Anthropometry and Physical Characteristics in English Premiership Women's Rugby

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SUBMISSION FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT

Rugby union is a field-based team sport characterized by repeated high-intensity activities (sprinting, agility and collisions) combined with periods of lower intensity activities (walking and jogging). Based on positional differences and match demands, athletes are generally grouped as forwards (front row, second row and back row) and backs (scrum half, inside backs and outside backs). English premiership women's rugby union has been continually growing in popularity and gaining participants every year. Besides increases in participation, the standard of women's rugby union has improved due to increased investment, which enabled international women rugby players to become semi or fully professional. The growth of women's rugby union has naturally led to an increase in scientific interest and research. Research into women's rugby union has focused on match demands, anthropometry, and physical characteristics.

In study 1, a systematic search of literature was undertaken to review existing research regarding identifying the characteristics to become a competitive women's rugby union player. The result revealed that a total of 25 studies focused on identifying and discussing match demands, anthropometry, and physical characteristics. Forwards were found to have participated in more collisions, were heavier, and demonstrated greater absolute strength. Backs engaged in more high-speed running, were leaner, aerobically fitter, and relatively stronger.

In study 2, anthropometry using dual-X-ray absorptiometry and physical characteristics made up of strength and power tests (countermovement jump, drop jump, and isometric mid-thigh pull) were investigated and grouped by position. Overall, forwards had significantly ($p < 0.01$) higher body mass, fat mass, lean mass, bone mineral content, and take-off momentum, and backs had significantly higher ($p < 0.01$, d > 0.5) jump height, reactive strength index modified, and shorter drop jump contact time.

In study 3, Seasonal changes of anthropometry and physical characteristics were observed throughout pre-, mid- and post-season. Based on the tests used in study 1, statistically significant

differences ($p < 0.01$) or moderate to large practical differences ($d > 0.5$) in lean mass (mid- > pre-season), reactive strength index modified (post- > mid-season), time to take-off (post- < mid-season) and drop jump flight time (pre- < mid- and post-season) were shown among forwards. Backs were found to have statistically significant differences ($p < 0.01$) or moderate to large practical differences ($d > 0.5$) in lean mass (post- > pre-season) and drop jump flight time (pre- < mid- and post-season) throughout the season.

In study 4, sprint performance and kinematics were discussed between positions and fast, moderate, and slow groups based on the split times of acceleration and top speed were formed. Findings demonstrate that during acceleration backs performed statistically significantly higher velocity, step rate, step velocity, and shorter contact time ($p < 0.05$, $g > 0.80$). Forwards, despite being slower, still produced moderately higher to statistically significantly higher initial and top speed momentum ($p < 0.05$ or $g > 0.7$) due to higher body mass. When comparing different speed groups, faster athletes used a shorter contact time ($g = 1.58$ to 1.64) to generate a moderate to larger toe-off thigh angle ($g = 0.57$ to 1.00), and a longer flight length ($g = 1.21$ to 1.34) to create a longer step length ($g = 1.12$ to 1.19) in both acceleration and top speed.

In study 5, seasonal changes of sprint performance and kinematics were observed throughout pre-, mid- and post-season. Velocity, initial momentum, flight time, toe off distance, and flight length statistically significantly decreased ($p < 0.05$, $g > 1.33$) in acceleration from pre- to mid-season. A similar trend was found in top speed, and step length, step velocity, foot strike distance, toe-off distance, and contact length all statistically significantly decreased ($p < 0.05$, $g > 1.87$) from pre-to mid-season. From mid- to post-season, trivial practical differences were found in acceleration velocity but large practical differences were observed in contact time, flight time, toe-off distance, and flight length ($g > 0.90$). Top speed had a moderate increase ($g = 0.68$) from mid- to post-season, and step velocity, foot strike distance, toe-off distance, contact and flight length all statistically significantly increased (p < 0.05, g > 1.38).

In study 6, change of direction ability and relationship was determined between positions. Further investigation using different speed groups was again undertaken and were based on the time of the 505 test, again split into thirds. Dominant side of the 505 test was based on the faster time compared between both left and right turn recorded during the test. Backs demonstrated statistically significantly faster 505 times in both the dominate and non-dominate side compared to forwards (p < 0.05, g = 0.93 and 1.06). However, no statistically significant differences were found in change of direction deficit between positions. Forwards' dominant side 505 time demonstrated a significant positive relationship (r = 0.67) with body mass. Furthermore, forwards' linear velocity had significant negative relationship (r = -0.70) with dominate side 505 time, but a positive relationship with dominate side change of direction deficit (r = 0.60). In contrast, no significant relationship in backs was found between linear velocity and dominate side 505 for backs. Backs linear sprint velocity was shown to have a significant positive relationship with both dominate (r = 0.60) and non-dominate side (r = 0.71) change of direction deficit. When observing speed group differences, faster athletes had statistically significantly lighter body mass, faster linear sprint, and non-dominate side 505 time (p < 0.05, g = 1.35 to 2.15).

In study 7, seasonal changes of change of direction ability were observed between mid- and post-season. No pre-season data was collected due to the impact the COVID 19 pandemic had to professional sport. Besides large practical increase in body mass and initial momentum, only small practical increases was found in 505 time on both the dominate and non-dominate side (g = 0.37 and 0.41).

In conclusion, the findings of this thesis determined the match demands that women rugby players face in different position. The results demonstrated that forwards, although slower than backs, have higher lean mass and fat mass, generated higher momentum and absolute peak force, which support positional match demands for forwards to face more frequent collisions. Backs were found to be leaner, faster in both linear and change of direction sprints, and were able to produce relative peak force similar to forwards. In addition, the results supported match demand studies identifying backs have more opportunity to reach high speed but also need the strength to face higher collision forces. The longitudinal studies determined that anthropometry characteristics are maintained throughout the season with only a small practical increase in lean mass from pre- to mid-season. However, in physical characteristics, both power tests and sprint performance results showed a decrease from pre- to mid-season and an increase from mid- to post-season. Lastly, as both sprinting and change of direction are motor skills rather than proxy measures of force and power output, understanding the kinematics in sprinting and change of direction can be used to identify common characteristics in fast athletes from which training can be devised and monitored. Overall, these finding represent novel contributions to women's rugby union literature as well as providing insights and baseline data for future research and practitioners to make informed recruitment and training decisions.

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PUBLICATIONS AND PRESENTATIONS FROM THIS THESIS

Peer-Reviewed Publications

1. Yao, X., Curtis, C., Turner, A., Bishop, C., Austerberry, A., & Chavda, S. (2021). Anthropometric profiles and physical characteristics in competitive female English premiership rugby union players. *International Journal of Sports Physiology and Performance*, *16*(9), 1234-1241.
2. Yao, X., Turner, A., Bishop, C., Austerberry, A., Chiang, CY & Wilson, L (2023). Seasonal variation and positional differences in anthropometry, strength, and power characteristics in English premiership women's rugby union players. *Journal of Strength and Conditioning Research*, *(In press).*

Presentation

1. Women's Rugby Conference 2023, Oral presentation: Physical and Anthropometric characteristics of female rugby union athletes.

