intensity nature of rugby sevens.

Furthermore, whilst this metric does not appear to have been studied in much depth in relation to women's rugby sevens, it is clearly of relevance in the sport, due to the intensive workload that is experienced by all athletes in the team. By tracking HMLD throughout the season, performance staff can gain a better understanding of the volume and intensity of certain sessions, or of that experienced throughout a tournament. The use of HMLD in performance monitoring can therefore demonstrate the high-intensity workload exposure and tolerance of an athlete at an individual level, again contributing to adaptations to training programmes, and informing recovery protocols.

By combining the two performance monitoring strategies of the CMJ test and tracking of HMLD, the two will produce a beneficial framework in the assessment of an athlete's physical status, and level of preparedness. Integrating the measures of neuromuscular readiness that the CMJ provides, with a unit of measurement that encapsulates the pitch-based metabolic load experienced by athletes- HMLD- gives context to the variations in workload that elicits certain performance outcomes. Together, these measurements can provide a clear understanding of the interaction between workload fluctuations and performance outcomes- knowledge that is essential over the course of a physically demanding rugby sevens season.

1.7 Summary

Despite the immense physical demand of the sport and its increase in popularity worldwide, the literature appears to be lacking in research directed at rugby sevens. Even more so in the women's game, there is an evident gap in knowledge that needs to be addressed, specifically when understanding the importance of a sevens programme that combines pitch-based measures of intensity with controlled testing of neuromuscular fatigue.

Understanding the metrics derived from GPS and their impact on performance will ensure that players are not only well equipped for the demands of the game, but to allow practitioners to carefully assess individual load tolerance. HMLD is often used in elite sporting environments to provide some insight into the degree of intensity experienced by athletes, providing a quantifiable measure of metabolic load. However, there seems to be a lack of research depicting its validity, especially when making comparison to the wide breadth of knowledge that exists around the CMJ test and its impact in performance monitoring. More notably, the research that does exist surrounding HMLD only appears to discuss its use mainly in football or rugby union, and does not extend to rugby sevens and its unique game demands, or required athletic profile.

Training structures that successfully monitor athlete progression with accurate testing throughout, and also replicate the physical requirements of players in a competitive environment, will result in maximal performance efforts. Whilst the CMJ test provides indication of neuromuscular fatigue through reduced performance outputs (Ronglan et al., 2005; Gathercole et al., 2015), integrating this with insights into the varying session and game intensities experienced by players may provide opportunities for more informed contributions to athlete and session adaptations. The two measures are clearly not interchangeable, and in a successful athletic development programme, both maybe implemented to elicit improvements in performance and robust athletes, particularly in the dynamic environment of rugby sevens. This research therefore intends to delve further into the knowledge that currently exists surrounding sevens and frequently used performance testing practices such as the CMJ, and aims to provide a novel insight into the validity of HMLD, for effective workload monitoring at an elite level of women's rugby sevens.

1.8. Study Aims

The aim of this research is to investigate the relatively novel GPS metric, high metabolic load distance (HMLD), and its role in performance monitoring in elite women's rugby sevens. A further aim of the study is to expand the evidence base that currently exists around the use of the gold standard countermovement jump (CMJ) test as a performance monitoring tool, and its application to rugby sevens. Finally, this study seeks to highlight and help to address the current disparity in performance monitoring research between men's and women's rugby sevens, by presenting data obtained across an entire competitive season in the women's game.

2. Materials and Methods

The research was conducted throughout one rugby sevens season, from October 2023 until August 2024. Data were continuously collected throughout this period, both in training and competition, and had the primary purpose of monitoring training and informing performance for the duration of the year. Its secondary purpose was to support this research and provide insight into the management of training load and performance outcomes in future.

2.1 Sample

Professional athletes within a women's rugby sevens squad were included in the study and monitored throughout their training and competitive season.

The sample consisted of seventeen female elite rugby sevens players (age: 26.4, ± 2.9 years, height: 167.6 ± 5.2 cm, body mass; 70.5 ± 8.9 kg). The sample included both forwards (n = 8) and backs (n = 9) players.

Participants included in the study were those involved on a contracted, full-time basis. It was anticipated that injury would be sustained by participants throughout this research period due to the nature of the sport, and therefore this did not impact eligibility for inclusion in this study. This was stated in the participant information sheet eligibility criteria, and written informed consent was obtained prior to the inclusion of participant data in this research.

Invitational athletes were omitted from the sample, as this data was not consistent throughout the data collection time frame. This data therefore was not an accurate reflection of the prescribed training load throughout the duration of the season, and relationships in these data could not be accurately identified.

2.2 Ethical Approval

Ethical applications for this research, detailing the confidentiality of participants and the use of their data, were submitted and approved by the College of Medical, Veterinary & Life Sciences Research Ethics Committee at the University of Glasgow.

Participants were also provided with an information sheet on the use of their data, and a consent form. Where informed consent was not obtained, participant data were not included in the study.

2.3 Data Collection

2.3.1. GPS Data Collection, The HDOP and Ensuring Accuracy

Performance metrics in training and competition were collected through the use of the Apex Pro Global Positioning System by STATSports (sampling rates: GPS: 18 Hz, GNSS: 10 Hz, triaxial accelerometer: 952 Hz, gyroscope: 952 Hz, magnetometer: 10 Hz; STATSports Group Limited (Newry, Northern Ireland)). It has been reported that GNSS units that have a higher sampling rate (e.g., 10 Hz) offer a greater degree of validity and reliability than those with a lower sampling rate (Scott et al., 2016). Additionally, research by Beato et al., (2018) evidenced the validity of these specific units supplied by STATSports, demonstrating that the units displayed both high accuracy and a low degree of bias in sport specific metrics (<5%). The devices in this research were used to track the movements of the athlete and monitor player loading throughout each training session or in competition, and were often used in combination with live GPS feedback. The live feedback device used was a STATSports Ultra-Wideband (UWB) positional beacon that allows for wireless communication from the units to a connected iPad for live monitoring of athletes. Inter-unit variability was minimised by ensuring that each athlete wore the same individually assigned unit for each season's entirety.

Data was obtained throughout training camps, which occurred approximately once a month and lasted for around 4 days. The number of training sessions within these camps would vary dependent on intensity and proximity to competition. However, usually a single training camp would comprise of 4 or 5 rugby sessions, with varying focuses on skills, tactical mapping, position specific requirements and high-intensity, game reflective sessions. Seventeen full-time, contracted athletes were included in this study. At the time of data collection, all athletes participating in the main session would have their GPS data recorded. This included invitational players where possible, however data from the seventeen contracted players included in this study were prioritised for consistency throughout the season. If one of the athletes in this research became injured and would instead be following an injury rehabilitation session modified under the supervision of the physiotherapist and strength and conditioning staff, their data for that particular session would not be included as part of the main team session or analysed in this research. However, for the purpose of the rehabilitation of the injured player, GPS data was still collected and analysed separately to assist in return-to-play planning by performance staff. Later in the season, players that were dealing with an injury were then managed by an external performance management and rehabilitation team, after which data was no longer collected or made available for the purpose of this research. Hence, the decision was made to exclude this from the research entirely.

Issues with indoor training also resulted in data loss, as in adverse winter weather conditions, training sessions were moved to an indoor third generation (3G) synthetic turf rugby pitch with a roof overhead. This meant that GPS data could not be collected due to signal obstruction, resulting in 11 training sessions not being recorded.

Data was also obtained during competition periods, including pre-competition training sessions following travel to various locations involved in the World Sevens Series. Due to some locations presenting issues with data collection because of signal obstruction, some of these data were unable to be collected, or following attempted data collection, were removed once the data had been identified as invalid. This resulted in no data being obtained from the competitive weekends of two of the World Series destinations, due to the stadium design and the closure of the stadium roof leading to signal obstruction of the GPS and resultant data inaccuracies. These two stages of the competitive series comprised of 10 games altogether, that were unfortunately unaccounted for.

It was ensured that the units were fully charged and in good working order prior to data collection. To collect the GPS data, units were switched on at least twenty minutes before the session, and allowed sufficient time to connect to surrounding satellites. The longer units were given to connect to a signal, the better the positional accuracy and resultant data reliability. To ensure the units consistently deliver accurate feedback, the system would be regularly checked to ensure that data were obtained with precise information on the horizontal position of the unit. The HDOP value was used as a key identifier for this and could be used when scrutinizing the reliability of data.

An 'ideal' satellite geometry was identified by a low HDOP value (e.g., < 1) (STATSports, no date), suggesting that satellites in the area are spread out enough to allow for improved accuracy in the calculation of horizontal position. HDOP values between 1 and 2 were classified as a moderate HDOP value, which continues to produce accurate feedback, however this may not be as precise as a value <1.

Any value greater than this is a high HDOP value, where the GPS signal may be obstructed, or satellites are too close together to establish the horizontal position of the GPS. In this instance, considerations would be made towards the reliability and inclusion of that data, or whether there was an issue with the technology itself, to ensure data was consistently of a high degree of accuracy. To reinforce this data reliability, any session recorded to have a less than moderate positional accuracy (HDOP value > 2) (STATSports, no date) was excluded in this study, ensuring that potential inaccuracies as a result of poor satellite communication were omitted.

Once successfully connected to a strong satellite signal, players would insert their unit into their personal GPS vest, with the pocket located between the scapulae. The vests were designed by STATSports specifically to fit the GPS unit, to restrict movement of the device and prevent incorrect readings during the session. In competition, these pockets were sewn into the player's match shirt.

Upon completion of the session, the units would be returned, switched off and placed in the STATSports GPS dock for data to be downloaded using proprietary software, Sonra. Data were observed in Sonra, where further scrutiny of the resulting session activity graph was conducted to ensure greatest accuracy. These may occur during a diving tackle or buildings and stadium roof obstruction causing irregularities in the velocity report (Malone et al., 2017). Any spikes in the athlete's activity that were unexplainable by real world movement were clipped and removed from the activity graph on Sonra. Unless an unusual spike in the data appeared to impact the entire session, removing only the error in isolation would be sufficient, to allow for the athlete's session to be included.

2.3.2. CMJ Test Data

Players were tested on CMJ performance on a regular basis, at least fortnightly, during training camps and competition weeks. Testing took place in the gym, on a flat and unobstructed surface using an Output Sports V2 sensor (Output Sports, Dublin, Ireland), attached using a foot strap. The sensor sits centrally on the dorsum of the foot, and the strap is secured tightly enough that the sensor does not become loose but does not cause discomfort to the participant. Technical specifications for the sensor are outlined in Table 1.

Table 1. **Output Sports V2 Sensor Technical Specifications**. Table displays the measurements of the Velocity Based Training (VBT) sensor using for Countermovement Jump (CMJ) testing throughout the season. Specifications dimensions (mm), mass (g), sampling frequencies (Hz), accelerometer and magnetometer (bit) and gyroscope (Microtesla)(μT). Dps = density-independent pixels.

Output Sports V2 Sensor Specification	***Measurement***
Dimensions	50 x 33 x 15 mm
Mass	21 g
Sampling Frequencies	100 – 500 Hz
Accelerometer	+/- 2G – 16G, 16 bit
Magnetometer	+/- 125 – 2000 dps, 16 bit
Gyroscope	+/- 1300 μT (x,y axis) , +/- 2500 μT (z axis) / Resolution: 0.3

The Output Sports V2 sensor used is small, easily transportable, and only requires one other device (a phone, tablet or laptop) to connect to Bluetooth for immediate feedback and analysis of jump test results through the Output Capture system. The use of Output has been found to be a very valid method for measuring vertical jump performance, particularly in assessing the smallest worthwhile change (SWC) in performance (Comyns et al., 2023). Hence, the use of the Output sensor for CMJ performance testing is both highly reliable and cost effective, making it an attractive option as a portable testing device for practitioners. The device was used consistently throughout the season, regardless of where the team had travelled to, which was beneficial throughout the sevens season with frequent travel around the world. Alongside the Rugby Sevens Series, with additional training camps to contribute to the preparation of it being an Olympic year, accessibility of equipment was essential for monitoring the team as effectively as possible. Where the opportunity arose to have access to force plates, these were used in testing for additional insights; however, these data were excluded from this study for consistency in analysis.

2.3.3. CMJ Testing

Countermovement jump testing was conducted during athletic development gym sessions, as part of the athlete's normal gym structure. Athletes were asked to perform 3 bilateral countermovement jumps, with a brief pause between each, to allow for reset of the test using the Output mobile app and for the athlete to reset their position for the next jump. It was recommended throughout testing that the athlete should have a recovery time of around 30-60 seconds between each jump to allow for maximal effort. However, self-selected rest intervals (SSRI) have been found to be efficient at eliciting post-activation potentiation (PAP) and optimising post-activation performance enhancement (PAPE) in CMJ performance in elite athletes (do Carmo et al., 2021; Fontanetti et al., 2024). Therefore, whilst athletes were provided with a recommended recovery time, the participant could ultimately decide when they felt prepared to attempt the next jump effort.

To ensure jump and data accuracy, clear instructions and verbal cues were given to athletes during testing.

Instructions:

- Both hands on hips at all times.
- Ensure a steady posture before attempting each jump.
- Attempt landing in the same place as takeoff for optimal vertical height.
- Pause after each jump effort and reset before the next attempt.

Verbal Cues:

- 'Down fast, up fast': Ensures that take-off is not delayed for optimum take-off velocity.
- 'Does the sensor feel loose at all? Is it comfortable on the foot?': Ensures the athlete is happy to start the test and that the sensor provides accurate readings.

Jump height (cm) and takeoff velocity ($m.s^{-1}$) were displayed after each jump and stored on the Output database alongside other performance metrics. The next athlete's profile was then selected, and the test was repeated. Depending on the assigned gym programme for that session, athletes would either complete 1 or 2 sets of 3 countermovement jumps.

In cases of injury, athletes would not participate. Any indication of fatigue or pain was also considered when testing. The decision to continue with the CMJ test in order to monitor potential fatigue in the athlete was made at the time. If the athlete expressed pain and discomfort, they were not obligated to participate.

The CMJ data accuracy would also be monitored, however, unlike the GPS data which would be analysed post session, the use of the immediate feedback from the V2 sensor meant that data accuracy could be scrutinised at the time of collection. Following each jump attempt, the practitioner would assess the validity of the output variables- jump height (cm), flight time (s) or takeoff velocity ($m.s^{-1}$)- and consider them in comparison to historical data. This was to ensure that the results from each jump attempt were both technically valid and aligned with the athlete's typical performance profile.

Data reliability throughout the CMJ testing was ensured firstly by the practitioner confirming the validity of the CMJ attempt- checking that the Output sensor was correctly positioned on the foot, and that each athlete's jump technique was consistent with the outlined CMJ test protocol. Secondly, each jump effort was compared with the athlete's historical CMJ data obtained throughout the season, which provided expected CMJ performance bandwidths for the individual. Any single jump resulting in values that were outside of the athlete's normal range would flag as a potentially unreliable reading- for example, an abnormally high or low jump height, or no take-off velocity being registered by the device. This would indicate loose or incorrect positioning of the sensor, or incorrect jump form. If test inaccuracy was suspected by the practitioner, the jump effort was deemed unreliable. Hence, the suspected error was corrected, and the athlete would be asked to repeat the jump. Additionally, the same practitioner would be present during testing for consistency and accuracy in the CMJ data, by reducing interobserver variability, and ensuring that the test protocol remained consistent throughout the season.

2.4. Final Data Processing and Statistical Analysis

All GPS data were processed from the Sonra performance analysis software from STATSports, from which each session was downloaded into an Excel format. The initial raw data analysis was then conducted within Excel, for further data scrutiny of accuracy.