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LIST OF ABBREVIATIONS

1RM= 1repetion maximum	HSR = high speed running
B3 = back three	IB = inside back
BF%= body fat percentage	ICC = intra-class correlation coefficient
BIA = bioelectrical impedance analyzer	IMTP = isometric mid-thigh pull
BJ = broad jump	JM = jump momentum
BM = body mass	JH = jump height
BMA = bone mineral area	LM = Lean mass
BMC = bone mineral content	LR ratio = length and rate ratio
BMD = bone mineral density	LST = lean soft tissue
BMI = body mass index	MAS = maximum aerobic speed
BR = back row	MF = mid fielder/ centre
CF ratio = contact and flight ratio	MV = maximum velocity
CI = confidence interval	ND = non-dominate side
CL = contact length	OB = outside back
CMJ = countermovement jump	PF = peak force
COD = change of direction	RD = running distance
CODD = change of direction deficit	RPF = relative peak force
CT = contact time	RSI = reactive strength index
CV = coefficient of variations	RSImod = modified reactive strength index
D = dominate side	SD = standard deviation
DJ = drop jump	SEM = standard error of measurement
FFM= fat-free mass	SH = scrum half
ES = effect size	SL = step length
FFMI= fat-free mass Index	SV = step velocity
FL = flight length	SR = second row
FM = fat mass	SR = step rate
FMI = fat mass index	TD = total distance
FR = front row	ToV = take off velocity
FT = flight time	TTT = time to take off
HB = half back	VJ = vertical jump
HI = high intensity	
HR = heart rate	

Chapter 1: Thesis Introduction

1.1 BACKGROUND

Women's rugby has been continually growing in popularity and gaining participants in recent years (World Rugby, 2021). This might be due to events shown live on media outlets, such as English women's premiership rugby matches streamed regularly, and the Autumn series live on BBC. Furthermore, there was a record-breaking crowd of 58,498 fans at Twickenham in the Women's Six Nation final in 2023. In addition to rising participation rates, investment in professional women's international rugby teams has also been steadily increasing. For example, in New Zealand and France, women's national standard players were awarded part-time contracts in 2018, and in recent years England (2019) and Welsh (2022) women's players were awarded full-time contracts (Jones, 2021; Rugby Football Union, 2019). Recent studies of both English and French women's international players have reported that during yearly longitudinal observations, recent players had become stronger and faster compared to previous cohorts of players (Imbert et al., 2023; Woodhouse et al., 2021b). English premiership women's rugby is the top tier competition in England, consisting of both professional and semi-professional players from all over the world. With all of the current England international players competing in the English premiership, and with England currently ranked No.1 in the world (World Rugby Rankings), it is testament that the English premiership is a competitive league that is abundant with world class women's rugby players. However, there are only a limited number of studies identifying anthropometry and physical characteristics in English premiership women's rugby. The distinct lack of comparative data on competitive English premiership women's players may affect the practitioners' decision-making process during talent identification, performance monitoring, and match strategy. Therefore, it is crucial to minimize the gap in the research for coaches to understand the physical profile of the competitive English premiership women's rugby athletes. This thesis aims to identify the current literature discussing anthropometry and physical characteristics in women's rugby union and to further determine these characteristics in English premiership women's rugby union. Furthermore, to identify the locomotive skill (sprint and change of direction) and to observe seasonal differences in these physical profiles in English premiership women's rugby union.

1.2 OVERVIEW

Study 1: *Match Demands, Anthropometry and Physical Characteristics in women's Rugby Union Athletes.* The purpose of this review was to understand the needs analysis of the sport and review the anthropometry and physical characteristics across different playing levels and countries. Furthermore, it helped shape the direction and methodologies employed within this thesis.

Study 2: *Positional differences in anthropometry, strength, and power characteristic in English premiership women rugby players.* The purpose of this study was to determine the differences in anthropometry, strength and power characteristics between forwards and backs in women's rugby union athletes. This may support practitioners for talent identification and understanding the physical standard in English premiership women rugby.

Study 3: *Seasonal changes in anthropometry, strength, and power characteristic in English premiership women rugby players.* The purpose of this study was to understand the trend of these characteristics during a competitive season in forwards and backs. Furthermore, having a better understanding of seasonal changes may support practitioners to make appropriate training and nutritional adjustments for athletes.

Study 4: *Positional differences in sprint performance and mechanics in English premiership women's rugby players.* The purpose of this study is to understand speed and momentum differences between positions and to further understand the kinematics of sprinting between fast and slow athletes. Having an understanding of sprint performance and kinematic characteristics in women's rugby union may help shape practitioners to characterize sprinting strategy and prescribe sprint training accordingly.

Study 5: *Seasonal changes in sprint performance and mechanics in English premiership women's rugby players.* The purpose of this study was to observe the kinematic changes in both acceleration and top speed during a competitive season to identify mechanic changes that affect sprint performance. Furthermore, the kinematic changes support practitioners to monitor specific variables to adjust training plans accordingly to prevent fatigue or to improve performance.

Study 6: *Positional differences in change of direction ability in English premiership women's rugby players.* The purpose of this study was to identify the relationship between linear speed, momentum and change of direction speed and to compare the positional differences between positions and fast and slow athletes. The combination of these variables may support practitioners to identify what type of change of direction training an athlete need to improve change of direction performance.

Study 7: *Seasonal changes in change of direction ability in English premiership women's rugby players.* The purpose of this study was to observe how change of direction ability changes throughout a competitive season and whether linear speed and momentum changes affect change of direction ability. The change of direction ability and momentum changes may support practitioners to adjust training plans accordingly to prevent fatigue or to improve performance.

Chapter 2: SYSTEMATIC REVIEW OF LITERATURE- Match Demands, Anthropometry, and Physical Characteristics in Women's Rugby Union

Abstract

Background: Rugby union is a field-based team sport characterized by repeated high-intensity activities (sprinting and collisions) combined with periods of lower intensity activities (walking and jogging). Women's rugby has been continually growing in popularity and gaining participants every year. Besides increases in participation, the standard of women's rugby has improved due to increased investment, which enabled female international rugby players to become semi or fully professional. The growth of women's rugby union has naturally led to an increase in scientific interest and research. *Aim:* To review existing research regarding the match demands, anthropometric and physical characteristic in women's rugby union.

Method: A systematic search of literature was implemented utilizing SPORTDiscus, Medline, and CINAHL, as well as the use of existing reference lists of articles obtained during the subsequent search results.

Results: A total of 25 articles comparing positional differences in women's rugby union were found, 8 of these studies focused on match demands, 6 studies examined anthropometric characteristics, and 11 studies discussed both anthropometric characteristics and physical characteristics.

Conclusion: Forwards were found to engage in longer duration low intensity running (< 10.8 $km.h^{-1}$) and a higher number of collisions. Backs were found to have longer duration in walking/standing, high speed running, sprinting, and reached higher maximum speeds. For anthropometry and physical characteristics, forwards were heavier (especially front row), stronger (especially front row) and created more momentum, while backs were lighter, leaner, faster (especially outside backs), relatively more powerful, and had better aerobic capacity. The gap in match demands, anthropometry, and

physical characteristics should be the priority for researchers in women's rugby union to support practitioners and coaches having more specific training plans and benchmark criteria, based on positional needs.

2.1 INTRODUCTION

Rugby union is a field-based team sport characterized by repeated high-intensity activities (e.g., sprinting and collisions) combined with periods of lower intensity activities (e.g., walking and jogging) (Bradley et al., 2019; Imbert et al., 2023; Woodhouse et al., 2021a). Different from other rugby codes, such as rugby league and rugby sevens, rugby union is played with two teams of 15 players, playing two 40 min halves, separated by a half-time period of 10 mins. Each team consists of primarily two positional groups: forwards and backs (Duthie, Pyne, & Hooper, 2003). Forwards, which includes front-row, second-row, and back-row, are typically responsible for gaining possession and engaging in collisions during scrums, rucks, and mauls (Harty et al., 2019a). Backs include a scrum-half, inside-backs, and outside-backs, and are primarily responsible for controlling possession of the ball and require higher speeds to out-run or avoid defenders to create scoring opportunities (Harty et al., 2019a). However, while these are considered the primary roles for backs and forwards, every player is likely to be involved in high-speed running and all types of collision-based scenarios.

The growth of women's rugby union has also led to a concurrent increase in scientific research (Woodhouse et al., 2021b). A number of studies have described the match demands (Bradley et al., 2019; Busbridge et al., 2020; Callanan et al., 2021; Nolan et al., 2023; Sheppy et al., 2019; Suarez-Arrones et al., 2014; Virr et al., 2014), anthropometric characteristics (Curtis et al., 2021; Escrivá et al., 2021; Harty et al., 2021; Posthumus et al., 2020a; Ramos-Álvarez et al., 2021) and physical characteristics (Hene et al., 2011; Imbert et al., 2023; Nyberg & Penpraze, 2016; Woodhouse et al., 2021b; Yao et al., 2021) of women's rugby union athletes. When looking at match demands, studies have reported that female players exhibit lower total distance covered and lower intensity of activity compared to male players (Bradley et al., 2019; Busbridge et al., 2020). Differences also exist in anthropometry and body composition (Ramos-Álvarez et al., 2021; Santos et al., 2014), as well as physical characteristics (Clarke et al., 2017).

The match demands placed on female rugby union players has been known to differ to their male counterparts (Bradley et al., 2019). Studies comparing male and female trained athletes in anthropometry characteristics found that male athletes had higher muscle mass, muscle thickness and lower body fat percentage (Abe et al., 2020). Male athletes were also reported to have significantly higher physical characteristics in countermovement jump, bench press throw, 1RM squat and 1RM bench press (Bartolomei et al., 2021). The sex differences between athletes in performance emerge with the onset of puberty and coincide with the increase in endogenous sex steroid hormones, in particular testosterone in males, which increases 30-fold by adulthood, but remains low in females (Hunter et al., 2023). Furthermore, when considering female-specific physiology such as the menstrual cycle, which is commonly divided into three phases (early follicular phase, the ovulatory phase and mid-luteal phase), research has reported female athletes may show decreases in both wellness and performance outcomes during the early follicular phase of the cycle, however, differences on a group level are generally trivial (Hayward et al., 2024; Heyward et al., 2020; McNulty et al., 2020). Therefore, given the anatomical, physiological and endocrinological differences between sexes, it would be naive to assume research in male rugby can be directly applied to female rugby players and the impact of the menstrual cycle should be considered on an individual basis (McNulty et al., 2020).

Due to all the physiological differences between male and female rugby union players, and across different rugby codes (Sella et al., 2019), specific studies focusing on women’s rugby union are needed. Understanding anthropometric and physical requirements in women’s rugby union is fundamental for developing effective physical training programs (Woodhouse et al., 2021b). Furthermore, this type of research provides normative data for coaches and support staff to better understand the requirements needed for players to transition to the highest level (Busbridge et al., 2020).

Finally, besides the standard distinction between forwards and backs, rugby union athletes can broadly be categorized into six positional categories (as aforementioned) and understanding the position-specific demands may have important implications to further increase a player's physical preparation. Therefore, the purpose of this systematic review was to summarize the current research in women's rugby union, addressing match demands, and anthropometric and physical characteristics. Furthermore, to highlight the differences between competition levels and playing positions and provide direction for further research.

2.2 METHODS

This systematic review adhered to the structure and reporting guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al., 2021). A search of three electronic databases (Medline, SPORT Discus and CINAHL) was conducted through EBSCOhost on 5th January 2022 and were monitored until January 2024. The search strategy combined specific terms "female OR women* rugby AND match demands OR body composition OR anthropometry OR physical profile OR physical characteristics OR profile" to avoid excessive quantities of unrelated articles.

2.2.1 *Inclusion and exclusion criteria*

For the inclusion criteria, studies were required to either measure the match demands, anthropometry, or physical characteristics of female rugby union players as the primary or secondary outcome of the study. (i.e., a clearly outlined assessment protocol and not solely provided as part of the descriptive characteristics of study participants). All data were required to be presented separately for positional groups to be included (i.e., forwards and backs). Studies were included from peer-reviewed journals, published conference proceedings, theses, or dissertations, to minimize the effect of any potential publication bias. Studies were excluded if they did not investigate rugby union (i.e., rugby league or rugby 7s), examined male rugby union players, or data was not split into positional groups.

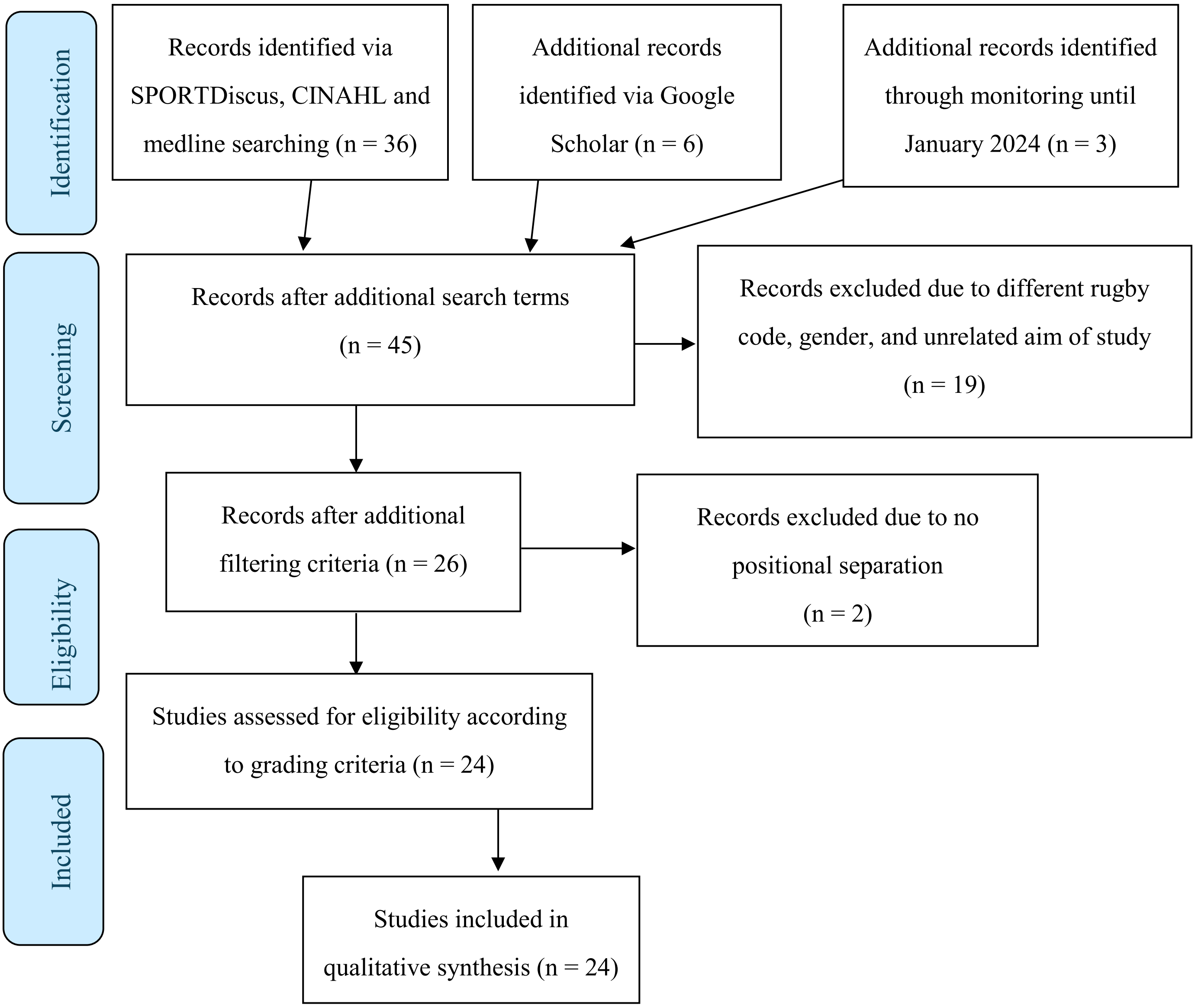

Figure2.1. Flow chart of search methodology

2.2.2 Grading Article Quality

Study quality was evaluated using a standard procedure (Table 2.1). The score list of each category was define on how many criteria the study matched in each category rather than just 1 point per category from previous versions (Soriano, Suchomel, & Comfort, 2019). Total scores for each study were then converted to a percentage ranging from 0–100% (Table 2.2). Studies that scored a zero in any category were excluded from the final analysis. Two authors (Yao and Turner) assessed the quality and classified the design of studies independently. Results were subsequently compared. In case of disagreement between authors without reaching a consensus rating, a third author was available to resolve differences in opinion but was not needed.