Quality of signal and the number of satellites available at the time of data collection were analysed using the ‘raw data extended export’ option provided in the STATSports system. In both the general session export and the extended export, data outputs that were identified to be out with the expected bandwidths for the session, or with obstructed signal were interrogated before accepting the final session data.

Countermovement jump data from the Output sensor was extracted from the Output Hub analysis platform and into Excel following testing. All CMJ data would also remain stored in the Output device as a backup, and to monitor performance adaptation across the season.

Both GPS and CMJ data from the entire season were compiled into their respective master MS Excel datasets for statistical analysis. Statistical analysis of the data was completed using the latest version of the RStudio Statistics Package (version 4.4.3, R Core Team (2025)). Analysis using RStudio provided descriptive statistics for both the GPS and CMJ datasets, and also provided the finalised graphs.

To begin the analysis of the data, the data was first imported into the RStudio project workspace and was then checked for any missing data using the ‘mice’ package in RStudio, from which it was reported that there were no missing values. Therefore, no imputation techniques were required for this dataset. The variable names provided by the raw GPS export were then cleaned and standardised for consistency throughout the text. For example, ‘High Speed Running >5.5 $m.s^{-1}$’ became ‘HSR’. Each of the variables in the dataset were then assigned to the correct type of data in R, with categorical variables being assigned as factors, dates converted to a date format, and all training load variables were converted to numeric. Histogram plots were created to visualise the spread of the data, and to check for normality.

Prior to the multivariate analysis, descriptive statistics were computed for all the training load variables in the GPS dataset, and the same was done for the CMJ data. This analysis was completed first on the entire squad, and then with the athletes categorised into their playing position group of forwards and backs, all of which were then presented in the results tables 2, 3 and 4.

For the multivariate analysis, a subset of the variables within the GPS dataset that represented training load measures were extracted. This consisted of total distance (m), high speed running (m), very high-speed running (m), accelerations (count), decelerations (count), HMLD (m), and maximum velocity ($m.s^{-1}$). These metrics were combined into a new correlation dataset, which was then used to generate a Pearson correlation matrix. The correlation matrix produced a visual to further explain the relationships between each GPS metric being analysed and their correlation to HMLD. The matrix provided the input for the Principal Component Analysis (PCA) that would follow.

PCA was conducted on the correlation dataset. Seven components were initially extracted for the analysis, which was equal to the number of training load variables present in the data. Eigenvalues were then obtained to determine the variance that was explained by each component. This identified which components are of interest, and should be retained to help explain the majority of variance in the GPS dataset. A scree plot was also produced to help visualise the results of the eigenvalues, and the resultant biplot from the PCA displays each GPS metric in relation to each other across the retained dimensions.

Across all of the performance metrics presented in the GPS dataset, positional differences between forwards and backs within the squad were investigated using the Welch's t-Test. To investigate the positional differences between forward and back players in the CMJ performance, the data was first tested for normality using the Shapiro-Wilk test, following which the data obtained from the forward players was deemed suitable, whereas the backs players did not present a normal distribution. Therefore, the non-parametric alternative of the Mann-Whitney U test was used to compare the two, and following this the Welch's t-Test was used to confirm the findings. A boxplot was created to present the CMJ jump height results of forward and back players. The final scatterplot was created in Excel, to display the trends of both HMLD and CMJ results. A logarithmic scale of log base 2 was used to better visualise the performance trends of both measures of performance across the season.

3. Results

Seventeen female elite rugby sevens players were included in the sample, including both forwards (n = 8) and backs (n = 9) (age: 26.4, ± 2.9 years, height: 167.6 ± 5.2 cm, body mass; 70.5 ± 8.9 kg). Of the entire data obtained from GPS data collection, there were 943 individual observations taken from training session data, and 237 observations from match play data. The range of observations per player was 9-20 in the match data, and 39-66 in the training data.

Descriptive statistics were calculated for the training data collected from the GPS units across the season (table 2). The same was done for the data obtained during competition. However, due to some difficulty with GPS signal obstruction, and data inaccuracies as a result of this, this meant that a significant amount of competition data was unable to be included in this research. Descriptive statistics for the competition data are outlined in the results (table 3). However, the discussion regarding these results is limited as a consequence of the missing data, as HMLD volumes for competition cannot be clearly observed throughout the season.

All other statistical analysis included all 1,180 observations together. Both the training and available competition data were included in the further analysis to understand the relationship between HMLD and the other GPS performance metrics included in the analysis, and to visualise the fluctuations of HMLD throughout different phases across the season.

The CMJ dataset included only the data that were available from the Output VBT sensor. The data comprised of 29 separate testing days across the entire season, recording a total of 1,305 individual jump efforts, which were then used for analysis. CMJ testing occurred every month at least once, from October 2023 until July 2024, and were, on average, 10 days apart (9.8 ± 8.3 days). The intervals between each of the 29 CMJ testing observations varied, with the duration between testing days ranging from 1 to 28 days apart across the season.

Table 2 summarises the descriptive statistics for each metric included in the GPS dataset. This analysis was conducted using only the training data observations throughout the course of the season. For all GPS metrics included in the analysis, backs (n = 9) accumulated greater values than forwards (n = 8) on average. However, backs also displayed greater variation across all metrics. Positional differences were found to be statistically significant across all metrics in the training load data. From the GPS analysis, backs accumulated greater total distances than forwards (3444.32 m ± 1020.32 vs 3219.10 m ± 936.02) as well as HMLD (560.68 m ± 258.58 vs 470.17 m ± 217.42), and both metrics were found to be statistically significant between the two groups. There were also statistically significant differences in accelerations, decelerations, high-speed running and maximum velocity, reflecting the different physiological requirements amongst the squad, and the varying degree of intensity observed in training and competition periods throughout the year.

Table 2. **Descriptive Statistics of Metrics Presented in the GPS Dataset from Training Sessions Across the Season.** The table displays both the mean and standard deviation (SD) for the metrics reported in the training load dataset, collected using STATSports GPS units across a competitive rugby sevens season. Metrics reported are Total Distance (TD), High Speed Running (HSR), Very High-Speed Running (VHSR), Accelerations, Decelerations, High Metabolic Load Distance (HMLD), and Max Velocity.

Player Group		**TD (m)**	**HSR (>5.5 $m.s^{-1}$) (m)**	**VHSR (>80%) (m)**	**Accelerations (count)**	**Decelerations (count)**	**HMLD (m)**	**Max Velocity ($m.s^{-1}$)**
Squad	Mean	3363	182	47	31	26	527	7.47
	SD (+/-)	996	141	67	13	12	243	0.89
Forwards	Mean	3219	158	35	28	22	470	7.22
	SD (+/-)	936	122	56	11	11	217	0.82
Backs	Mean	3444	194	55	33	28	561	7.61
	SD (+/-)	1020	137	71	13	12	259	0.90

Table 3 summarises the descriptive statistics for each metric included in the GPS dataset using only the data obtained from match play throughout the season. Alike the training data, backs (n = 9) accumulated greater values than forwards (n = 8) on average for all

GPS metrics included in the analysis. Backs also displayed greater variation across all metrics, with the exception of maximum velocity ($m.s^{-1}$). As a result of limited competition data obtained throughout the season, further research is required to investigate these performance metrics across match play in elite rugby sevens.

Table 3. **Descriptive Statistics of Metrics Presented in the GPS Dataset from Competition Across the Season.** The table displays both the mean and standard deviation (SD) for the metrics reported from match play data, collected using STATSports GPS units across a competitive rugby sevens season. Metrics reported are Total Distance (TD), High Speed Running (HSR), Very High-Speed Running (VHSR), Accelerations, Decelerations, High Metabolic Load Distance (HMLD), and Max Velocity.

Player Group		**TD (m)**	**HSR (>5.5 $m.s^{-1}$) (m)**	**VHSR (>80%) (m)**	**Accelerations (count)**	**Decelerations (count)**	**HMLD (m)**	**Max Velocity ($m.s^{-1}$)**
Squad	Mean	1087	100	25	8	10	247	7.36
	SD (+/-)	417	66	31	5	7	115	0.83
Forwards	Mean	999	83	15	6	8	217	6.98
	SD (+/-)	387	63	23	4	5	105	0.86
Backs	Mean	1137	110	31	9	12	264	7.57
	SD (+/-)	426	65	34	5	7	117	0.74

Table 4 summarises the descriptive statistics for jump height (cm), flight time (s) and take-off velocity ($m.s^{-1}$) from the CMJ performance dataset performed by forward and back elite rugby sevens players. Positional differences in countermovement jump performance are evident between forwards and backs, with backs on average accumulating higher values in each performance measure. In alignment with the finding that in the GPS training data, backs players accumulated higher figures across all metrics, it was also found that backs players performed CMJs at greater mean jump heights than forwards in every instance of

CMJ testing. However, greater variation is seen in jump performance across the backs players.

Table 4. **Descriptive Statistics of Countermovement Jump (CMJ) Height (cm) in Forwards and Backs Across a Season.** Table displays the key descriptive statistics for the countermovement jump height (cm) data acquired from forwards (N= 8) and backs (N=9) in an elite female rugby sevens team across the season. Backs perform greater jump heights; however, measures of statistical dispersion demonstrate a greater variability amongst their performance outputs in comparison to forwards.

Playing Position	**CMJ Metric**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Forward	Jump Height (cm)	38.02	2.94	29.69	47.96
	Flight Time (s)	0.556	0.022	0.492	0.625
	Take-off Velocity ($m.s^{-1}$)	2.73	0.11	2.41	3.07
Back	Jump Height (cm)	40.78	5.09	30.28	51.41
	Flight Time (s)	0.575	0.036	0.497	0.647
	Take-off Velocity ($m.s^{-1}$)	2.82	0.18	2.44	3.18

Table 5 summarises the eigenvalues, corresponding percentage variance (%) and cumulative percentage variance (%) explained by all seven principal components extracted from the GPS dataset. Component number 1 explains the most variance within the dataset (60.84%), with an eigenvalue of 4.26. Component number 2 has an eigenvalue of 1.46, and explains a further 20.85% of the variance, with both components 1 and 2 cumulatively explaining 81.70% of the variance within the data. Components 1 and 2 have an eigenvalue greater than 1. In line with the Kaiser Criterion, where components with an eigenvalue greater than 1 contribute the most significant explanation of the overall dataset in PCA, components 1 and 2 were retained. All remaining components of 3 through 7 fall below this threshold and explain progressively less variation in the dataset. They are therefore not of significant importance when explaining the GPS data.

Table 5. **Eigenvalues, Percentage of Variance (%) and Cumulative Percentage of Variance (%) of Principal Components Extracted from GPS Data.** Table displays the eigenvalues of each of the components derived from the GPS dataset using principal component analysis (PCA). Each component represents a new uncorrelated variable that explains the variance in the GPS data. The eigenvalues of components 1 and 2 are greater than 1, and hence explain the greatest amount of variation in the dataset (81.7% cumulatively).

Component Number	**Eigenvalue**	**Percentage of Variance (%)**	**Cumulative Percentage of Variance (%)**
1	4.26	60.84	60.84
2	1.46	20.85	81.70
3	0.45	6.36	88.05
4	0.33	4.70	92.76
5	0.22	3.20	95.96
6	0.19	2.78	98.74
7	0.09	1.26	100.00

Figure 1 presents the results from the Pearson's Correlation Coefficient analysis using the GPS data. The matrix includes the seven performance metrics included in the entire GPS dataset. A colour scale is observed, where darker fonts represent increased positive correlation between metrics, and lighter fonts represent more negative correlations. High correlations towards HMLD are observed for total distance, high speed running, accelerations and decelerations (0.82, 0.75, 0.75 and 0.76 respectively). Notably, HMLD is more highly correlated to total distance (TD) than to high-speed running (HSR). The correlation matrix analysis indicates that all metrics are positively related to each other, which is to be expected in training load data.

Correlation Matrix of GPS Dataset

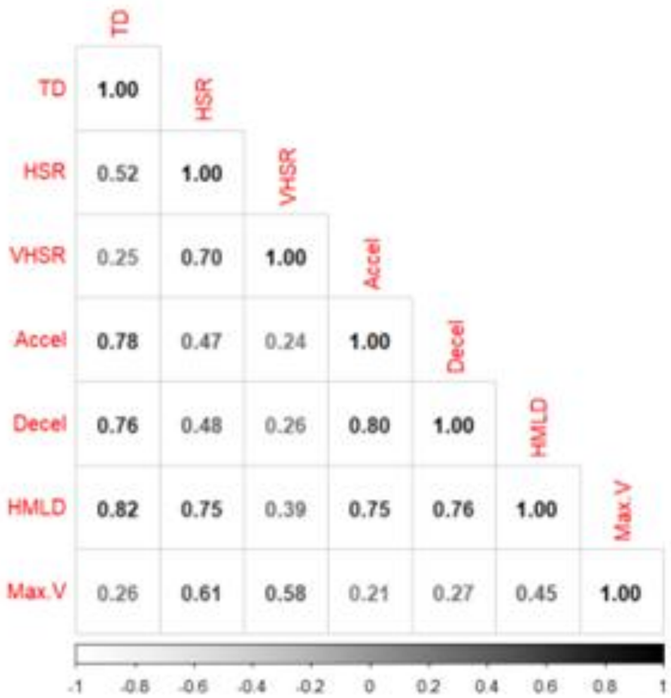

Figure 1. Correlation Matrix of the GPS Metrics in the Dataset. Correlation matrix displays the Pearson correlation coefficients between the GPS metrics used in the training dataset: Total Distance (TD), High-Speed Running (HSR), Very High-Speed Running (VHSR), Accelerations (Accel), Decelerations (Decel), High Metabolic Load Distance (HMLD), and Maximum Velocity (Max.V). Stronger correlations are indicated by darker shades of grey. All metrics positively correlate with each other. HMLD is strongly correlated with high-speed running (0.75), accelerations (0.75) and decelerations (0.76), but is most highly correlated to total distance (0.82).

Figure 2 displays a scree plot which illustrates the weighting of the eigenvalues associated with each of the seven components extracted from the entire GPS dataset. In line with the Kaiser Criterion for retaining components in principal component analysis, only the components with eigenvalues greater than 1 were considered of importance. The blue dashed line intercepts the y-axis at y = 1 to indicate the threshold for this. Hence, components 1 and 2 were retained for use to explain the most variance within the dataset, with eigenvalues 4.26 and 1.46 respectively (as outlined in table 5).

Scree Plot of Component Eigenvalues

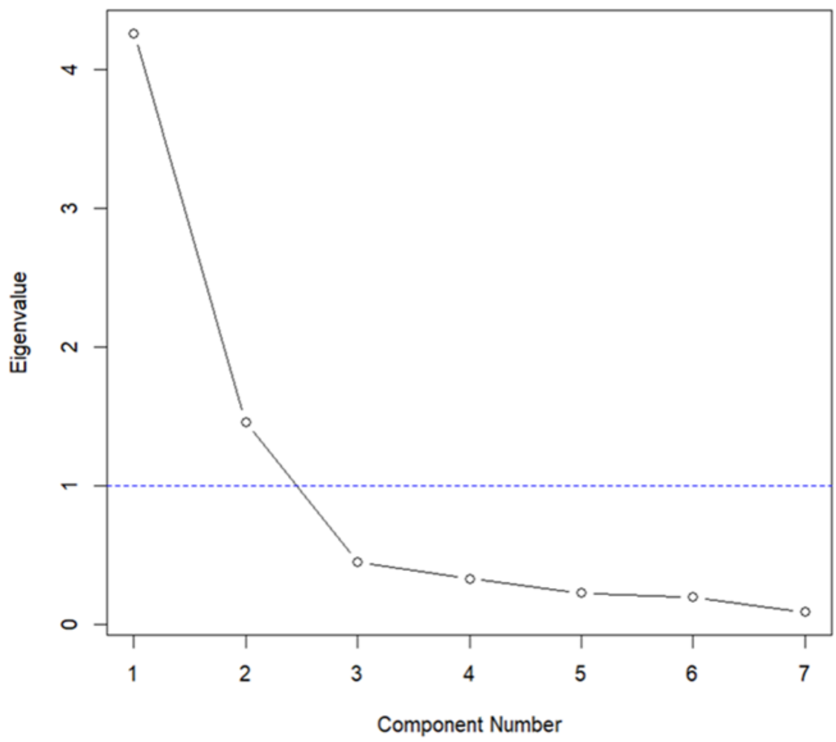

Figure 2. Scree Plot Displaying Eigenvalues of Available Components Extracted from the GPS Dataset. Plot displays the respective eigenvalues of all seven components extracted from the analysis. Dashed line (blue) intercepts at y = 1 to represent the Kaiser Criterion for retaining components in factor analysis. Components 1 and 2 are within the threshold for consideration of components that explain most of the variation in the dataset (81.7% of total variance).