Table 2.1. Criteria list for the methodological quality assessment

No.	Item	Score
1	Sample description: - Properties of the subjects (age, weight, height, sex) - Training history of the population (well-trained, recreationally trained, or untrained) - Definition of participants (forwards, backs, compete level)	0 to 3
2	Procedure description: - Detailed description of the test (exercise and rest period employed) - Detailed description of the testing protocol	0 to 2
3	Data collection and data analysis: - Dependent variables defined. - Defined sampling frequency - Defined and developed reliability test when proceed. - Defined collection software for recording and analyzing data	0 to 4
4	Results detailed: - Measure of the central tendency - Reliability score reported. - Effect size reported	0 to 3
5	Discussion and Conclusions insightful: - Limitations mentioned. - Discussion of generalizability beyond the target population - Future directions	0 to 3

Table 2.2. Quality score results of the studies included in this review

References	Sample description	Procedure description	Data collection	Results detailed	Discussion and Conclusions	Total score	%
Alveraz, 2021	2	2	3	3	3	13	86.7
Bradley, 2019	3	2	4	3	3	15	100
Busbridge, 2020	3	2	4	2	3	14	93.3
Callanan, 2021	3	2	4	3	3	15	100
Curtis, 2021	3	2	3	3	3	14	93.3
Escriva, 2021	3	2	4	3	3	15	100
Harty, 2019	2	2	4	3	3	14	93.3
Hene, 2011	2	2	3	2	2	11	73.3
Hene, 2013	2	2	3	2	3	12	80
Imbert, 2023	3	2	3	3	3	14	93.3
Kirby, 1993	2	1	2	2	2	9	60
Neto, 2021	3	2	4	2	3	14	93.3
Nolan, 2023	3	2	3	3	3	14	93.3
Nyberg, 2016	2	2	3	2	3	12	80
Posthumus, 2020	2	2	4	3	3	14	93.3
Quarrie, 1995	2	2	3	3	2	12	80
Sarkar, 2019	3	2	4	3	3	15	100
Sheppy, 2019	2	2	3	2	2	11	73.3
Suarez, 2014	3	2	2	3	2	12	80
Virr, 2014	2	3	2	2	3	12	80
Wallance, 2008	2	2	3	2	2	11	73.3
Woodhouse, 2021	3	2	4	3	3	15	100
Woodhouse, 2021	3	2	4	3	3	15	100
Yao, 2021	3	2	4	3	3	15	100

2.3 RESULTS

The initial electronic database and manual search, followed by the removal duplicates returned a total of 45 studies (Figure 2.1). Twenty studies were excluded after title and abstract screening, leaving a total of 25 articles meeting the inclusion criteria. A summary of the participants, testing environment, quality score, and variables of interest for each study is reported in Table 2.3. Of the 25 studies reviewed in the final analysis, eight of these studies focused on match demands including total distance, running at different intensities, and maximum speed (Bradley et al., 2019; Busbridge et al., 2020; Callanan et al., 2021; Nolan et al., 2023; Sheppy et al., 2019; Suarez-Arrones et al., 2014; Virr et al., 2014; Woodhouse et al., 2021a). Eight studies examined anthropometric characteristics reporting fat mass, lean mass, or skin fold sum differences between positions (Curtis et al., 2021; Escrivá et al., 2021; Harty et al., 2021; Posthumus et al., 2020a; Ramos-Álvarez et al., 2021; Sarkar & Dey, 2019; Wallace & Donovan, 2008). Nine studies discussed both anthropometric characteristics and physical characteristics including body composition, strength, power, speed, and aerobic capacity (Hene et al., 2011; Hene & Bassett, 2013; Imbert et al., 2023; Kirby & Reilly, 1993; Neto et al., 2021; Nyberg & Penpraze, 2016; Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021).

2.3.1 Match demands

A total of eight research papers discussed match demands in women's rugby union with seven using GPS systems and one using time motion analysis. Besides forwards and backs, five of the match-demand studies also went into depth regarding positional groups (front row, second row, back row, half backs, inside back and outside back) differences. Summary of participants playing level, testing variables, and brief results can be found in Table 2.4.

When looking at GPS match demand data, three studies reported no significant differences in total distance (TD) covered between forwards and backs (Bradley et al., 2019; Busbridge et al., 2020; Sheppy et al., 2019). In contrast, four studies reported statistically significant differences in TD between positions (ES = 0.65 to 2.16) (Callanan et al., 2021; Nolan et al., 2023; Suarez-Arrones et al., 2014; Woodhouse et al., 2021a). When considering speed zones between forwards and backs, all seven GPS-based match demand studies reported backs had statistically significantly higher high intensity running distance (above 4.4 to 5.5m/s) with outside backs covering significantly higher distances than all forward positions (Callanan et al., 2021; Nolan et al., 2023; Suarez-Arrones et al., 2014; Woodhouse et al., 2021a). Similar results were found using time-motion analysis reporting backs sprint more frequently and undertake longer duration sprints (Virr et al., 2014). Work rate, player load, body impact and collision were also reported across different studies (Bradley et al., 2019; Suarez-Arrones et al., 2014). From time motion analysis, forwards spent statistically significantly more time in ruck/maul/tackle activities throughout an entire match (Virr et al., 2014). Similar results were reported that forwards are shown to have statistically significantly higher collision load in rugby matches (Woodhouse et al., 2021a). By the nature of the requirements of their position, forwards utilize the lift movement, the pre-scrum pack down, and the scrum categories exclusively, which increase collision load (Virr et al., 2014).

Table 2.3. Summary of studies included in this review

Reference	Focus	Subjects	Testing Environment	Variables/ Tests of Interest
Alvarez, 2021	Anthropometry	First Spanish National League (n = 35)	Not mentioned	BM, skinfold (six), girths, bone breadths and multi-frequency bioimpedance analysis (Inbody 720)
Busbridge, 2020	Match Demands	amateur rugby (n = 96)	New Zealand Provincial Rugby competition	Maximum speed, TD, meters per minute, running (≧ 6.4 km·h^{-1}) distance, and HI (≧16.1 km·h^{-1}) running
Bradley, 2019	Match demands	English women's premiership (n = 129)	English women's premiership Competition	Total distance, meters per minute, walking (0-6 km·h^{-1}), jogging (6.1-12 km·h^{-1}), slow running (12.1-14 km·h^{-1}), medium intensity running (14.1-18 km·h^{-1}), HI running (18.1-21 km·h^{-1}), sprinting (>21.1 km·h^{-1}), maximum speed (km·h^{-1})
Callanan, 2021	Match demands	Ireland interprovincial women rugby squad	Interprovincial series in Ireland across 2 seasons	TD, RD, MV, speed zone 1 (0–1.0 m·s $^{-1}$), speed zone 2 (1.0–3.0 m·s $^{-1}$), speed zone 3 (3.0–5.0 m·s $^{-1}$), and speed zone 4 (5.0 m·s $^{-1}$)
Curtis, 2021	Anthropometry	English women's premiership (n = 15)	Pre-season and post season	BM, FM, LM BMD, and BMC
Escriva, 2021	Anthropometry	Spanish National Women's RU Championships (n = 56)	In season (before the last two matches)	Stature, BM, skinfold (seven)
Harty, 2019	Anthropometry	Division 1 collegiate athletes (n = 101)	Pre-season	Stature, BM, BMI, fat%, FM, FFM, LST, BMC, BMA, and BMD
Hene, 2011	Anthropometry Physical characteristics	South African High-Performance Squad (n = 32)	Pre-season training camp	BM, skinfolds (seven), sit-and-reach, VJ, 10m, 40m, 1RM bench press, max rep pull up, 1min push-ups, multistage shuttle run
Hene, 2013	Anthropometry Physical characteristics	South African High-Performance Squad (n = 32)	Pre-season, mid-season, post-season	BM, skinfolds (seven), VJ, 10 m, 40 m, 1RM bench press, multistage shuttle run

Imbert, 2023	Anthropometry Physical characteristics	French internationals (*n* = 631)	Over two years longitudinal	Fat%,10 m,20 m,50 m sprint, level 1 Yo-Yo (MAS), 1RM bench press, 1 RM pull ups
Kirby, 1993	Anthropometry Physical characteristics	England regional squad standard or above (*n* = 39)	Not mentioned	Stature, BM, 4sites skinfold, somatotype, grip and back strength, broad jump, VJ, VO_2max
Neto, 2021	Anthropometry Physical characteristics	University rugby team (*n* = 17)	Pre- and post-season across three years	Stature, BM, BMI, grip strength, VJ, push-ups 40m, sit and reach.
Nolan, 2023	Match demands	Six nations international (*n* = 53)	International games	Total distance, distances covered at <1, 1-3, 3-5,5-5.5 and >5.50 ms. Total collisions (contacts >8 g) were also recorded.
Nyberg, 2016	Anthropometry Physical characteristics	Scottish women's premiership squad (*n* = 19)	Prior to normal training session	BM, body volume, LM, FM, fat%, sit-and-reach, Illinois agility, 40 m (10 m split), Estimated VO_2 max (Level 1 Yo-Yo)
Posthumus, 2020	Anthropometry	New Zealand women rugby	In-season	Stature, BM, skinfold (eight), LM, FM, fat%, BMC, BMD
Quarrie, 1995	Anthropometry Physical characteristics	New Zealand senior women and schoolgirl (*n* = 91)	Pre-season club training	Multistage shuttle run, VJ, agility run, max rep push-ups, 30 m, high intensity shuttle, somatotype
Sarkar, 2019	Anthropometry Physical characteristics	Indian national women rugby players (*n* = 25)	Pre-competitive phase	BM, body composition (multi-frequency bioelectrical impedance analyzer), 20m beep test, Illinois agility, flying 30 m and broad jump
Sheppy, 2019	Match demands	Welsh international (*n* = 29)	International games	TD, HSR (>4.4 $m \cdot s^{-1}$), worst-case scenario demands
Suarez-Arrones, 2014	Match demands	Spanish women rugby (*n* = 8)	International games	HR, activity intensity, total distance, maximum speed, impact standing or walking (0-6 $km \cdot h^{-1}$), jogging (6.1-12 $km \cdot h^{-1}$), running at low intensity (12.1-14 $km \cdot h^{-1}$),

				at medium intensity (14.1-18 km·h^{-1}), at high intensity (18.1-20 km·h^{-1}), and at sprint (>20.1 km·h^{-1}).
Virr, 2014	Match demands	Canadian premier division club level (*n* = 38)	Division club games	HR, time motion of stand, walk, jog, stride, sprint, lift, ruck, scrum
Wallace, 2008	Anthropometry	Club level rugby or above (*n* =27)	Not mentioned	Stature, BM, FM, LM fat%, BMC, BMD
Woodhouse, 2021	Anthropometry Physical characteristics	England international (*n* = 68)	In-season before international competition	BM, skinfold (eight), SL ISO-squat, SL DJ, one-rep max bench press, 40 m (each 10 m split) time and momentum
Woodhouse, 2021	Match demands	England international (n = 78)	International competition	TD (m), distance at low-speed (<3 m/s), moderate-speed (3−5.5 m/s) and high-speed (>5.5 m/s), high-speed zone entries, total collisions, maximum-intensity periods
Yao,2021	Anthropometry Physical characteristics	English women's premiership (*n* = 22)	Pre-season	Stature, BM, FM, LM, 40 m (10 m and 20 m split), CMJ, DJ, IMTP, 1200m, 1rep max squat and bench press

TD= total distance; HI= high intensity; HSR= high speed running; HR= heart rate; BM= body mass; BF%= body fat percentage; BMI= body mass index; FM = fat mass; FMI= fat mass index; FFM= fat-free mass; FFMI= fat-free mass Index; LST= lean soft tissue; BMA= bone mineral area; BMC= bone mineral content; BMD= bone mineral density; VJ= vertical jump; 1RM= 1repition maximum; MAS = maximum aerobic speed.

Table 2.4. Summary of studied investigating match demands via GPS and time-motion analysis in women's rugby union.

Reference	Participants	Competition Status	Methods	Results
Busbridge, 2020	Forwards (*n* = 49): FR (*n* =24) SR (*n* =14) BR (*n* = 11) Backs (*n* = 47): HB (*n* = 9) IB (*n* = 18) OB (*n* = 20)	NZ Amateur rugby	- 10Hz GPS unit - maximum speed ($km \cdot h^{-1}$), total distance (m), meters per minute ($m \cdot min^{-1}$), running distance (≧ 6.4 $km \cdot h^{-1}$) (m), and HI (≧16.1 $km \cdot h^{-1}$) running (m) was collected - Collected 7 games with players completed >60mins per game	-TD: Forwards: 5616 ± 809m; Backs 5829 ± 1022m - Running distance: Forwards 3181 ± 586m; Backs 3095 ± 805 m - HI running distance: Forwards: 252 ± 229m; Backs: 651 ± 252m (p = 0.0001) - Maximum speed: Forwards: 22.0 ± 3.0 $km \cdot h^{-1}$; Backs: 26.0 ± 2 $km \cdot h^{-1}$ (p = 0.0001) - Half backs cover the most TD (6812 ± 277m) and running distance (4292 ±171m) compared to all other positions (p < 0.05) -Front row covered less running (3035 ± 104m vs 3477 ± 154m) and HI running (98 ± 36m vs 451 ± 55m) compared to back row (p = 0.02) - Front row had the lowest maximum speed (21 ± 0.4 $km \cdot h^{-1}$) compared to all other position (p <0.05)
Bradley, 2019	Forwards (*n*= 68): Backs (*n*= 61):	English women's premiership	-10Hz GPS 104Hz microsensor -Collected 14 games with players completed >60mins per game - Total distance, duration in walking (0-6 $km \cdot h^{-1}$), jogging (6.1-12 $km \cdot h^{-1}$), slow running (12.1-14 $km \cdot h^{-1}$), medium intensity running (14.1-18 $km \cdot h^{-1}$), high intensity running (18·1-21 $km \cdot h^{-1}$), sprinting (>21.1 $km \cdot h^{-1}$),	-TD: Forwards 5049 ± 852 m; Backs 4908 ± 985 m - Jogging distance, Forwards: 1858 ± 466 m; Backs: 1472 ± 468 m (p < 0.001, ES = 0.83) - HI running distance: Forwards: 58 ± 60 m; Backs: 133 ± 97 m (p < 0.001, ES = 0.94) - Maximum speed: Forwards: 20.5 ± 2.4 $km.h^{-1}$; Backs: 23.2 ± 3.0 $km.h^{-1}$ (p < 0.001, ES = 1.00). - Backs spent greater total time at walking, HI running, and sprinting (Walking: p = 0.014, ES = 0.47; HI: p < 0.001, ES = 0.81; Sprinting: p = 0.044, ES = 0.43)