Figure 3 presents the biplot from principal component analysis on the entire GPS dataset, including both training and competition data. All variables are positively loaded towards dimension 1, which explains 60.84% of variation in the dataset and is indicative of training load volume. Dimension 2 explains a further 20.85% and is more indicative of intensity derived metrics: high-speed running (HSR) (m), very high-speed running (VHSR) (m) and maximum velocity ($m.s^{-1}$). There is a clear split between dimensions 1 and 2, with HMLD sitting in the middle of both. However, it appears more heavily correlated to dimension 1 following PCA. A finding of interest is that through PCA using the GPS dataset, HMLD appears to be more closely correlated with total distance, accelerations and decelerations, despite its components for calculation being high speed running, accelerations and decelerations. When investigated in isolation, both the training data and match data display the same relationships, with all variables positively loading towards dimension 1. As can be seen in figure 3, dimension 1- indicative of workload volume- accounts for the majority of variance in the dataset for both training data (58.3%) and match data (65.6%). Intensity derived measures indicated by dimension 2 accounted for 20.6% of the variation in the training data, and 19.5% in the match data. The clear split of the variables between the two dimensions is still apparent in both datasets.

Principal Component Analysis of GPS Metric Loadings

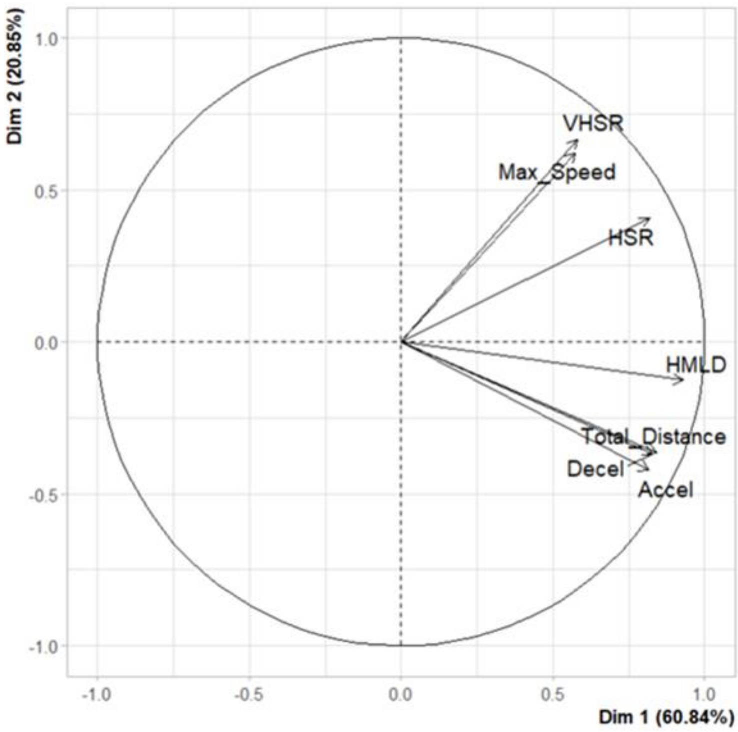

Figure 3. Principal Component Analysis (PCA) Results of GPS Metric Loadings. Factors included in the analysis are total distance, high speed running (HSR) (>5.5 m.s^{-1}) (m), very high-speed running (VHSR) (>80% of maximum velocity) (m), accelerations (Accel) (count), decelerations (Decel) (count), high metabolic load distance (HMLD) (m) and max speed (m.s^{-1}). Presented in the graph are 2 dimensions as determined by the scree plot analysis. Dimension 1 (Dim 1) explains 60.84% of the GPS dataset variation, and dimension 2 (Dim 2) explains 20.85%.

Figure 4 displays a boxplot which compares the results of the CMJ test across the season between forwards and backs players. It can be seen from the plot that despite there being some outliers in the forwards group, results appeared to be more consistent than the wider range of outputs seen in the backs, indicating some varied physical capabilities within the group in CMJ performance. Statistical analysis on these results found that between forwards and backs players, there was a significant difference in countermovement jump height (cm) across the season ($p < 0.05$). Overall, backs achieved a higher median jump height value (41.60 cm), in comparison to that of forwards (38.08 cm). The 95% confidence interval [1.87, 3.65] suggests that backs are likely to jump higher than forwards in the CMJ by anywhere between 1.9cm to 3.7cm. The variable split between dimensions 1 and 2 in the PCA biplot (figure 3) remained the same when match data and training load were investigated in isolation, highlighting that the underlying structure of volume and intensity is shared in both training and match play.

Comparison of Jump Height (cm) Between Forwards and Backs Across Season 2023-2024

Figure 4. Boxplot of Average Countermovement Jump (CMJ) Height (cm) Performance in Elite Female Rugby Sevens Forwards and Backs Players Across a Season. Boxplot displaying average jump heights (cm) performed by forwards (N=8) and backs (N=9). Countermovement jumps performed by backs displayed a greater median jump height (41.6cm) than forwards players (38.1cm) across the season. The difference in jump height between forwards and backs is statistically significant ($p < 0.05$, 95% CI [1.87, 3.64]). Dots represent the outliers, determined by points lying further than 1.5 times the interquartile range.

Figure 5 presents a scatterplot that illustrates the trends in countermovement jump height (cm) and HMLD (m) across a rugby sevens season, in both forwards and backs players. To effectively visualise the wide range of HMLD values, and to identify potential impacts of training load on performance outcomes in CMJ height, both training and competition data are presented on the same graph. Due to the differences in scale between the CMJ and HMLD data, the plot uses a logarithmic scale of base 2, to more clearly illustrate the results. The results indicate that throughout the course of a training season, athletes demonstrate seasonal adaptations, monitored through the testing of countermovement jump performance, and experience variations in training and competitive load, displayed by

HMLD values. Although small, there was an improvement in jump height at the end of the season in comparison to the beginning across the entire squad. The backs displayed an improved jump height of 2.0 cm on average, from the initial testing to the end of the season, with forwards improving by 3.8 cm. This improvement was not linear as is shown in the scatterplot, and again reflects the fluctuations in physical demand throughout a competitive season and its resultant impact on neuromuscular fatigue and performance outputs. Backs regularly expressed greater jump heights than forward players, however the performance trends remained similar during the season across the team. The results also indicate that unlike the more controlled and repeatable nature of the countermovement jump height testing, high metabolic load distance appears to show significant fluctuations across the season (526.57 m ± 243.03) (table 2). This is often impacted by the nature of the rugby sevens cycle and variations in training and competitive load.

<u>Average Countermovement Jump (CMJ) Height (cm) and Average High Metabolic Load Distance (HMLD) (m) Between Forward and Back Rugby Sevens Players Across a Season</u>

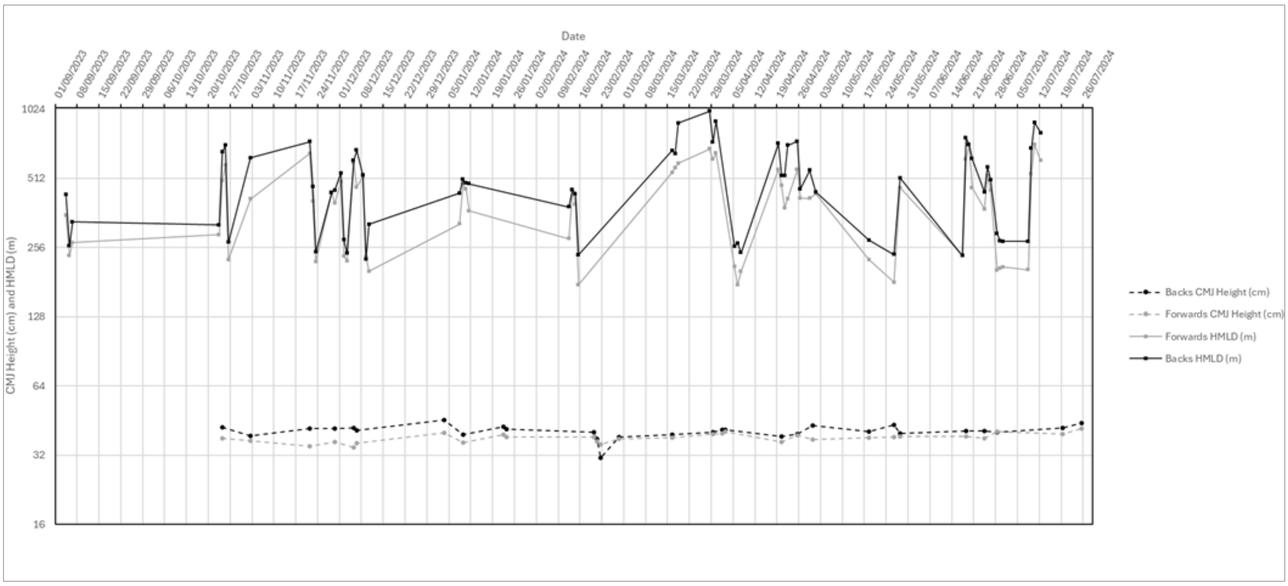

Figure 5. Scatterplot of Average Daily Countermovement Jump (CMJ) Height (cm) Performance and High Metabolic Load Distance (m) in Elite Female Rugby Sevens Forwards and Backs Players Across a Season. Scatterplot displays the average jump height (cm) and average HMLD (m) across the season. Each data point represents the date of data collection. Forwards: HMLD represented by the solid grey line. CMJ height represented by dashed grey line. Backs: HMLD represented by the solid black line. CMJ height represented by dashed black line. Backs players demonstrate greater jump heights and HMLD than forwards, however both playing positions demonstrate similar performance and workload patterns. Significant fluctuations are observed in HMLD, and reflect seasonal variations in training and competitive load. Logarithmic scale used where Y-axis = log base 2.

4. **Discussion**

4.1. Overview

To my knowledge this study is the first of its kind to investigate the rationale of using high metabolic load distance, and the potential insight it may offer into assessing training load in an elite rugby sevens environment. Whilst it is a metric commonly reported in GPS tracking, its purpose has been seldom studied, despite its value in high intensity workload monitoring. Furthermore, there appears to be no research that discusses the use of this metric in the context of women's rugby sevens. In comparison, the countermovement jump test is frequently used by practitioners in many sporting disciplines, to monitor responses to training load, assess lower-limb power output and contribute to injury rehabilitation. The benefits of the CMJ test have been widely reported in the literature, as it doubles as both a diagnostic tool and as a measure of performance, allowing for assessments of neuromuscular fatigue and observations into seasonal adaptations. Hence, this study investigates these two methods of performance analysis in isolation: the countermovement jump test, which is thoroughly researched and conducted in a controlled gym environment, and the use of HMLD, a pitch-based metric of intensity, which appears to have no supporting evidence in women's rugby sevens.

This study finds that alongside the use of the CMJ test for tracking performance outcomes and fatigue levels, monitoring HMLD can help to inform seasonal fluctuations and quantify training load. Hence, both methods are of importance in rugby sevens, given the nature of the competitive season at an elite level, and the intense physical demand presented by this code of rugby.

The results highlight positional differences between forwards and backs in female elite rugby sevens, with this relationship being observed in both CMJ performance and in the GPS training load data. However, greater variation is seen in those playing as a back in both. These positional differences may be reflective of the tactical roles that characterise forwards and backs players in rugby, which have been frequently observed and evidenced in rugby fifteens (Bevan et al., 2022; Lino-Samaniego et al., 2025). The variability observed from the backs in both the training data and CMJ performance may reflect the broader range of athletic profiles and playing styles within the sample. Similarly, the more dynamic, fluid nature of rugby sevens may also account for this variation. Particularly in comparison to rugby fifteens, fewer players and more space on the pitch in rugby sevens introduces the possibility of more individuality in an athlete's nature of play. Additionally, these differences in physical demand may impact the physical adaptations of the athlete, and are reflected in the performance variability seen in the CMJ in the current study. However, further research is required to support the evidence of positional variation in women's rugby sevens, in line with the results presented in this research. With the high physicality required from all sevens athletes- whereby the entire squad possesses a high degree of strength, speed and endurance- positional variation in rugby sevens may not be so clearly defined. A greater understanding of positional variation in women's rugby sevens, both in the CMJ test and in the workload experienced on the pitch, can help inform better training and recovery strategies.

Both in the correlation analysis (figure 1) and the PCA biplot (figure 3) using the GPS data, HMLD is more closely correlated to total distance than it is to high-speed running (HSR). This finding was unexpected, considering HSR is one of the contributing metrics towards HMLD, and not total distance. With these results, this would suggest that in sevens, the original parameters of HMLD lead the metric to behave more as an overall distance (i.e. volume) measure rather than the intensity measure it is intended to be. Therefore, what is currently understood about the metric in football for example may not be entirely applicable to the unique demands of rugby sevens. Hence, this study suggests a re-evaluation of the speed parameters used to calculate HMLD based on sport-specific demands, to enhance its validity as a measure of intensity.

Significant fluctuations of HMLD were observed throughout the season (figure 5), reflecting the dynamic variations in physical demand throughout a competitive, elite rugby sevens competition cycle. In high performance sport environments- and particularly in rugby sevens with the involvement in the World Sevens Series tournament- these fluctuations are accompanied by external factors like travel, climate, and competition scheduling. These factors then ultimately have an impact on fatigue levels, recovery and overall performance. This suggests that alongside training camps and tournaments, these additional factors should be considered when investigating seasonal workload fluctuations in elite rugby sevens, particularly when planning training sessions of varying intensity around long-haul journeys.

HMLD values may also vary due to the number of training sessions completed, the intensity of training and competition, or because of deliberate changes in workload in preparation for competition, or prior to travelling. Training intensity may differ dependent on the session type- for example, skills and mapping sessions were of low intensity, and game-reflective training blocks accumulated much more high-intensity volume. Competition variation is less controllable, and can vary because of match-to-match variation, including changes in game tactics, or the difficulty of the opposition. Further consideration regarding this training and competitive variation is outlined in pages 50 and 51.

Reductions in training volume were observed in the same week as a tournament, purposefully to avoid overworking the athlete, as the additional workload would later be accumulated throughout the days of competition. With game duration being much shorter than a training session, HMLD values were lower across a competition weekend in comparison to a 4-day training camp, as players are exposed to less time on feet, and hence, have less time to accumulate HMLD. However, further research is required to better establish HMLD values across competition, whether these values are impacted by training sessions in the same week, as well as how the metric trends throughout each tournament in the season.

The purpose of training camps are to effectively prepare the athlete for the physical demand and intensity of competition. Therefore, the physical demand experienced in a training week was reflective, or even more demanding, than a competition week, so that competitive demands felt easier for the athlete to withstand. Furthermore, and as previously mentioned, other external factors can impact intensity, such as long-haul travel, sleep adjustments and acclimatisation, and should also be considered within this field of research. With the highly variable nature of the elite rugby sevens season, and its involvement in an international tournament, this further demonstrates the requirement for effective load monitoring across teams, not only to mitigate the risk of injury, but also for optimal athlete preparedness.

This study suggests that utilisation of both the CMJ test and monitoring HMLD throughout a season can provide significant benefit to a sevens training programme. Considering the CMJ test with the use of HMLD in performance monitoring, it is evident that the two are advantageous in their own specialised way, and when used together, are instrumental in providing a comprehensive and robust training model. Effective integration of both assessments in rugby sevens will contribute to a holistic evaluation of an athlete and their adaptations across a season. Further research will also more clearly identify positional variations in women's rugby sevens, which will contribute towards informing specific training structures and workload management, fatigue and recovery strategies, and prevention of injury.

4.2. Differences in Workload Requirement with Competitive Level in Rugby Sevens: The Importance of Monitoring

This study was conducted with the contribution of participants competing at an elite, international level of rugby sevens. At this elite level of performance, athletes experience the highest training and competitive volume than any other level of their sport, and so there is an expectation of efficient and reliable workload monitoring to allow players to be both physically and mentally prepared for this demand.

In women's rugby sevens, the differences in training load and subsequent physical performance outputs in various divisions of the game have been identified. Research by Clarke et al., 2016 investigated game movement demands at junior, senior and elite levels of rugby sevens, and found that whilst demands in the men's game were similar across competitive level, elite women could not be so clearly differentiated from junior and senior level. This is potentially explainable by the lack of prior data in the women's game, however later research (Sella et al., 2019) found that there are in fact clear differences in elite and non-elite playing levels, with elite players demonstrating greater maximal speeds, aerobic capacity, strength and power. Therefore, as more research emerges with the growth of the women's game, the differences between playing levels will likely become more clearly defined.

Differences in performance testing outputs have also been identified across different experience levels. In a study in women's rugby sevens comparing Olympic and non-Olympic players, it was found that those playing at an elite level reached higher peak velocities (7.96 ± 0.26 vs 7.53 ± 0.27 m.s^{-1} in non-elite players), and demonstrated better performances in 40-metre sprint tests (5.63 ± 0.07 vs 5.79 ± 0.17 s, respectively) (Loturco et al., 2021). These findings highlight that with increased competitive standard, players demonstrate more entries to high-speed zones, improved acceleration capability, and better overall endurance.

The current study found that in terms of HMLD, there were large fluctuations in observed training values throughout the season (526.57 m ± 243.03), which are reflective of the physical demands experienced by athletes during training and competitive cycles. These fluctuations throughout a competitive season have been identified in the literature, with research in rugby league presenting a progressive increase in HML distance through increased volume and intensity, prior to tapering in preparation for competition (Fairbank et al., 2022). Whilst this steady progression in external load is less explicit in the current study, the variability in the metric is clear, and can be attributed to the nature of the competition cycle of rugby sevens. Rather than the entire season consisting of a more structured, cyclical periodisation, rugby sevens presents a much more intensive cycle, with monthly competition events within the World Sevens Series, accompanied by long-haul travel and greater fluctuations in training load. Hence, the argument for monitoring HMLD throughout the season becomes even more prominent in a sevens context, due to the intense fluctuations in workload within a shorter time frame.

As a result of this study involving athletes competing at the highest level of rugby sevens, it can be confidently asserted that these values would be higher than what is observed at lower and non-elite levels of the game. Referring to the knowledge that is currently in the literature surrounding rugby sevens, as competitive level increases, game demands and performance outputs are also seen to increase (Sella et al., 2019; Loturco et al., 2021). The same has been identified in rugby league (McLellan and Lovell, 2013; Gabbett, 2014). It would therefore be reasonable to suggest that this relationship could be applicable to women's rugby sevens, despite the lack of existing research in this field. However, due to the relatively novel nature of HMLD, and the lack of rugby sevens-specific knowledge regarding its application, further work is required to understand the metric in the context of training and match play, across different playing levels of the sport.

It could also be suggested that due to this improved physical capacity, elite players are more efficient in recovery periods, which is a crucial asset to an athlete's physical profile given the low recovery periods available within and between matches of rugby sevens. This has been supported by evidence of long-term physiological adaptations in elite athletes, as a result of chronic exposure to high-intensity workloads. It has been found that in elite athletes, there is an increase in the ratio of mitochondrial inner membrane surface per mitochondrial volume (Nielsen et al., 2016), with its function improving with frequent high-intensity training (Fiorenza et al., 2019; Bossung et al., 2025). This correlates to increased oxygen uptake and generation of adenosine triphosphate (ATP), better lactate clearance, and improvements in exercise performance and recovery (Hoppeler et al., 1985; Jubrias et al., 2001; Emhoff and Messonnier, 2023). Particularly at an elite standard of the game of sevens, and as the standard of the competing teams improve, the required work rate for performance success is heightened in response. Under the demands of the compact sevens series, sufficient recovery is difficult to achieve, yet it is crucial, especially between consecutive games and tournaments. This further highlights the need for efficient monitoring of workload and wellbeing of players in the sport.

It has been reported that in women's rugby sevens, impacts on both wellbeing and neuromuscular performance can be seen due to the physically demanding tournament set up of the World Sevens Series. Across a typical two-day tournament, athletes demonstrated significant impairments on mood, fatigue, muscle soreness, stress, and quality of recovery following the first day of the tournament. More notably, these values only returned to baseline two days after the tournament (Doeven et al.,2019). These effects are very likely due to the intense match-play demands, repeated collision events, shortened recovery times and games being scheduled in quick succession. With teams having to compete in up to three games in one day of tournament, recovery protocols and management of competitive training load- both psychologically and physically- is crucial for athlete wellbeing. Whilst in the short term these impacts are unavoidable, monitoring these demands is essential in avoiding long term consequences of fatigue, overtraining and injury risk.

Similarly, as the competitive level of a sport increases, so does the training and match loads experienced. Match play total distance, number of sprints and sprint distance were all greater in professional rugby league than in the junior-elite level (McLellan and Lovell, 2013), and it has been found that higher divisions of rugby league accumulate more relative total distance and report more collisions than those playing at lower divisions (Gabbett, 2014). Other research has identified that compared to a professional participation level of rugby league, elite players experienced a 22-fold increase in injury risk in training, however, the greatest amount of injury occurrence was reported at a semi-professional level (358.5 per 1,000 match-hour) (King et al., 2022).

This escalation in workload is mirrored in many other sports, too, with ice hockey and basketball also being found to have an enhanced game demand, improved aerobic and anaerobic capacities in comparison to sub elite players (Scanlan et al., 2011; Vigh-Larsen et al., 2019). Naturally with increases in mechanical load and neuromuscular stress, athletes develop a better tolerance of increased workload, preparing them for heightened physical demands at different levels of competition. Equally, they are exposed to greater risk of injury which can be closely correlated to over exhaustion, also classified as cumulative trauma (Gregory, 2002). Hence, the implementation of monitoring is essential for athletic development, regardless of the discipline or level of sport, and understanding how physical characteristics vary across competition level can therefore help to prepare athletes for game specific demands, structure training plans, and guide recovery protocols.

Although perhaps an obvious observation, with increases in complexity and intensity of workload experienced by players, it is vital that player development pathways have some degree of monitoring in place. Whilst considering different accessibility to resources in junior clubs, there is still the capacity to monitor wellbeing, even at a basic observational level. Wellness monitoring can be used as a cost effective, easy to implement method of monitoring where more advanced systems such as GPS are not available or of realistic practice at lower levels of the sport, and can still provide beneficial insight into adaptations to training load and player performance. Coaches and practitioners should ensure players at any level are coping with their training and competitive workload. By doing so, this will ensure athletes are not being overtrained, help in avoiding injury occurrence, and can contribute to better enjoyment and retention of those interested in the sport. By instilling these practices at early developmental levels of sport, athletes will be better accustomed to their own perceptions of intensity, and will only have positive implications as they progress in their sporting disciplines.

It has also been identified that in young individuals, involvement in youth sport clubs that have effective support pathways and monitoring in place then develop to be more robust in their athletic capabilities and have better well-being, ultimately enhancing their long-term development (Sinha, 2024). Additionally, exposure to high training volumes in adolescence without appropriate monitoring has been suggested to result in higher likelihood of injury, and early retirement as a result, placing further emphasis on the importance of quantification of training and athlete wellness (Huxley et al., 2013; Bourdon et al., 2017). Therefore, these practices should, where possible, be put into place when dealing with young athletes, and will subsequently benefit their future sporting careers and athletic development. Similarly at any level of sport, these methods will elicit positive results and should be implemented for the benefit of the athlete, the squad, and overall performance outcomes.

From these findings, there are clearly specific requirements to be accounted for at different playing levels in sport, including women's rugby sevens. When developing training programmes, these considerations towards power output and neuromuscular fatigue in performance testing, alongside pitch-based intensity levels, are important to maximise athletes' preparedness and avoid over or undertraining for the demands of the game. Particularly in the women's game, developing an understanding of HMLD volumes throughout the season is critical when investigating fluctuations in physical demands- not only as a result of the competitive cycle, but also due to the various impacts the menstrual cycle can have on performance and fatigue levels (Shakhlina et al., 2016; Rodrigues et al., 2019).

By establishing a clearer understanding of training volume variations at elite, sub-elite and developmental playing levels of rugby sevens, practitioners can be better informed to calibrate training intensities, and utilise recovery strategies on an individual basis. In combination with an effective monitor of neuromuscular fatigue, such as the CMJ, there is significant scope for potential to individualise training prescriptions for optimal benefits- both for the athlete and their performance outcomes.

4.3. The Countermovement Jump

4.3.1. Monitoring CMJ Performance in Rugby Sevens

The countermovement jump test has been widely used in a variety of sports, and its use and benefit in collision sports such as rugby sevens is well established. The test offers metrics that help advise in performance profiling, neuromuscular fatigue and in an athlete's return from injury. Output metrics such as jump height, peak power and propulsive force all correspond with performance outputs and physical capacity in linear speed, strength, and change of direction. In rugby sevens, better performance in these factors can offer advantages in physiological adaptations and game success, hence this study focuses primarily on jump height as a simple performance profiling metric.

Descriptive statistics for the countermovement jump data are presented in table 4. From the initial jump testing to the final testing of the season, forwards and backs players both showed an average increase in jump height performance of 3.8 cm and 2.0 cm respectively, with an overall squad improvement of 3.2 cm. This reflects positive adaptations to training loads, enhanced neuromuscular function, increased lower-body power and rate of force development (RFD), which can all translate to improved on-field performance in rugby players (West et al., 2011; Tillin et al., 2012) and other sports requiring explosive movement, such as football and track and field (Nuzzo et al., 2008). However, it should be noted that this increase in jump height was not a linear relationship against time throughout the course of the season, with average jump height amongst the squad increasing and decreasing throughout varying training and tournament blocks (figure 5). Whilst there was an overall improvement in the squads' jump performance, this can be attributable not only to physical adaptations, but also familiarity with the testing protocol and the Output VBT Sensor equipment used. With frequent implementation of the CMJ test in athletic development gym sessions, and the participants in this research being contracted- and therefore present for the entire season- they were regularly exposed to this test. With this in mind, the element of familiarisation should be considered when assessing these results.

Whilst there is an overall improvement when considering the entire season, figure 5 also shows decreases in jump height performance. This is likely as a result of increased training load, particularly through intensive competition schedules, resulting in fatigue and reduced performance output. Research has identified large decreases in CMJ performance because of tournament fatigue. A study by West et al., (2014) assessed CMJ outputs across two consecutive tournaments. Twelve hours after the first tournament was completed, jump height was significantly reduced by 26%, and these reductions were still seen five days later at the beginning of the second tournament, with declines in jump height of 8%. A later study by Yamashita et al., (2024) found that countermovement jump height can help to predict performance capabilities. It was found in the study that the CMJ was the sole predictor of 10-m linear sprint times, and that the rate of force development in the CMJ was the only predictor of change of direction ability. Similar impacts on performance have been identified in the unilateral countermovement jump (UCJ) and unilateral drop jump (UDJ). In young female athletes, acute exercise-induced neuromuscular fatigue resulted in significant reductions in jump height in the right leg in the UCJ, and in both legs in the UDJ ($p = 0.018$ and < 0.001, respectively) (Fort-Vanmeerhaeghe et al., 2023). These findings help to explain the changes in jump height performance in this study across the season, as these data will reflect performance improvements and detriments as a result of varying physical demand and fatigue levels.

The focus on reporting jump height in this study is beneficial for simplicity, as it indicates clear changes in performance. However, for a comprehensive assessment of an athlete's performance profile and fatigue levels, other metrics should be considered. This study only examined typical variables from the CMJ outputs (CMJ-TYP), however from these metrics, several new, alternative variables (CMJ-ALT) were derived. These variables focus mainly on phase durations in the CMJ (Gathercole et al., 2015) and include metrics such as the Reactive Strength Index-Modified (RSI-Mod), eccentric and concentric phase duration, and the Flight Time:Contraction Time ratio (FT:CT). The introduction of CMJ-ALT suggested that the typical measures of the CMJ test overlooked certain performance indicators, and that the use of CMJ-ALT variables- in particular, FT:CT – can provide better identification of neuromuscular fatigue. The use of CMJ-ALT variables in research has indicated short and long-term training adaptations (Kijowski et al., 2015; Heishman et al., 2020), and residual deficits in neuromuscular performance following injury (Hart et al., 2019), whilst CMJ-TYP values remained stable, and did not reflect any impact of these varying circumstances. In rugby sevens, it has been found in the assessment of CMJ performance, the use of alternative variables may provide improved quantification of chronic workload exposure (Lonergan et al., 2022). The study by Lonergan and colleagues found that there were no significant changes in typical variables such as jump height and peak power across the season, placing emphasis on the use of CMJ-ALT variables in rugby sevens CMJ analysis to highlight neuromuscular performance improvements. In the current study, jump height results were found to lack statistical significance ($p = 0.12$) and hence did not increase, however given what is known about alternative variables, the investigation into CMJ-ALT variables may have provided different insights.

CMY-TYP variables can also provide useful insights to allow for improvements, and should not be overlooked, despite the existing discussion surrounding the use of CMJ-ALT variables and the FT:CT ratio. Other metrics within the CMJ test have been proven to be highly correlated to strength and power output, which is an essential driver for rugby sevens performance success. Particularly, CMJ peak power and peak force have been strongly correlated to improvements in maximal performance capabilities in strength tests such as in one-repetition maximum (1RM) back squat and the 1RM power clean (Nuzzo et al., 2008). In rugby league, improved CMJ outputs have also been highly correlated with better tackle and sprint ability (Cronin and Hansen, 2005; Gabbett et al., 2011). Therefore, effective utilisation of the CMJ test in rugby sevens can not only play critical roles in the identification of neuromuscular fatigue and in injury risk reduction (Lauersen et al., 2013), but also in key strength outputs that are essential for athletic development, all contributing to resultant game day success (Suchomel et al., 2016).