			maximum speed, player loads (AU) and work: rest ratio was collected.	- Forwards have significant higher total and relative player loads (Total: $p = 0.012$, ES = 0.46; Relative: $p = 0.004$, ES = 0.53) - Second row cover the most TD (5297 ± 1057m) with outside backs significant lower (4701 ± 1055m) ($p = 0.043$, ES = 0.56)
Callanan, 2021	Forwards ($n = 34$): FR ($n = 13$) SR ($n = 9$) BR ($n = 12$) Backs ($n = 29$): HB ($n = 8$) MF ($n = 9$) B3 ($n = 12$)	Ireland interprovincial series	- 10Hz GPS -Collected from 2 teams playing across 2 seasons that have completed >60 minutes in a match. - TD (m), RD ($m \cdot min^{-1}$), MV ($m \cdot s^{-1}$), speed zone 1 (walking: 0–1.0 $m \cdot s^{-1}$), speed zone 2 (jogging: 1.0–3.0 $m \cdot s^{-1}$), speed zone 3 (moderate intensity running: 3.0–5.0 $m \cdot s^{-1}$), and speed zone 4 (high-speed running: >5.0 $m \cdot s^{-1}$).	- TD: forwards: 5,456 ± 764m; backs: 5.964 ± 807m ($p < 0.001$, ES = 0.65). -MV: forwards: 6.2 ± 0.6 $m \cdot s^{-1}$; backs: 6.9 ± 0.5 $m \cdot s^{-1}$ ($p < 0.001$, ES = 1.27) -Walking: forwards: 1072 ± 145m; backs: 1152 ± 152m ($p = 0.001$, ES = 0.54) -Jogging: forwards: 2866 ± 369m; backs: 3120 ± 519m ($p = 0.001$, ES = 0.56) -high speed running: forwards: 155 ± 131m; backs: 294 ± 150m ($p < 0.001$, ES = 0.99) -TD: FR (5263 ± 754m), SR (5342 ± 743m) < HB (6135 ± 822m), MF (6144 ± 516m) ($p < 0.05$, ES = 1.01-1.30) -MV: FR (6.0 ± 0.4 $m \cdot s^{-1}$), SR (6.1 ± 0.5 $m \cdot s^{-1}$) < MF (6.9 ± 0.4 $m \cdot s^{-1}$), B3 (7.2 ± 0.4 $m \cdot s^{-1}$) ($p < 0.001$, ES = 1.78-2.49) -Jogging: FR (2859 ± 405m), SR (2866 ± 383m), BR (2873 ± 327), B3 (3000 ± 565m) < MF (3384 ± 404m) ($p < 0.05$, ES = 0.75-1.42). -Moderate-intensity running: FR (1237 ± 386m), B3 (1213 ± 320m) < BR (1555 ± 360m) ($p < 0.01$, ES = 0.85, 1.01) FR (1237 ± 386m), SR (1293 ± 324), B3 (1213 ± 320m) < HB (1719 ± 373m) ($p < 0.01$, ES = 1.22-1.48)

				-High-speed running: FR (144 ± 180m), SR (125 ± 101) < MF (269 ± 68m), B3 (353 ± 175m) ($p < 0.01$, ES = 0.84-1.52)
Nolan, 2021	FR (n = 11), SR (n = 7), BR (n = 9), SH (n = 5) FH (n = 5) centre (n = 5) B3 (n = 11)	Women's six nations	- APEX GPS units -12 matches recorded across three campaigns. - TD, distances covered at 5.50 m·s −1. Total collisions were recorded	-B3 covered more relative distance than FR (64.4 ± 7.76 vs 55.0 ± 7.58) ($p \leq 0.05$) -Back three achieved significantly higher peak velocity (7.92 ± 0.56 ms) compared to forwards and SH ($p \leq 0.05$). -Backs covered more relative distance in (>5 $m.min^{-1}$) than forwards, with FR being the lowest.
Sheppy, 2019	Forwards (n= 15): FR (n = 6), SR (n = 3), BR (n = 6), Backs (n= 14): HB (n = 4) centre (n = 6) back three (n = 4)	Welsh international female RU	- 10Hz GPS unit -Collected 8 games with players completed ≧ 60mins per game - TD, FIXED and ROLL periods from 60-s to 600-s, HSR (> 4.4 $m·s^{-1}$) were collected	- TD was similar between forwards and backs (5784 ± 569 m) - ROLL method reported higher TD and HSR in all epoch ($p < 0.0001$) -Forwards reported lower HSR and covered less TD during 60-s, 180-s, 420-s and 480-s epochs ($p < 0.001$) - Front row showed the lowest HSR compared to all other positions at all epoch durations ($p \leq 0.05$)
Suarez-Arrones, 2014	Forwards (n = 4): Backs (n = 4):	Spanish female RU	-5Hz GPS 100Hz triaxial accelerometer. -Collected during an international top-level test match with players playing full match - HR, time, speed, distance, location, and number and intensity of impacts and accelerations expressed as g forces was collected.	- TD: Backs: 6,356 ± 144m; forwards: 5,498 ± 412 m (p = 0.010; ES: 2.16 ± 1.09) - Backs covered greater distances at HI running (105 ± 74m, p = 0.02, ES = 1.89) - Maximum speed: Backs: 24.4 ± 0.8 $km.h^{-1}$; Forwards 22.0 ± 3.5 $km.h^{-1}$ (p = 0.18, ES = 0.86). -HR during match play shown no significant difference between forwards and backs. -Backs experienced substantially more impacts (5–6g, 6.5–8g, and >10g) compared with forwards

			walking (0-6 km·h^{-1}), jogging (6.1-12 km·h^{-1}), slow running (12.1-14 km·h^{-1}), medium intensity running (14.1-18 km·h^{-1}), high intensity running (18·1-21 km·h^{-1}), sprinting (>21.1 km·h^{-1})	
Virr, 2014	Forwards (n = 20): Backs (n =18):	Canadian premier division club level	-Four video cameras were instructed for time motion capture -From a total of 10 matches, 4 players (2 forwards and 2 backs) per game were videotaped for the entire 80 min match - Scrumhalf (no.9) was omitted from due to the specific role -HR was monitored and HRmax was determined on a separate day during a graded exercise test to exhaustion on a treadmill.	-Backs spent more time walking (51:00 ± 5.30 vs 36:42 ± 4:24 min:s), while forwards spend more time jogging (10:54 ± 3:00 vs 7:24 ±1:42 min:s) (p < 0.05). -Backs sprint a longer duration (2:36 ± 0:54 min vs 1:42 ± 1:24 min) and higher frequency (37 ± 12 vs 25 ± 16) (p < 0.05). -Forwards were involved in the ruck/maul/tackle for a greater duration (5:42 ± 1:42 min vs 2:12 ± 1:12 min) and higher frequency (61 ± 12 vs 25 ± 11) (p < 0.05). -Forwards had significant (p < 0.05) higher mean game HR (173 ± 10 vs 161 ± 10 beats · min^{-1}) and percent of match time above 80% HR (81 ± 14 vs 63 ± 20). - Forwards had significant higher total work time (17.6 ± 3.6 vs 8.5 ± 2.0 min), and lower rest time (68.7 ± 5.2 vs 77.4 ± 4.8) (p < 0.05). - Mean work: rest ratio was 1: 4.0 ± 0.9 for forwards and 1: 9.1 ± 2.4, which was significant different (p < 0.05).

Woodhouse, 2021	FR (n = 16) Locks (n = 10) BR (n = 15) SH (n = 6) IB (n = 17) OB (n = 14)	England international	-10Hz GPS unit -From a total of 53 matches of 5 years (2015-2019) -TD (m), distance at low-speed (<3m/s), moderate-speed (3−5.5 m/s), high-speed (>5.5 m/s) as well as high-speed zone entries. moderate zones (2−3 m/s^2), high (3−4 m/s^2) and very-high (>4 m/s^2). -collisions events were recorded as absolute and relative to match playing time -Maximum-intensity periods (MIP) for collision frequency and average speed, were calculated for each player, for a fixed period of 2.75 min in each match.	- Running demands increased between 2015 and 2017 (World Cup year) and plateaued thereafter - TD: BR, IB, OB > FR ($p < 0.001$) -Average speed: 65.9m/min SH > FR, L, BR, IB, IB; OB > FR, L; BR > FR ($p < 0.001$) - Accelerations and decelerations >3 $m.s^2$ which increased between 2017 and 2019. - Collisions were higher in forwards than backs, and highest against stronger opposition ($p < 0.001$). - Running demands were greater against weaker opposition, but the 'most intense periods' of running were greater against stronger opposition in 2017 -OB has the highest high-speed distance (281 ± 17.6m) compared to all positions - IB, OB has the highest number of total sprints compared to all other positions (12.9 ± 1.1 to 15.7 ± 1.1)

FR = front row; SR = second row; BR = back row; HB = half back; SH = scrum half; IB = inside back; OB = outside back; MF = mid fielder/ centre; B3 = back three; TD = total distance; HI running = high intensity running; MV = maximum velocity; HR = heart rate

2.3.2 Anthropometry

A summary of the anthropometric studies in women's rugby union can be found in Table 2.5. In the 14 studies examining anthropometric data, different methods were used including air displacement plethysmography (Nyberg & Penpraze, 2016), multifrequency bioelectrical impedance analyzer (Ramos-Álvarez et al., 2021; Sarkar & Dey, 2019), four (Kirby & Reilly, 1993; Sarkar & Dey, 2019), seven (Escrivá et al., 2021; Hene et al., 2011) and eight (Posthumus et al., 2020b; Woodhouse et al., 2021b) sites skinfolds, somatotype measures (Escrivá et al., 2021; Kirby & Reilly, 1993; Posthumus et al., 2020b; Sarkar & Dey, 2019)and dual-energy x-ray absorptiometry (Curtis et al., 2021; Harty et al., 2021; Imbert et al., 2023; Wallace & Donovan, 2008; Yao et al., 2021). Across these studies, four studies reported forwards were statistically significantly taller than backs (Harty et al., 2021; Posthumus et al., 2020b; Quarrie et al., 1995). Within the nine studies that compared body mass (BM) differences between forwards and backs, ten studies reported forwards (range from 57.5 to 93kg) were statistically significantly heavier than backs (range from 49.5 to 73.3kg) (ES = 1.07 to 2.19) (Escrivá et al., 2021; Harty et al., 2021; Hene et al., 2011; Imbert et al., 2023; Kirby & Reilly, 1993; Posthumus et al., 2020b; Quarrie et al., 1995; Sarkar & Dey, 2019; Wallace & Donovan, 2008; Yao et al., 2021) and one study reported no significant difference between forwards and backs (Nyberg & Penpraze, 2016).

When split by positional groups, props had statistically significantly greater BM than all other positions (Harty et al., 2021; Woodhouse et al., 2021b). A study of South African players reported that although there was no statistically significant change in BM in the forwards, sum of skinfold dropped significantly from mid-to post season. In the same study, there was a statistically significant increase in BM of backs from pre-to mid-season, but no significant changes in sum of skinfold. (Hene & Bassett, 2013). A study in English premiership players found that only when comparing the whole squad's seasonal differences there were statistically significant differences in BM and bone mineral content (BMC), and when separated into forwards and backs, all anthropometry variables reported no significant changes from pre- to post-season (Curtis et al., 2021).

2.3.2.1 Somatotype and skinfold measures

Four studies presented somatotype measures in this review. For endomorphy, Quarrie et al., (1995), Escrivá et al. (2021) and Ramos-Álvarez *et al.* (2021) found statistically significantly higher results in forwards (ES = 1.04 to 1.2). For mesomorphy, both Kirby and Reilly, (1993) and Quarrie et al., (1995) found forwards had statistically significantly higher results (ES = 0.8). Three studies reported backs had statistically significantly higher scores in ectomorphy (ES = 0.89 to 1.0) (Escrivá et al., 2021; Kirby & Reilly, 1993; Quarrie et al., 1995). Studies using skinfold measures had used either 4, 6, 7, or eight sites method. Similar results were found in most studies reporting forwards had statistically significantly higher sum of skinfolds and body fat percentage (BF%) (Hene et al., 2011; Posthumus et al., 2020a; Ramos-Álvarez et al., 2021; Sarkar & Dey, 2019; Woodhouse et al., 2021b) and with only one study reporting no significant differences in sum of skinfold between positions (Kirby & Reilly, 1993). When split by positional groups, front row had the highest skinfold measurements compared to all other positions (ES = 2.01) (Posthumus et al., 2020a; Woodhouse et al., 2021b).

2.3.2.2 Air displacement plethysmography and bioelectrical impedance analyzer

Besides skinfolds studies, one study used a body composition assessment system based on air displacement to determine anthropometry parameters (Nyberg & Penpraze, 2016) and two studies used a bioelectrical impedance analyzer (BIA) (Ramos-Álvarez et al., 2021; Sarkar & Dey, 2019). Nyberg & Penpraze., (2016) reported no statistically significant differences between forwards and backs in BF% (29.34 ± 2.20 vs 30.23 ± 8.86), fat mass (FM) (23.2 ± 4.9 vs 22.4 ± 8.8 kg), lean mass (LM) (53.6 ± 6.9 vs 49.2 ± 2.2 kg). In contrast, both studies using BIA determined forwards had significantly higher BM, BF% and LM ($p < 0.05$) (Ramos-Álvarez et al., 2021; Sarkar & Dey, 2019).

2.3.2.3 Dual-energy X-ray absorptiometry

In this review, there were six studies using DEXA scans to determine body composition and four of them compared the differences between forwards and backs. Forwards were found to have statistically significantly higher (ES = 0.95 to 1.83) fat mass (FM) (Harty et al., 2021; Posthumus et al., 2020a; Wallace & Donovan, 2008; Yao et al., 2021), BF% (Harty et al., 2021; Imbert et al., 2023; Posthumus et al., 2020a; Wallace & Donovan, 2008; Yao et al., 2021) and LM (Harty et al., 2021; Posthumus et al., 2020a; Wallace & Donovan, 2008). When positional groups were examined, the tight five possessed statistically significantly greater (ES = 0.97 to 1.77) LM, FM, and BF % compared to back row forwards (Posthumus et al., 2020a). Harty *et al.* (2019) observed that in FM, fat free mass (FFM), and lean soft tissue mass, props had statistically significantly higher results than all other positions. FFM index was statistically significantly greater in props than any other position and FM index was also statistically significantly greater in props than any other position except hookers (Harty et al., 2021).

2.3.3 *Physical Characteristics*

A summary of physical characteristics can be found in Table 2.6. Ten studies were included for discussing positional differences between, strength, power, linear speed, change of direction speed and endurance (Hene et al., 2011; Hene & Bassett, 2013; Imbert et al., 2023; Kirby & Reilly, 1993; Neto et al., 2021; Nyberg & Penpraze, 2016; Quarrie et al., 1995; Sarkar & Dey, 2019; Woodhouse et al., 2021b; Yao et al., 2021).

2.3.3.1 Strength

For upper body strength, forwards were reported to have statistically significantly higher absolute 1 repetition maximum (1RM) bench press (ES = 0.98) and no statistically significant differences in relative strength (ES = 0.06) (Woodhouse et al., 2021b; Yao et al., 2021) In contrast, Imbert et al., (2023) reported no statistically significant difference in absolute strength in 1RM bench press and pull ups but backs had statistically significantly higher relative strength in both upper tests. Similar results were reported by Hene et al. (2011) showing no significant differences in absolute 1RM bench press between forwards and backs. For grip strength, no significant differences between forwards and backs were found (Kirby & Reilly, 1993; Neto et al., 2021; Sarkar & Dey, 2019). For maximum repetition tests, forwards were found to perform statistically significantly less push-ups than backs (ES = 0.5 to 0.97) (Hene et al., 2011; Kirby & Reilly, 1993; Neto et al., 2021; Quarrie et al., 1995). For lower body strength between forwards and backs, Yao et al. (2021) reported no statistically significant differences (ES = 0.14 to 0.40) in absolute 1RM squat (kg), isometric mid-thigh pull peak force (IMTP PF, N) and relative IMTP peak force (IMTP RPF, N). Similar results were shown in studies using single leg isometric squat reporting there were no significant differences in RPF between front row, lock, back row, scrum half, inside back, and outside back (Woodhouse et al., 2021b). However, when fixed effect pairwise comparisons were conducted across five seasons, front row had statistically significantly higher PF than scrum half, inside- and outside back, and locks had statistically significantly higher PF than scrum half and outside back (Woodhouse et al., 2021b).