It could be argued that the current study may have benefitted from the use of CMJ-ALT variables, to further investigate the impact on CMJ performance under different circumstances that have been evidenced- such as long-term adaptations or residual post-injury deficits. However, for the purpose of this study, it was deemed that typical CMJ variables were suitable for the aims of this research. Through the Output V2 Sensor app, typical variables such as jump height and peak power could be viewed on screen immediately following the jump effort, providing jump performance feedback with speed and efficiency at the time of testing. The accessibility of this information therefore makes the discussion of these results more easily applicable to what can be seen in practice and throughout the CMJ test, providing quick and efficient insights to practitioners. Future research should, however, consider the desired focus of the study, and determine if there is benefit from using CMJ-ALT variables for different- and potentially more study specific- insights.

4.3.2. The Relationship Between Strength Tests and CMJ Performance in Sevens

It is undeniable that strength assessments play an integral role in the evaluation of an athlete, to test their physical capacity and adaptation to training, and to identify any markers of fatigue. In most team sports, players are required to rapidly accelerate and decelerate, change direction, and quickly accumulate high speed to beat defenders, which is vital for match play advantages. All of which, can be enhanced by the ability to generate explosive muscular force (Dawes and Lentz, 2012). Especially for those competing at an elite standard of rugby sevens, increased muscular strength, force production, and the ability to express this on the pitch- all whilst enduring frequent collisions and high-speed bouts of running- are all fundamental components for performance success. Strength sessions in a rugby sevens environment are designed to complement the on-field requirements in training. As with training load, the goals of these sessions vary throughout the season, with focus on general conditioning and building strength in pre-season. As tournaments approach, these sessions become driven on power and force production, combining whole body strength and functional movements that translate to what is required on match day.

Research has identified a clear relationship between CMJ performance and strength test outputs. As mentioned prior, Nuzzo et al., (2008) investigated the correlation between particular CMJ metrics and improvements in both isometric and dynamic multi-joint strength tests. It was found that relative 1RM tests in both the squat and power clean were significantly correlated to peak power, peak velocity, and jump height in the CMJ test- all of which are classified as typical CMJ variables. In women's rugby sevens, research by Sella et al., (2023) provided evidence that connected physical testing to match performance, where positive effects of squat and jump height on tries scored were observed. It was therefore suggested that improving the players' performance in the back squat and in jump height performance could be advantageous in women's sevens, and enhance the likelihood of winning a match. These findings indicate that explosive lower body movements such as the countermovement jump can be improved as a result of increases in maximal strength, and these can have positive implications for overall performance and game success. Strength and conditioning programmes should therefore ensure that weights are calculated relative to body mass for optimal adaptations in athletes.

4.3.3. Injury Prevalence in Rugby Sevens and the Importance of CMJ Testing

Due to the injury rates in rugby sevens, World Rugby has classified injury prevention as a topic of the upmost priority of research around the sport (Tucker, 2016). Rugby sevens presents an evidently higher injury occurrence rate in comparison to other codes of the sport, with an average of 110.7 injuries per 1,000 player hours. This is substantially higher than the injury rate reported in rugby fifteens (92.6 injuries per 1,000 player-hours) and in rugby league (87.7 injuries per 1,000 player-hours) (Cruz-Ferreira et al., 2016; King et al., 2022). With the considerable difference in match-play duration between the two rugby codes- 14 minutes in rugby sevens compared with 80 minutes in rugby fifteens- the magnitude of this injury rate statistic becomes even more pronounced. With a higher injury rate per 1,000 player-hours in comparison to rugby fifteens, the degree of injury risk in rugby sevens is higher within a shorter time frame, highlighting the condensed, high-intensity, and high-risk characteristics of the game. Furthermore, out of all the sporting codes that participate in the Olympic Games, rugby has also been identified as a sport with one of the highest rates of injury incidence, because of its full-contact nature, with rugby sevens being the sport with the highest injury occurrence in the Buenos Aires Youth Olympic Games in 2018 (Steffen et al., 2019).

Because of the small squad sizes observed in rugby sevens, it is critical that players can return to play quickly, but also do this in a way that they can safely return to their game performance level prior to injury. Since the Sevens Series is such an intense tournament structure, effective athlete preparation for returning to play at this level is essential to avoid re-injury. This therefore highlights the need for frequent assessment of a sevens athlete, not only to provide indication of prerequisites of injury, but of physical status following injury- all of which can be achieved by CMJ testing. Similarly, research has identified that poor CMJ performance can be linked to injury risk. It has been discussed that in rugby league, players performing lower CMJ heights are at a greater risk of injury than those who perform better in vertical jump testing (Gabbett and Domrow, 2005), and when testing the unilateral CMJ in soccer players, peak force asymmetries when landing were determined to be a key predictor of injury (Pedley et al., 2020).

Metrics given by CMJ testing such as peak propulsive and peak landing forces, landing impulses and percentages of asymmetries can all provide insight into an athlete's physical status post injury and in return to sport. The test is an essential part of an athletes post injury progress assessment, and provides practitioners with clear indications of any inter-limb asymmetries that need to be focused on in the rehabilitation process. Particularly in sevens, where players must complete rapid changes of direction and explosive movements, monitoring power output and any lower limb asymmetries through CMJ testing will provide useful insight to practitioners. Data from CMJ testing can help to assess an athlete's tolerance to variations in training load, with guiding load progression throughout injury rehabilitation, and to prevent any premature reintegration of the athlete to full contact and competition.

Therefore, in combination with training load monitoring and strength-based training for game specific demands in sevens, the use of the CMJ test provides further benefit in performance optimisation. However, further investigation is required into the rate of injury prevalence in women's rugby sevens. Considering the recent growth in popularity in the women's game, longitudinal observations into injury rates and responses to load variability are lacking. CMJ testing as a component of strategic and effective athlete monitoring allows for insights into an athlete's response to progressive loading, while supporting injury prevention and rehabilitation strategies. Its use aligns with World Rugby's prioritisation of research into injury prevention in rugby sevens and is of benefit for the overall player welfare of female sevens athletes.

4.3.4. Methodological Considerations

There are certain testing protocols that were kept in place consistently across the entire season, as outlined in the methodology. In the CMJ, athletes were instructed to keep their hands on their hips for each jump effort, and to allow time to restabilise themselves between each jump. The consistent use of the no arm swing CMJ (CMJ NAS) protocol meant that throughout the season, the test was more sensitive to the identification of neuromuscular fatigue and changes in athlete readiness. Additionally, ensuring that an arm swing was eliminated allowed for the removal of any arm swing variation, placing focus on the isolation of lower body force production. However, it has been indicated in research by Heishman et al., (2020) that the CMJ with added arm swing (CMJ AS) can improve CMJ height by around 24%, and is more representative of sport-specific movements. In rugby sevens, where the sport is characterised by explosive movements involving arms such as tackling and jumping, the inclusion of an arm swing would likely be more replicative of in-game movement demands. However, considering the jump variation that results from the AS protocol, the NAS is the preferred method of testing when assessing neuromuscular fatigue and recovery across the season, for better replicability and validity. Therefore, for this study the protocol was an appropriate choice, however future studies should consider the intended focus of their assessment- whether this is based on jump improvement for performance, or for monitoring of lower body fatigue.

It should be noted that due to the training schedule and with regular long-haul travel across the World Sevens Series, CMJ testing was not completed at fixed time points, and instead was done at varying intervals throughout the season. The sometimes opportunistic nature of data collection throughout this time creates some difficulties when assessing changes in performance across the competitive season schedule. However, this emphasises the importance of having effective performance monitoring strategies in place, and the ability of performance staff to interrogate these results and make adaptations, to ultimately reduce any negative impacts that result from disrupted training regimes. Additionally, the data collection for this study was conducted during an Olympic year, and the timeframe that would usually be the end of the competitive season, with the completion of the World Series, was also alongside preparation for the Olympics. With the approach of the Olympics, readiness of athletes at the end of this season may not be comparable to what would be seen at the end of a normal season only involving the World Series competition. Athletes were required to be of peak fitness and availability for a time period extending past what is required in a normal sevens cycle. Therefore, the findings in this study may differ slightly to what is seen in competitive involvement in a non-Olympic year.

The countermovement jump test offers an abundance of insights into an athlete's status of neuromuscular fatigue and overall preparedness for match demand. Where resources are available to do so, the implementation of CMJ testing in any sport environment is highly recommended, especially at an elite level, where workload and physiological stress is increased. Even more so, considering the competitive format of rugby sevens, with intense tournament weeks, training camps, and fluctuations in training load, tracking CMJ performance outputs are crucial as part of an elite training programme.

Whilst typical CMJ variables in this study did not demonstrate significant changes as a whole, HMLD values displayed large and significant variations throughout the season (figure 5). This emphasises that the use of the CMJ test alone may not reflect an athlete's response to significant changes in training load. With the use of HMLD- a pitch-based measure that is reflective of the load experienced by an athlete- practitioners are provided with a quantifiable, rugby-specific volume metric. Alongside the CMJ test to measure power output and neuromuscular fatigue, monitoring the volume of physical load throughout a dynamic rugby sevens season provides crucial insight for practitioners, surrounding athlete preparedness and training programme structure.

Therefore, although valuable in athletic development, due to the controlled, gym-based nature of testing, CMJ data can become an isolated focus on performance. To enhance its applicability to the fluctuating physical demands of rugby sevens across a season, there is still a requirement for a metric that is reflective of on-pitch intensity. This can be achieved through the integration of CMJ performance metrics with the data obtained through GPS measures, providing a holistic view of player status. Whilst GPS tracking systems yield a variety of useful metrics, practitioners would benefit from utilising an interpretable measure of both session and competitive load- such as high metabolic load distance (HMLD)- to enable the quantification of intensity in a way that is context-specific to rugby sevens.

4.4. High Metabolic Load Distance

4.4.1. The Findings Against Existing Literature

With the increased relevance of this novel metric, the investigation into the results of this study aims to provide further knowledge on the use of high metabolic load distance in load monitoring, and discuss ways in which its implementation can be better tailored to sevens. Whilst previous research has been done to understand the metric primarily in soccer, there is some uncertainty as to how applicable those results are not only to the sport in the current day, but even more so to rugby sevens. As a result of the current demand for high-intensity actions in soccer match play increasing in recent years (Pons et al., 2021), most of the already limited research surrounding HMLD is outdated. Therefore, in terms of the physiological requirements of rugby sevens, and in light of the lack of research in this code of rugby, consideration of previous research in rugby union may provide a more favourable comparison to what can be seen in this study- however, there is limited knowledge again in the women's game. Hence, with the bank of resources surrounding HMLD becoming even narrower, identifying the differences in values between similar studies, and highlighting the need for more regular insights into this metric when informing practitioners, is of great importance.

This study found that the average high metabolic load distance accumulated throughout a training session by each athlete was around 530m- however this value was seen to range drastically. Throughout the season, HMLD values fell anywhere from around 100 to 1,000 metres, which is likely explainable by the nature of the session- both in intensity and duration. The analysis in this study did not focus on the categorisation of the type of training session being recorded, which accounts for such a significant expanse of values in the dataset. For example, skills and mapping sessions are very low intensity, often with very little to no running, which as a result will not accumulate HML distances. Alternatively, sessions that include game blocks reflective of a competition level of intensity will accumulate much greater totals. This study does not delve significantly into the values obtained from match data, due to certain considerations in the data collection period. However, for reference and for comparison in future research, the descriptive statistics for the data that was obtained from competitive match play is outlined in table 3. The analysis reported that athletes covered an average of 246.72 ± 115 m of HMLD, and that players that endured the entire duration of the game could be seen to accumulate anywhere between 250 and 450 m of HMLD. Again, this large range of values is likely to be dependent on the nature of that game, for example, whether it consisted of more set piece movements that slow the game down, or increased attack and defensive efforts where players cover more of the pitch at high speed. Essentially, competitive demand can be highly influenced by variations in team tactics, competitive standard and general match-to-match variation.

Considering that the average amount of HMLD covered in a game was reported to be approximately 250 m, the vast majority of all the training data observations were above this value (85.58%) demonstrating that a rugby sevens training session accumulates much higher HML distances than in gameplay. As a result of game duration being much shorter than a standard training session (approximately an hour long), it would be useful to consider these values per minute. This would result in the athlete performing at a relative HMLD work rate of 17.64 $m \cdot min^{-1}$ in competition, and 8.78 $m \cdot min^{-1}$ in training- indicating twice as much intensity in gameplay. This calculation is based on the average values found in this research, against the approximate durations of training and matchplay: 527m of HMLD on average across an hour of training, compared to 247m of HMLD covered in a 14-minute game of sevens. It would be therefore recommended for practitioners as a standard practice to measure HMLD in $m \cdot min^{-1}$, for a clear indication of intensity in the comparison of training and competition. Consideration should also be made towards the nature of the session or match, as these values will vary dependent on the exact durations and intensities.

Whilst absolute training HMLD values in rugby sevens are much greater than what is accumulated in a game, general findings in football- where the majority of HMLD research is currently concentrated- finds the opposite. In a study conducted by Marshall et al., (2024) investigating first league soccer players, it was found that training sessions recorded significantly lower absolute and relative total HMLD in comparison to their match data. It was reported that on match day, HMLD was 1,404 ± 304 m, and was highest in midfield positions (1,561 ± 303 m), whereas on a standard training day the average HMLD was 160 ± 21 m across the team (n = 18). Earlier research by Clemente et al., (2020) further supports the contrast between these values in a football context, whilst also using the same STATSports GPS technology as was used in the present study to assess HMLD load. When investigating HMLD outputs across a competitive season of professional soccer, it was found that athletes could accumulate weekly HMLD distances of between 5,385m and

7,875m- a larger total than what is likely to be accumulated across a standard week in rugby sevens. Positional differences were also evident in this study, with strikers, external defenders, wingers and midfielders accumulating significantly greater weekly HMLD totals than central defenders (17%, 24%, 31% and 38%, respectively).

With the research by Marshall et al., (2024) seemingly being one of the most recent studies to quantify HMLD in the sport, evidently, there are largely noticeable differences in the HMLD results from an elite rugby sevens environment in comparison to that of soccer. This is explained by the greater number of players, the much longer game duration of 90 minutes, and ultimately, the very different physiological demands experienced by professional soccer players. Whilst it is clear that the game of sevens is unlike many other team sports, it can be suggested that the element of time may impact how intensity is perceived when basing observations solely on HMLD results. Although it appears that training sessions in rugby sevens are more intensive, due to the majority of training sessions resulting in much higher values, the reality is that the longer the duration of data collection per session, this metric continues to increase without suitable parameters to define intensive periods. Therefore, when considering the characteristics of rugby sevens, the standardised calculation of HMLD arguably becomes more representative of distance, rather than of intensive workload. Hence, as time goes on and HMLD accumulates, it seems as though training results in a greater degree of intensity, when instead, it may be more attributable to the fact that the training sessions are often around 4 times longer than a match.

In figure 3, the biplot produced from the principal component analysis displays the relationship of each of the GPS metrics provided. With particular focus on HMLD, it appears that the metric is more closely correlated to total distance, accelerations, and decelerations, whereby all four metrics in dimension 1 explain 61% of the training load data. This finding may initially be deemed as contradictory to what is already understood about HMLD. With the knowledge that the metric is calculated from high-speed running metres rather than total distance, HMLD sitting between high-speed running and total distance, yet favouring total distance, is of interest. This would therefore suggest that the metric is sport specific, and should be approached in such a way that accounts for variation across different sporting disciplines.

4.4.2. HMLD Speed Thresholds and Sport Specific Considerations

At the time of this study, existing literature on high metabolic load distance is predominantly focused on soccer and rugby union, yet there appears to be no evidence to support the use of HMLD in rugby sevens and its applicability to its unique physiological demands, despite its appeal in load monitoring. The results in this study regarding HMLD align with what would be expected in sevens, where the metric becomes more dependent on total distance, as a result of the rugby code being high intensity by nature. The low work to rest ratio in a game of sevens sees athletes running at high speeds, for a large proportion of the total distance covered in match play. Hence, the speed threshold that is used to calculate HMLD can have significant impact on the sessions total.

When calculating HMLD, the pre-defined speed threshold for high-speed running is classified as distances covered at speeds >5.5 m.s^{-1} (≈19.8 km/h). Particularly in the context of rugby sevens and considering these athlete's highly conditioned aerobic and anaerobic capacities, athletes consistently work at a high degree of intensity and complete frequent bouts of running at high speeds, especially in gameplay. Whilst the contribution of accelerations and decelerations towards HMLD still nods to its value in quantifying intensity, this is also calculated using the total distance covered whilst accelerating and decelerating. Consequently, the categorisation of HMLD arguably becomes more heavily weighted toward a distance metric rather than one of intensity in sevens athletes, given the inherent high-intensity and high-speed characteristics of the sport. Particularly when assessing its ability to provide an individualised, pitch-based marker of intensity, HMLD is a valuable tool when assessing training and game scenarios. However, without disregarding the benefit this metric presents in load monitoring, in athletes that consistently operate at high intensity work rates, it may require some adjustment to more effectively reflect the specific demands of the sport in question.

It could therefore be suggested that when analysing HMLD in training and competition in sevens, greater focus should be placed on distances covered in different high-speed zones, rather than accumulating all distances covered above the set threshold of 5.5 m.s^{-1}. When considering match data where an athlete played the full match, some athletes were found to reach speeds of above 8 m.s^{-1}, however even in training sessions, athletes achieved an average speed of 7.47 m.s^{-1}. 98.41% of maximum velocity data entries across the entire season were above 5.5 m.s^{-1}, indicative of the speeds that these athletes are capable of achieving. However, with most of the research surrounding rugby sevens using only male participants, the respective thresholds that performance metrics are standardised to will likely be biased towards what is seen in male athletes also. It has been suggested in the literature that in rugby, maximum speeds reported in female athletes can be 2-6 km.h^{-1} slower than their male counterparts (Cahill et al., 2013; Virr et al., 2013; Suarez-Arrones et al., 2014). This emphasises the need for investigation into set GPS speed thresholds in the game. Evidence by Clarke et al., (2015) found that speed demands in elite female sevens match play may be overshadowed when compared to those used in the men's game. Their study suggests that when comparing values to reference speed thresholds in males, speed demands in women's rugby sevens can be underestimated by up to 30%. Similarly, a recent study by Bradley et al., (2024) found that when investigating the use of male-derived absolute speed thresholds in rugby union, high-speed running in the women's game is underestimated. When adapting high-intensity running (HIR) and sprint thresholds to female-adjusted speeds (HIR >14 km.h^{-1} (3.89 m.s^{-1}); sprint ≥17 km.h^{-1} (4.72 m.s^{-1}), high-intensity locomotion in the women's game was better represented. With the use of these adjusted thresholds, the volume of high-intensity activity demonstrated a better alignment to what is seen in the men's game. As a result, this would suggest that the set speed threshold for high-speed running in the calculation of HMLD in women's rugby sevens is not as reflective of 'high intensity' in comparison to male-specific thresholds. This suggests that the metric would benefit from some adaptation for its application in the women's game.

Hence, when obtaining GPS data from rugby sevens, the standard speed zone for HMLD of >5.5 m.s^{-1} should be re-evaluated in sevens specific analysis, for the most appropriate approach to the quantification of training and match intensity. By altering the velocity threshold that contributes to the overall HMLD, it would be expected that the metric will be more reflective of intensity in women's sevens, with increased specificity towards the physiologically based speed zones in female athletes. Whilst this speed threshold is a suggestion based on the results of this study and some prior research in rugby union, more specified assessments into game play versus training sessions would provide a deeper understanding about how intensity- and similarly, the average speed thresholds by which HMLD should be calculated- varies in sevens.

It is clear that in women's sevens specifically, the hypothesised speed thresholds may not be a 'one size fits all', and removes the capability for the individualised monitoring specificity that HMLD has the potential to offer. Consideration therefore should be made not only towards manipulating the speed zones in HMLD for game-specific analysis, but to other suggestions in the literature that investigate male and female specific thresholds in performance monitoring.

4.4.3. Consideration of Ball in Play

An additional point of note when monitoring HMLD is that particularly in team sports, understanding the physiological requirements and increased intensity in match play specifically, may provide benefit towards more efficient training programmes and in injury prevention. Furthermore, it has been identified that there is increased value in isolating the most intensive periods of a game (Blanch and Gabbett, 2015). By reporting only mean values and total values accumulated in a game or in training, this will likely undermine intensity levels, and a significant increase in demand can be observed in moments of higher intensity. With particular focus on HMLD, the percentage relative HMLD (HMLDrel) has been found to range from 17.2 to 31.9 % in a maximal intensity period of a rugby union game, which was a 21 % increase from the mean value (Flanagan et al., 2017). Therefore, by referencing only mean values, the intensity of match play may be significantly underestimated, and variation in positional physical requirements becomes unclear.

This would then indicate the need for more focused analysis into position-specific ball in play sequences, of which are rarely longer than 60 seconds in duration in a rugby sevens match. It has been reported by Schuster et al., (2017) that fewer than 10% of ball-in-play events exceed this time in a game, and with no more than 45 seconds of recovery time between each during a play stoppage, the high-intensity nature of this code of rugby must be attainable by all athletes on pitch. It may be that analysis of short but frequent and highly intensive passages of play could provide better insight into the true requirements of peak demand in a game of sevens, and improve athlete preparedness for these moments. The same can be applied to training analysis, to evaluate how reflective training is to the most physically demanding moments of a game. By focussing on this ball-in-play analysis, practitioners can gain a better understanding of match HMLD values and its indication of intensity, and ensure that training sessions are applicable to game specific demands. This will ensure athletes are prepared to withstand the most demanding passages of play throughout competition, and to avoid overtraining or injury.

4.5. Positional Differences in Rugby Sevens: Training Load and the CMJ

4.5.1. Overview

As with the workload variation across different stages of development in sport, similar focuses can also be placed on potential positional differences in the game, for enhanced specificity to individual requirements in these training regimes. There is a consideration towards positional differences between forwards and backs players in rugby sevens, both in training load and when analysing CMJ test results, most likely due to the physiological requirements that vary between athletes, and their roles on the pitch. It is commonly observed that specifically in rugby fifteens, these positional differences are evident. Research has found that in female rugby union matches, backs achieve greater maximum speeds and cover more distances at high speed and sprinting than forwards (Bradley et al., 2020). This is to be expected, due to the differences in roles experienced by players on the pitch, with forwards being involved in more stationary movements such as scrums and lineouts, in comparison to backs who have a greater running requirement and will naturally accumulate greater distances, particularly at high speeds.

However, due to the fast-paced nature of rugby sevens and the reduced player count on the pitch, all athletes are required to cover substantial ground, regardless of their position. As a result, differences in total distances may not offer the most meaningful insights into training load variation between forwards and backs. Instead, the differences in more high intensity movements may offer a more detailed explanation of positional demands. This study found that as a result of backs accumulating greater total distances in each session recorded across the season, the difference between playing positions were statistically significant. Additionally, backs completed more accelerations and decelerations, accumulated more distance at high speed, and achieved a higher maximum velocity than forwards players, all metrics of which were also found to be of statistical significance. These findings align with research by Higham et al., (2016), which found that in a rugby sevens game, forward players covered a total distance of 96 ± 12 m·min^{-1} on average, whilst backs covered 103 ± 14 m·min^{-1}, yet obvious positional differences in playing position when considering match physiological load and total distance remained unclear. Furthermore, it was found that backs experienced greater training and competition load than forwards when considering accelerations, decelerations and distances covered in all velocity zones ≥ 3.5 m·s^{-1}. Whilst these differences were small, perhaps explained by the more hybrid and versatile characteristics of rugby sevens athletes, there is value in understanding the variation in physiological demands between the different playing positions.

Suarez-Arrones et al., (2014) further supports this finding in sevens, where in the men's game, backs covered significantly greater distances per match, both at medium intensity (>14.0 km/h) and high intensity (>20.0 km/h) speeds. However, forwards were involved in more collision events, which the current research did not investigate for comparison to the women's game. Particularly in the context of the women's game of sevens, observational research obtained over an international sevens tournament found that across 6 games, and despite players covering similar total distance, backs achieved greater maximum velocities and sprint distances than forwards (Misseldine et al., 2021).

As previously mentioned, whilst this study does not specifically focus its investigation on match data due to a lack of observations, findings from those that were recorded in data collection (table 3) are in alignment with previous studies. This study found that in a game, backs completed more distance at high speed than forwards (110.00 m ± 65.38 vs 82.70 m ± 62.56, respectively) and achieve higher max velocities (7.57 ± 0.74 $m.s^{-1}$ vs 6.98 ± 0.86 $m.s^{-1}$). Hence, there is definite value in investigating positional differences in sevens, despite the more homogenous physical profiles of these athletes in comparison to those playing 15-a-side rugby union. Additionally, research by Bradley et al., (2020) also identified that the values observed in women's rugby fifteens differ from those that are observed in the men's game, emphasising that in the women's game, training and match-load data cannot be directly inferred from male athlete's data. There is, therefore, a clear requirement for the consideration of sex-specific threshold values, as well as positional ones, when interpreting rugby performance metrics.

4.5.2. Positional Differences in HMLD

Positional differences in HMLD between forwards and backs were also found to be of statistical significance. This can again be explained by the physical demands of rugby sevens athletes. Backs players accumulate more of each of the components that HMLD comprises of- these being high speed running, accelerations and decelerations- due to the nature of their role. They therefore naturally accumulate greater HMLD in a training session on average, with this study finding that backs averaged 560.68 m of HMLD in a session (± 258.58 m), compared with 470.17 m ± 217.42 in forwards, with this difference found to be statistically significant. Similarly, from the match play data that was obtained, backs achieved higher HMLD values in comparison to forwards (263.85 ± 116.83 m, and 216.64 ± 104.70 m, respectively). However, it should be reiterated that further research is required to investigate the findings of this study in regard to match play, due to the limitations experienced in data collection. Whilst the results of this study do align with the expected outcome that backs would cover greater distances of HMLD, it is more difficult to identify clear thresholds between the two positional groups than in other team sports, again due to the complex and unique nature of sevens, and a lack of prior research around this metric.

Whilst there appears to be little research that exists that explains positional differences in HMLD in women's rugby sevens, consideration of these results alongside existing literature may offer an explanation towards how HMLD can be used, and attempt to understand positional demands in the sport. HMLD has been researched primarily in soccer, with prior studies investigating positional differences in professional soccer players finding that HMLD is effective in reflecting the unique physical demands and varied level of training intensity that players experience. In a study in soccer conducted by Martín-García et al. (2018), it was found that during the most intensive passages of play, midfielders and wide midfielders accumulated the greatest amount of high metabolic load distance. In contrast, central defenders recorded lower totals of HMLD, likely due to players maintaining a compact playing structure in defense, and covering less ground. Research by Akyildiz et al., (2022) also found that in the first half of a game, central midfielders have also been shown to have significantly higher metabolic power than all other positions, whilst central defenders have been found to demonstrate the lowest metabolic power output. García-Calvo et al., (2022) later supported this finding, demonstrating that between positions and across competitive levels, significant differences were observed in HMLD in both the first-half of a game, and overall.

All of these findings are reflective of the physical demands of the positions these athletes play in. As a result of midfielders largely being involved both in attack and defence on the pitch, they also complete frequent accelerations, decelerations and change of direction, and cover the most distance. From a systematic review in soccer (Sarmento et al., 2024), midfielders achieve the highest total distance of all playing positions in a game- averaging around 11,000 m- with wide midfielders accumulating the most high-speed running distance in comparison to all others (Dalen et al., 2016; Modric et al., 2021), which results in high HMLD values. Whereas, whilst central defenders and forwards also accumulate significant total distances- 9,598 m and 10,068 m in a game, respectively- this distance is covered at low running intensities. In the study by Modric et al., (2021), from those playing as central defenders of forwards, 84% and 81% of their total distances covered were at a lower intensity (<14.3 km/h, or <3.92 m.s^{-1}). Hence, their positional demands result in lower totals of HMLD, due to the speed requirement of HMLD only considering distances covered above 5.5 m.s^{-1}.

In another investigation into match play demands in soccer, Tierney et al., (2016) also found that HMLD values can also be impacted by various tactical positional changes. For example, by altering player formation into a 3-5-2 layout both HMLD and HSR totals increased (2,025 ± 304 m and 642 ± 215 m respectively, where $p = 0.001$ in both). Changing from a 4-4-2 formation to a 4-3-3 resulted in central midfielders accumulating >14% more HMLD (1686 ± 628 m). However, in line with the findings of Dalen et al., (2016) and Modric et al., (2021), wide midfielders always accumulated the highest HMLD, and this remained true regardless of playing formation. This demonstrates that some playing positions regularly accumulate the highest workload simply due to the nature of their role, however, there are ways to effectively manage this exposure to intensive training and competitive load in individuals through changing playing formation.

Based on the evidence in a football setting, this could be useful for consideration in other team sport environments like rugby sevens. Particularly with the intensive competition schedule that rugby sevens athletes are exposed to, performance staff should direct their attention to playmakers that frequently accumulate high match load. As seen from research in soccer, tactical changes in playing formation can have significant impact on an athlete’s overall workload. In an effort to avoid overtraining, fatigue and resultant injury through overworking players in particular positions, mindfully rotating athletes may offer some reprieve from the already excessive workload experienced throughout a tournament. This is a reasonable suggestion in sevens, because of the clear adaptability amongst elite level squads to transition into various roles presented on the pitch.

With the evident contrast between the physical demands within rugby sevens to that experienced in football or rugby union, findings from existing studies can only partially explain the variation of intensity across playing positions. Additionally, whilst important data in elite female rugby sevens athletes were gathered throughout the season and are applicable to the sample used in the current study, generalising these findings to the wider population of female sevens players becomes difficult, as a result of the variability in the data, and a small sample size. Further consideration should therefore be made towards HMLD in rugby sevens overall, with additional focus on the intensity experienced in training and competition environments, to then clearly distinguish any relationship between high metabolic load distance and playing position.

The previous discussion of HMLD in this study aims to therefore continue to explore the importance of appropriately monitoring high-intensity loading, particularly in women's rugby sevens, for more robust training programmes, injury prevention and athlete monitoring. Regardless of the fact that current literature regarding HMLD is heavily focused on applications in football, these findings still present meaningful implications for the use of the metric in rugby sevens. Although positional requirements can become blurred in a sevens context, as a result of each players ability to be diverse in both attacking and defensive responsibilities, the current study still highlights significant differences in HMLD between forwards and backs. Hence, monitoring HMLD outputs across playing positions is still warranted, and should be taken into consideration when quantifying training and match load- particularly in intensive competition schedules- and in planning recovery protocols. With the application of insights derived from other team sports, HMLD can act as a versatile performance metric in the quantification of metabolic demand and intensity in sevens.

4.5.3. Considerations Towards Collision Impacts in Workload Quantification in Sevens

This study did not investigate differences in impacts and collisions between forwards and backs, however it has been identified that a large majority of the workload experienced by forwards players is primarily due to the frequent impacts they experience throughout a game. In rugby union, research often reports significant positional differences in both tackles made, as well as sustained collisions. Quarrie and Hopkins (2008) reported that forwards made 28% more tackles than backs and similarly in research by Van Rooyen (2012), this was found to be 32%. These findings are again explainable by positional differences, with forward players being involved in the set piece movements of scrums and lineouts, and hence being more exposed to contact situations.

Therefore, despite perhaps not accumulating as much distance and at high speeds as backs players, forwards in rugby union experience higher workloads and energy expenditure, due to a greater degree of static exertion and collision events during a game, both overall and per minute of match play (Macleod et al., 2018). It could therefore be hypothesised that similar observations surrounding energy expenditure can be made with regards to rugby sevens, however there are a multitude of factors to consider when drawing these conclusions, such as the frequencies and velocities at which these collisions occur, and the gap in literature not only in sevens but more so in the women's game.

Forwards and backs work rates appear to be more similar to each other in rugby sevens than in the rugby fifteens code, whereby all players are exposed to frequent bouts of high-speed running and impacts as a result of the more fast paced and high intensity nature of the game. However, there are still clear positional requirements in the game of sevens which elicits different physical demand, which is supported in this study by the statistical significance in distance metrics- both HMLD and total distance- between forwards and backs. Whilst positional differences in rugby sevens are less distinct than in fifteens, there is a notable difference in high-speed metres covered by backs players compared to forwards (193.63 m vs 158.07 m respectively). Hence, there is evident value in understanding the increased physiological load experienced by forwards due to a higher frequency of collision events, the increased speed of impact experienced by backs, and the physical exertion that accompanies this. In a recent study by Reardon et al., (2017), it was found that in competitive match play in rugby union, forwards experienced significantly more collisions per minute in comparison to backs. Across 17 matches, running and collision demands from 39 elite professional rugby union athletes were monitored using GPS tracking. The study reported that more collisions were completed by the tight five and back row forwards (0.73 and 0.89 collisions·min^{-1}, respectively), whilst collision rates were reported as 0.28 collisions·min^{-1} for inside backs, and 0.41 collisions·min^{-1} for outside backs. Whilst this study did not report collision intensity, other studies have highlighted that whilst backs experience a lower collision number, the impact load experienced by backs is usually higher due to an increased running speed and momentum going into a collision, with supporting evidence for this in both fifteens (Tierney et al., 2020) and sevens (Ross et al., 2013).

Whilst collision load and the number of collisions are quantifiable using GPS technology, monitoring HMLD may provide some insight into the overall physiological demands experienced by an athlete. HMLD acts as an easily measurable marker of intensity, and with effective and consistent tracking, has the potential to be monitored individually for increased specificity that reflects each athlete's workload. However, regarding collision load, it is important to recognise that HMLD should not be viewed as a substitution for detailed, collision-specific metrics. The calculation of HMLD includes deceleration count, which is loosely reflective of elements of a collision, whereby a collision impact would cause the athlete to slow down. However, relying on this measure alone to inform collision frequency and load lacks the context and accuracy of collision specific data that is available. Decelerations occur as a result of various non-contact scenarios, particularly where frequent change of direction is involved in rugby sevens, and is not reflective of collision frequency. HMLD, therefore, should be interpreted as a measure of work rate which complements the insights provided by dedicated collision metrics.

In practice, performance staff should place additional consideration towards these metrics, such as collision load and collision count, to accurately quantify the impact felt by an athlete. Specifically in contact-based sports like rugby, these insights are vital for performance optimisation, management of training load and recovery, and for injury prevention. Specifically in the context of women's rugby sevens, further research is required to delve into the impact of collisions on an athlete, and to better explain positional differences within the game.

4.5.4. Positional Differences in the Countermovement Jump

The findings from the boxplot in figure 4 align with other studies in the literature, with significant jump height differences being observed in both rugby fifteens and in sevens. In research by Heffernan et al., (2021) which investigated positional variation in CMJ characteristics at an elite level of women's rugby union, it was reported that jump height, reactive strength index and relative force production were all greater in backs in comparison to forwards. These results have also been found in other studies in rugby league (Jones et al., 2016), although there again appears to be limited research into positional differences for the countermovement jump in women's rugby sevens.

In one study conducted by Ohya et al., (2015) in women's sevens, a CMJ height mean difference of 0.9cm between forwards and backs was reported (37.5 cm ± 4.0 vs 38.4 cm ± 4.2 respectively). However, contradictory to the findings in the current study, this research by Ohya et al., (2015) found that the differences between playing positions were not significant, likely explainable as a result of the homogenous athletic profile of a sevens athlete. This would be the expected outcome, given that the physical requirements of a sevens athlete expect all players to be agile whilst demonstrating explosive power. However, the observed differences in CMJ height in the current study may be more reflective of the role-specific demands of the two groups. Forwards are typically engaged in more static movements including repeated collisions and rucks- actions of which are often performed at lower speeds following the athlete bracing for impact. Hence, it is likely that an athlete playing as a forward presents a strength profile that favours horizontal force production. In contrast, athletes that play as a back are regularly involved in aerial contests for the ball, as well as high-speed running and quick, evasive lateral movement. It has been documented that backs therefore present higher power outputs in the CMJ test (Ross et al., 2015), likely as a result of their increased exposure to these demands.

This is partly supported by research by Lonergan et al., (2022) in male rugby sevens, which found that although differences in commonly reported variables in the countermovement jump were not significant between playing position, concentric peak velocity, concentric peak power and eccentric peak power were all higher in backs- highlighting the variation in positional demands, and physical adaptations to those requirements. It should be noted however that this study used CMJ performances from male rugby sevens athletes. However, evidence of sex differences in phase characteristics have been highlighted in research, such as increased concentric phase velocity and larger concentric impulses, resulting in greater velocities and jump heights (McMahon et al., 2017). Therefore, conclusions may not be entirely applicable to female rugby sevens players. When investigating this relationship in the context of the sevens game, there is a lack of exploration into the women's game specifically, again identifying a requirement for improved research in this field.

It would appear that whilst the current study's findings align with that of rugby fifteens, it is difficult to draw conclusions to limited research previously done in sevens, especially when results appear contradictory. Whilst significant differences were reported in forwards and backs for the CMJ in this study, categorisation into these two groups may cause conclusions to be unclear, due to the power and explosive strength of sevens athletes across all playing positions. Whilst the participants in this study can be grouped into forwards and backs, it is also a consideration that some athletes are adaptable to other playing positions. The dynamic and intense nature of the game requires athletes to participate in scrums, rucks, mauls and lineouts, all of which occur at low velocity, but are very physically demanding (Smart et al., 2014). The athlete must therefore possess a high external force output, and efficiently express these outputs on pitch, for both improvements in physiological adaptations to the requirements of the game, as well as match day performance success.

It is therefore undeniable that whilst the high degree of agility and physicality in the sevens game is experienced across the whole squad, there are also some biomechanical differences to consider because of varying positional roles, and their impact on performance outputs. Hence, with frequent CMJ testing, an individualised performance profile can be produced for each athlete. Furthermore, when investigating the positional requirements, forwards players could benefit from a more tailored approach to their specific demands. Whilst all players in rugby sevens should display a high force output, and in general the tackle demand in a sevens game is quite low (Ross et al., 2015), forwards athletes who are involved in more collision events and in scrums will benefit from increases in momentum and power production. Therefore, particular focus on metrics that are more specific to this would be useful to consider, such as jump momentum, which combines mass and velocity measures, and is a crucial metric for analysis of force production under load.

Considered against more pitch-based performance outputs, indication of injury, fatigue, or seasonal adaptations with increased training load can be more effectively identified. With the existing evidence of CMJ performance in women's rugby establishing positional differences in performance output, this study is an addition to the already abundant support in the literature surrounding the benefit of testing and monitoring CMJ performance throughout a season.

4.5.5. Summary of Positional Differences in Rugby Sevens

When considering different positional demands in rugby sevens, there is an evident shared need for explosive movement, power, speed and endurance from all players. However, by implementing position specific training drills into a training programme, match demands experienced by both forwards and backs can be appropriately tailored. With further research into the behaviour of HMLD in particular, this metric may offer a clear quantification of metabolic load and intensity experienced by athletes.

This study's findings of significant differences across playing position in accelerations, decelerations, high-speed running and maximum velocity may be slightly contradictory to current literature. This may be explained by the fact that the data used in the current study is more heavily weighted towards observations obtained from training, with fewer data from match play, whereas literature that currently exists surrounding positional differences appears to place more focus on competition data. The nature of a training session may place more specific focus on the positional demands of forwards and backs, hence creating more significant differences in performance metrics. Positional differences naturally become more homogenised in a game context, as a result of the adaptability, pace and physicality required by all players in rugby sevens.

It has been suggested that physical preparation across positions in rugby sevens could be approached in a more generalised manner than what is implemented in rugby fifteens (Schuster et al., 2017), due to both the stark contrast of positional roles in fifteens, and also the clear versatility of a sevens athlete. Sevens players are often capable of demonstrating exceptional adaptability to varying roles, and can often comfortably shift between these roles when required. Whilst forwards are typically involved in static movements and frequent collision events, athletes can also reach high speeds in match play and cover significant distance, because of the notably open space presented on a sevens pitch. Similarly, backs possess high physicality, and frequently dominate in tackles whilst also being agile and accumulating greater high-speed distances (Ross, Gill & Cronin, 2014). All players therefore are expected to successfully execute most actions in a game, despite their stereotypical movement demands, and as a result, would potentially be of most benefit following more generalised performance programmes amongst the squad, that focus on the match demands that are prevalent in sevens, such as frequent collisions and high-speed running, against a significantly reduced work to rest ratio (Henderson et al., 2018). This should not undermine the need for more specified focus amongst the group on game play execution and position specific drills. All of these elements should be integrated into a successful overarching framework in elite teams, in order to establish multifaceted physical profiles for all athletes.

The difficulty in expressing clearly defined positional differences in sevens only further emphasises the need for both CMJ testing and monitoring of training and competition load using GPS tracking- potentially whilst specifically monitoring HMLD as an individualised unit of intensity. By quantifying this load and monitoring physical exertion through appropriate athlete tracking, athletes can be monitored at an individual level, and game specific positional demands can also be accounted for.

Whilst HMLD offers some insight into the workload completed by an athlete, it may be of maximum benefit when considered alongside other metrics, and not in isolation. The comparison of both datasets amongst the season (figure 5) shows that whilst the two are not directly comparable, observing CMJ performance outputs in response to variations in training load and intensity can be very useful to practitioners. Using appropriate sport-specific bandwidths, the quantification of load through HMLD provides an easily measurable metric to outline session intensity, and has the capability to provide personalised thresholds for each athlete. Used alongside frequent CMJ testing, practitioners can be provided with a more thorough visualisation of how the athlete is tolerating this workload, drawing comparison to a pitch-related metric of intensity in HMLD. This study highlights that whilst the two measures yield very different observations, the implementation of both in an elite competitive set up is crucial to provide strong foundations for performance excellence, tailored, individualised programming, and enhanced strategies to monitor fatigue and recovery.

5. Study Reflections and Future Considerations

5.1. Gender Bias in Rugby Sevens Research

An evident limitation in this study is the lack of research that exists between elite female rugby sevens athletes and their male counterparts. The women's game has demonstrated a clear rise in popularity, participation and opportunity- made even more prevalent in recent years- and is accompanied by a poignant cultural shift to celebrate female excellence in contact sports. Despite this, there is a notable disparity in existing research in women's rugby sevens in comparison to the men’s game, let alone any in-depth investigation into varying positional requirements. Hence, supporting evidence for the findings of this study using previous research in women's rugby sevens is lacking in places, and often draws comparison to research from the men’s game and other codes of rugby, or to other sports such as soccer, which are not as applicable to rugby sevens. Especially in the current research that exists around HMLD, the focus is primarily on soccer and therefore cannot be directly compared to the increase in intensity level and the physical requirements that are observed in rugby sevens.

Furthermore, whilst it may be that in recent years, research interest in women’s rugby sevens is increasing- potentially even more so than that of women’s fifteens- the longitudinal element of these studies, and comparison to research that is comparable to the demands of rugby sevens is difficult at this time. In both sevens and fifteens, research in the men’s game dominates, and so there should be greater effort to re-evaluate the focus in emerging women’s research away from studies surrounding male athletes. With time, a greater expansion of evidence that is more closely related to the demands of the women’s game specifically will help to tailor current measures more accurately, in order to reflect these differences.

Clearly there is a continued requirement for more gender specific evaluations in rugby sevens, of factors such as positional differences, appropriate speed thresholds in GPS tracking, and longitudinal research into injury prevalence and prevention, for enhanced player welfare in the women’s game. This study attempts to add to the knowledge that does exist currently, and provide suggestions for improvements towards performance monitoring in the women’s game of sevens going forward.

5.2. Competition Data and Variations in Training Session Intensity

This study does not clearly distinguish the variation in the data during training in comparison to competition, whereby physical demands can differ greatly. Firstly, due to factors impacting data collection such as stadium obstruction as mentioned previously, some match data did not meet the preferred degree of accuracy for observations in this study, and so was excluded. Specifically, two tournament locations on the World Series were held at stadiums that were covered by a roof during games, hence no data were obtained from those tournaments. Whilst acknowledgement has been made in this study towards some of the observations made from game data, accurate conclusions from tournament periods throughout the whole season could not be made.

Even when only considering training data, sessions would vary significantly, and workload was dependent not only on the intended goal outcomes of the session, but also in duration. For example, when analysing HMLD from the training session data, totals could range from anywhere between 100 and 1,000 metres. Each training session would, for the majority, be allocated a one-hour time frame in the training schedule. However, these could run over or be completed sooner, depending on factors such as the goals of the session, the intensity of the session, and whether top-ups in training volume were required to reach expected values for the week. Session duration was not a factor that was included in the data and subsequent analysis, although on reflection of this research, the results would have benefitted from this to add greater detail to its findings. This sessional variation could explain the resultant variability in HMLD values. It is therefore suggested that future research should classify training sessions into their intended levels of intensity and durations. This will allow for a clearer comparison of workload between training sessions, a better understanding of the total HMLD that is accumulated, and the overall playing time that the athlete is exposed to. Athletic development programming may also benefit significantly from these classifications, as by using repeatable session plans that produce a known degree of intensity, workload monitoring becomes easier to anticipate.

Additionally, from the match data obtained, playing duration amongst the team was not specified. Hence, this does not account for differences in workload between athletes who were substitutes and who may have only played for a few minutes, and those that played for the entire match duration. It has therefore been identified as a limitation that these data lacks specification into the type and duration of training or competition data, and so future research should focus data collection using these different groupings for more relevant conclusions. Furthermore, as a result of these limitations, for the purpose of this study, the primary focus remained on training load, however future research should also incorporate match play data for greater insights into seasonal variation in the sport.

Further research is required when understanding HMLD as a measure of individual intensity, and there is significant scope for exploration of the metric in rugby sevens, comparing match play to training, and between playing positions. With this comes an added level of detail in recommended data collection, as total minutes played per athlete should also be considered. In instances where a player only accumulates a few minutes of game time, this can have significant impact on the calculation of HMLD, and future studies should be careful not to assume that an athlete plays the full 14 minutes and any additional time in a game of sevens. It is unlikely that a sevens athlete will play the entire duration of the game, with playing time being dependent on the individuals own performance, the coach's strategy and intentions for that game, and equally the performance of the opposition. This study did not investigate playing duration per athlete, and so future research should include this element of time when analysing HMLD and in quantifying session and match intensity.

5.3. Training Programme Constraints

Another limitation to this study was that the team were training on the basis of a part-time training set up, with approximately monthly competitions. Athletes were not all locally based, and training facilities were varied throughout the season, with most athletes having to commute for only a few days a month at a training facility, before having to then return home. This presents particular concerns surrounding consistency of performance testing, as training camps were not as consistent as teams that are all based in and around the same facility, and train together most days.

With the changes in location and variations of the programme set up that players were experiencing, performance testing also became inconsistent at points and should be taken into account when drawing conclusions from the results of this study. Occasionally, and dependent on the training location in some camps, the CMJ testing was conducted using VALDhub force plates, as opposed to the Output sensor used for data collection in this study. The force plates were not always available for use, however when they were, jump testing was prioritised using this equipment. This is because despite the compact, easy to use system of the foot sensor, the force plates had increased benefit to performance staff for the extended analysis and insights it can provide, such as takeoff and landing limb asymmetries. It should also be noted that this study was based on secondary analysis of data, and so it was not a requirement to only use the Output device within the programme. Hence, in those scenarios there would be some testing days that were not recorded using the Output sensor. However, this happened very rarely throughout the duration of the season and so did not impact the overarching goals of this study, nor detract from any results from the Output device. Despite the few instances where the force plates were used, the Output sensor was used for all other CMJ tests, and was therefore the most reliable and consistent platform to base this study's analysis on.

As a consequence of the training schedule, training camps would sometimes result in athletes only having the facilities to train together, in the presence of practitioners and test equipment, for around 4 to 8 days per month, not including tournaments. Whilst home based GPS tracking systems were provided, using the STATSports Athlete Series technology, these systems only provided some of the insights that the teams Pro Series technology would offer, including activity graphs and increased data complexity. CMJ testing was also unable to be conducted remotely because of there being no access to remote testing equipment or a practitioner to conduct the testing. So, where athletes were undergoing periods of home-based training, this data could not be obtained and therefore was only collected opportunistically. This contributes to the resultant non-uniform distribution of data points across the competitive season. This study therefore is at a disadvantage in comparison to a team that is based within close proximity to their own training facility, and are presented with the opportunity to train consistently together, with consistent data collection on the same platform, and to be tested at regular intervals. Whilst this is limiting in some regards, there is also a benefit that can be taken from this study. The key takeaway is that even in programmes that do not have a consistent base, or also have to incorporate home-based training, there are still ways to monitor individuals for the most optimal performance outcomes. Whilst there were external factors that may have impacted data consistency to some degree, adaptations to various training loads throughout the season, backed by an effective strength and conditioning programme and athlete monitoring, saw the team able to rightfully and successfully compete in the World Sevens Series.

5.4. Strengths and Practical Applications

Whilst this study discovered some difficulty with data variability and other constraints, key strengths should be highlighted. The research was successful in providing data from an elite women's rugby sevens team across an entire competitive season, and contributes to current literature surrounding the sport. Additionally, the study addresses the gap in the literature regarding women's rugby sevens in comparison to the men's game, and suggests approaches in future to better reflect the physical requirements of the game through GPS monitoring, such as a re-evaluation of speed thresholds. Investigation into performance monitoring strategies- the countermovement jump test and the monitoring of high metabolic load distance- were assessed in their application to rugby sevens, offering further insight into future studies, which will support training programmes, and tailor recovery strategies in an elite women's rugby sevens environment.

Whilst contributing to the knowledge around the relatively new metric of HMLD, the study also contributes to the bank of research surrounding the use of the countermovement jump test in rugby sevens. The study followed a consistent protocol of a no arm swing jump, and only included data collected through the Output sensor, ensuring data reliability, and to minimise variation in the results. Furthermore, the use of the easily transportable Output V2 Sensor meant that it was easier to conduct the CMJ test and obtain data throughout the World Sevens Series competition, without being reliant on the availability of force plates. Additionally, the test would only be conducted under the instruction of at least one of the same two members of performance staff throughout the season, reducing the potential for variability between testers. Fluctuations in CMJ height were visualised throughout the season, demonstrating how changes in workload, fatigue, and physical adaptations throughout training and competition can impact performance. This supports the use of the CMJ test as a gold standard practice to monitor neuromuscular performance and fatigue in rugby sevens. Using a clear, standardised test protocol, practitioners can be confident in the insights it provides when informing load management and supporting return-to-play decisions. Particularly with the fast paced, demanding nature of the rugby sevens season, the CMJ test is a quick and reliable method for monitoring sevens athletes.

This study emphasises the benefits and efficacy of HMLD in performance monitoring, making it a clear measure to understand intensity, accessible for practitioners and athletes alike. In practice, the visualisation of these data as displayed in the results of this research is important for practitioners to better understand the nature of the data, and enable detailed tactical discussions with coaches. For the purpose of clearer observations of each metric in the dataset, the biplot (figure 3) does not display where each datapoint lies. However, the use of this biplot presents a tool for the identification of clustered observations in the data from full sessions, or even for a detailed analysis of a game-specific drill. Practitioners can implement this analysis in both training and match play scenarios to highlight matches with similar workload profiles- for example, those more heavily focused on a higher running distance load, or a greater degree of intensity and pace. This analysis can also contribute to the justification of drills that are most closely related to the demands of the game, allowing coaches to identify where the emphasis should be placed in training for optimal game readiness and performance outcomes.

Similarly, this can provide crucial information to benefit the understanding of both the player and performance staff, regarding the demands of positional and tactical roles under changing scenarios. It can be seen in elite performance environments that athletes are exposed to large influxes of data throughout training and competition, used for both assessment of individual performance, and also during opposition analysis- both of which contribute towards overall performance success. However, this is often associated with an abundance of metrics that can become overwhelming, especially when combined with all of the additional requirements and responsibilities asked of an elite athlete. The difficulty lies with sport scientists effectively translating this into a language that is understood across the entirety of the squad. The clear benefit of further investigation into HMLD is that the metric offers to bridge this gap, combining three performance metrics into one figure that is representative of the intensity of the session or drill, and the work done by the individual. Frequent monitoring of HMLD within a performance team can produce individualised thresholds for the team and the athlete, providing tailored bandwidths for the intensity that is expected.

From the research, it can be confidently inferred that physical demands increase with playing level, and that particularly at an elite level of rugby sevens, effective load monitoring is crucial for player wellbeing and performance outcomes. Whilst research surrounding the application of HMLD to rugby sevens is scarce at the time of this study, the broader research base provides evidence of increasing match intensity and workload experienced with increased playing level (Scanlan et al., 2011; McLellan and Lovell, 2013; Gabbett, 2014; Vigh-Larsen et al., 2019). This study therefore provides justification for the use of HMLD monitoring in an elite rugby sevens environment. The metric encapsulates the high intensity workload experienced by athletes, which is likely to increase with competitive level, as has been evidenced in rugby league and other sports. Therefore, HMLD is a promising tool in performance monitoring, particularly at an elite level of the game, where increases in workload need to be carefully managed. In doing so, training adaptations and recovery can be balanced effectively, and heightened injury risk at this high level of competition can be more closely assessed.

6. Conclusion

This research at its core has identified a step forward in the women's game of sevens, which is reflective of its exponential growth in popularity at this time. Understanding how to monitor the intensity and demands of rugby sevens is crucial, given its high workload and unique physical demand. This research has provided justification for the use of HMLD as a marker of intensity in an athlete, and this study has attempted to provide a benchmark for future research into performance monitoring in elite women's rugby sevens, and in development pathways of the sport. HMLD should be used as a simple measure of intensity for practitioners to use as benchmark values, and provides context to better inform performance outcomes. It should not be used as a direct replacement for the detailed insights offered by dedicated performance metrics, however, such as collision-based metrics.

Monitoring workload using GPS-derived high metabolic load distance, alongside neuromuscular assessments like CMJ testing, offers a comprehensive approach to understanding elite rugby sevens demands, both in a controlled testing environment and on the pitch. Both provide their own undeniable worth when considering performance insights and load tolerance, and the implementation of both within a training programme will provide performance staff with better insight into training load monitoring and management. Further research should be done to investigate the implementation of HMLD monitoring in sport-specific contexts. Additionally, more research is required in the field of women's rugby sevens in general, for robust training programmes, improvements in player wellbeing and development pathways, and enhanced injury prevention strategies.

7. Appendix 1: Abbreviations

Abbreviation	Definition
ATP	Adenosine Triphosphate
AW	Acute Workload
ACWR	Acute:Chronic Workload Ratio
$ACWR_{HMLD}$/EP	Acute:Chronic Workload Ratio (High Metabolic Load Distance)/Endurance Performance
Bluetooth LE	Bluetooth Low Energy
CMJ	Countermovement Jump
CMJ AS	Countermovement Jump with Arm Swing
CMJ NAS	Countermovement Jump with No Arm Swing
CMJ-ALT	Countermovement Jump Alternative Variable
CMJ-TYP	Countermovement Jump Typical Variable
CW	Chronic Workload
EP	Endurance Performance
FT:CT	Flight Time:Contraction Time Ratio
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
HIR	High-Intensity Running

HMLD	High Metabolic Load Distance
HMLDrel	Percentage Relative High Metabolic Load Distance
HSR	High-Speed Running
IMS	Inertial Movement Sensor
IMU	Inertial Movement Unit
LT	Lactate Threshold
PAP	Post-Activation Potentiation
PAPE	Post-Activation Performance Enhancement
PCA	Principal Component Analysis
RPE	Rating of Perceived Exertion
RSI-Mod	Reactive Strength Index-Modified
sRPE	Session Rating of Perceived Exertion
SSRI	Self-Selected Rest Intervals
UCJ	Unilateral Countermovement Jump
UDJ	Unilateral Drop Jump
UWB	Ultra-Wideband
VBT	Velocity-Based Training
VHSR	Very High-Speed Running
1RM	One-Repetition Maximum
3G	Third Generation

8. Appendix 2: PCA Biplot

The biplot (figure 6) displays the results of principal component analysis after varimax rotation was conducted. The rotation allows for visualisation of the datapoints between each metric included in the GPS dataset, whilst retaining the two dimensions that explain the most variation (components 1 and 2).

The varimax rotation step contributes to the interpretation of the components in PCA. However, the original biplot before rotation was retained for a clearer, unobstructed visualisation of the metrics without the addition of each datapoint. The evident split between GPS performance metrics that is seen in the biplot in figure 3 remains visible, as rotation preserves the correlations between each variable.

Biplot of Principal Component Analysis (PCA) Results Following Varimax Rotation on GPS Dataset

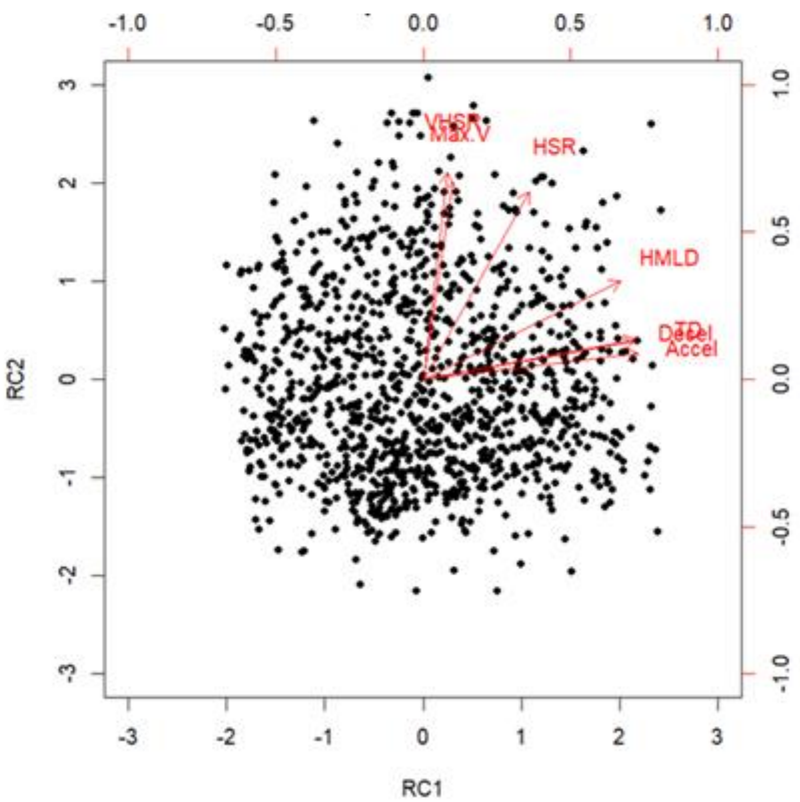

Figure 6. Biplot of Principal Component Analysis (PCA) with Varimax Rotation. Biplot demonstrating the relationship between rotated components in the dataset. Plot displays rotated components 1 and 2. Factors included in the analysis are total distance (TD), high speed running (HSR), very high-speed running (VHSR), accelerations, decelerations, high metabolic load distance (HMLD) and max velocity (Max.V).

9. Appendix 3: Impact of External Factors on Performance Outcomes

In any study in sport, consideration towards the changing environment and travel requirements should be made as this is likely to impact performance significantly when not appropriately managed and prepared for. These factors are of particular interest in rugby sevens, and even more so at the most elite levels of the sport. Teams involved in the World Rugby Sevens Series are expected to travel frequently around the world. Often accompanied by this long-haul travel is significant impact on sleep and mobility, inducing travel fatigue and jet lag, and which then has a negative impact on an athlete's cognitive and neuromuscular capacities. Players are also required to adopt acclimatisation strategies to help them to perform in changing temperatures and high humidity

Both long-haul (> 5 hours) and short-haul travel (< 5 hours) have been identified to cause detriments to performance in the countermovement jump (Mitchell et al., 2017) in elite rugby sevens players. Additionally, in hot and humid locations currently involved in the World Series such as Singapore, players have reached peak core temperatures (> 39 °C) that can impair repeated sprint performance capacities (Girard et al., 2015). Therefore, future research regarding performance monitoring and session intensity in rugby sevens should also account for the negative impact on performance that can result from travel bouts. Stressors such as travel fatigue, temperature and sleep cycle adjustments should all be a consideration when planning session schedules, monitoring athletes and assessing performance. Similarly, performance staff should ensure that sleep, hydration and nutrition throughout tournament periods are of the upmost priority. This will ensure athletes are appropriately fuelled for the demands of the game and can recovery effectively, eliciting overall performance successes.

It should be noted that although this study did not include discussion of a wellness questionnaire, there was a wellness monitoring system in place within the team. This contributed to training load response observations, and helped to inform performance staff of any muscle soreness, fatigue, and potential indications of injury. Particularly around travelling for tournaments, and the intensive training and competitive schedules that surround rugby sevens, athlete wellness responses become a crucial element of a player assessment. Future research investigating HMLD and performance monitoring in rugby sevens would also benefit from an accompanying wellness questionnaire, to gather insight into athlete adaptation and tolerance of this element of international travel. Wellness monitoring in female athletes should also include specific consideration of the impact of the menstrual cycle and contraceptive medications, acknowledging their effects on muscle-tendon unit function and fatigue levels. With this insight, physiotherapists, sport scientists and coaches can all benefit in their own department to inform rugby performances and player assessment. Combining the knowledge of varying session intensities with athlete wellness monitoring observations, staff can be better informed. This insight will allow for adaptations to workload and tournament schedules, in line with external factors that may influence an individual's performance and energy levels, such as jet lag, stress, and menses.

Additionally, practitioners should make conscious effort to educate themselves and the team they have responsibility for, around appropriate acclimatisation and jet lag recovery protocols, sleep and nutrition- ensuring optimal player readiness, and to efficiently prevent any detriment on performance as a result of travelling for competition. Future research into intensity-driven metrics such as HMLD, and neuromuscular fatigue assessments such as the CMJ test in rugby sevens should take these external stressors into account. Practitioners should also do the same when making observations of performance, and when planning training schedules ahead of competition. Especially due to the travel requirements of the World Sevens Series, the additional factors that accompany this may ultimately impact performance and player wellbeing, and should be taken into consideration. This will reduce the risk of injury and fatigue in players, ensure better load monitoring and recovery strategies, and optimise performance outcomes in elite rugby sevens tournaments.

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