Table 2.5. Summary of studies investigating anthropometry in women's rugby union

Reference	Participants	Competition Status	Methods	Results
Alvarez, 2021	Forwards (*n* = 22) Backs (*n* = 13)	Spanish National League	-six sites skinfold -somatotype - Direct segmental multi-frequency BIA	Forwards had significantly ($p < 0.05$) higher -BM: 73.5 ± 10.7 vs 57.6 ± 6.2 kg -BF%: 25.12 ± 12.2 vs 18.4 ± 7.5 -FM: 20.6 ± 9.0 vs 12.6 ± 3.1 kg -LM: 40.9 ± 22.0 vs 35.2 ± 22.1 kg Subscapular and medial skinfold were significantly higher in forwards, but not sum of skinfolds.
Curtis, 2021	Forwards (*n* = 8) Backs (*n* = 7)	English premiership	-DEXA scan - Height, FM, LM, BMD, BMC were measured - Match playing minutes over 20 matches - Compared between Pre-season and post-season	-BM: pre: 73.7 ± 9.6 vs post: 74.9 ± 10.2 kg ($p \leq 0.05$, ES = 0.13) -BMC: pre: 3.23 ± 0.35 kg vs post: 3.28 ± 0.36 kg ($p \leq 0.05$, ES = 0.15) - No difference ($p > 0.05$) in pre- vs post- measures FM: 20.1 ± 8.3 vs 21.0 ± 8.8 kg (ES = 0.11) LM: 50.2 ± 3.6 vs 50.7 ± 3.9 kg (ES = 0.14) BMD: 1.30 ± 0.07 $g{\cdot}cm^{-2}$ vs 1.31 ± 0.06 $g{\cdot}cm^{-2}$ (ES = 0.16) -Match-play durations: Forwards: 790 ± 298 min vs Backs: 1030 ± 338 min, ($p > .05$, ES = 0.81) - No significant relationships between match-play duration and all DEXA variables.
Escriva, 2021	Forwards (*n* = 26) Backs (*n* = 30)	Spanish National Rugby Championships	Height, BM, FM, FFM, somatotype and 7sites skinfolds were measured.	Forwards had significantly ($p = 0.001$) higher -BM: 71.5 ± 10.2 vs 60.6 ± 6.5 kg (ES = 1.28) -FM: 13.3 ± 5.3 vs 8.5 ± 2.2 kg (ES = 1.18) -BF% (Reilly): 19.1 ±4.3 vs 15.5 ± 2.6 (ES = 1.03) -FFM: 63.3 ± 7.4 vs 55.3 ± 5.2 kg (ES = 1.24) -Endomorphy: 5.56 ± 1.97 vs 3.92 ± 1.05 (ES = 1.04)

Harty 2019	Forwards (n = 58): Backs (n = 43)	US collegiate National Champion	- DEXA scan over a 3-year period - Height, BM, BMI, BF%, FM, FFM, LST, BMC, BMA, and BMD were measured	Forwards had significantly ($p < 0.014$) higher -Height (167.7 ± 7.2 vs 164.5 ± 5.1 cm), -BM (81.5 ± 15.1 vs 64.5 ± 7.7 kg), -BMI (28.9 ± 4.9 vs 23.8 ± 2.4), -BF% (28.2 ± 6.1 vs 21.9 ± 3.7) -FM (23.9 ± 8.7 vs 14.3 ± 3.5 kg) -FMI (8.5 ± 3.1 vs 5.3 ± 1.3 $kg{\cdot}m^{-2}$) -FFM (58.9 ± 8.0 vs 51.0 ± 5.7 kg) -FFMI (20.9 ± 2.3 vs 18.8 ± 1.6 $kg{\cdot}m^{-2}$) -LST (56.1 ± 7.7 vs 48.5 ± 5.5 kg) -BMA (2,215.8 ± 182.9 vs 2,051.5 ± 126.9 cm^2) -BMC (2,810.6 ± 392.6 vs 2,469.1 ± 284.6 g) -BMD (1.26 ± 0.09 vs 1.2 ± 0.08 $g{\cdot}cm^{-3}$)
Hene 2011	Forwards (n = 17) Backs (n = 15)	South African international squad	-Height, BM and 7sites skinfolds were measured.	Forwards vs Backs -BM (78.94 ± 13.01 vs 62.97 ± 5.96 kg, p = 0.0001) -Sum of skinfolds (137.40 ± 30.08 vs 106.66 ± 19.12, p = 0.0003) -BF% (30.81 ± 4.56 vs 26.11 ± 3.81, p = 0.0008)
Hene 2013	Forwards (n = 17) Backs (n = 15)	South African international squad	-Compared BM and 7sites skinfolds data between pre-, in-season and post-season	-Back's BM significantly (p= 0.007) dropped from pre- (62.7 ± 6.0 kg) to mid-season (63.3 ± 6.6 kg). - The sum of skinfolds in the forwards decreased significantly (p = 0.001) from pre- (133.30 ± 33.77 mm) to post-season (116.84 ±20.02 mm).
Imbert, 2023	Forwards (n = 229) Backs (n = 163)	French international	BM, DEXA scan	-Forwards were taller and heavier than backs (height: $p < 0.001$, ES: 0.77; weight: p < 0.001, ES: 1.55). -Backs had significantly lower BF% ($p < 0.001$)
Kirby, 1993	Forwards (n = 20) Backs (n = 19)	English regional level	-Height, 4sites skinfold, fat%, somatotype Were measured	Forwards vs Backs -BM: 68.9 ± 6.6 vs 60.8 ± 5.7 kg ($p < 0.01$) -Fat%: 21.2 ± 1.7 vs 20.2 ± 2.1

				-Mesomorphy: 4.8 ± 0.7 vs 3.9 ± 0.9 ($p < 0.01$) -Ectomotphy: 2.5± 1.0 vs 3.1 ± 0.8 ($p < 0.05$)
Nyberg 2016	Total ($n = 19$)	Scottish premiership squad	- BM, BF%, body fat weight, lean weight and body volume were determined using the BodPod, height was also measured.	-There were no significant ($p \leq 0.05$) differences in all anthropometric testing between forwards and backs. Forwards vs Backs -BM: 78.3 ± 9.4 vs 68.7 ± 10.1 kg ($p = 0.085$) -Body volume: 72.30 ± 10.5 vs 67.6 ± 8.0 L ($p = 0.43$) -Lean weight: 53.6 ± 6.9 vs 49.2 ± 2.2 kg ($p = 0.242$) -Fat weight: 23.2 ± 4.9 vs 22.4 ± 8.8 kg ($p = 0.838$)
Posthumus, 2020	Forwards ($n = 15$) TF ($n = 9$) LF ($n = 6$) Backs ($n = 15$) IB ($n = 8$) OB ($n = 7$)	New Zealand female RU	-Height, BM, 8sites skinfolds, -DEXA scan: LM, FM, fat%, BMC, BMD were measured	Forwards vs Backs (p< 0.05) -Height: 175.6 ± 6.3 vs 167.0 ± 6.6 cm (ES = 1.34) -BM: 93.7 ± 10.9 vs 73.3 ± 7.5 kg (ES = 2.19) -Sum of skinfolds: 128.2 ± 36.6 vs 94.4 ± 29.0 mm (ES = 1.02) -LM: 66.2 ± 6.3 vs 55.6 ± 5.3 kg (ES = 1.83) -FM: 25.3 ± 5.4 vs 15.4 ± 3.1 kg (ES = 2.25) -Fat%: 26.5 ± 3.1 vs 20.8 ± 3.0% (ES = 1.87) -BMC: 3.1 ± 0.3 vs 2.7 ± 0.2 kg (ES = 1.40)
Quarrie 1995	Senior: Forwards ($n = 35$) Backs ($n = 31$) U18: Forwards ($n = 13$) Backs ($n = 12$)	New Zealand senior women and schoolgirl grades.	-Height, BM, neck circumference, and the measurements for calculating the somatotype were measured.	Senior Forwards vs Backs -BM: 75.6 vs 61.4 kg ($p = 0.001$, ES = 1.5) -Neck: 34.9 vs 32.7 cm ($p = 0.001$, ES = 1.2) -Endomorphy: 5.1 vs 3.6 ($p = 0.001$, ES = 1.2) -Mesomorphy: 5.9 vs 4.3 ($p = 0.001$, ES = 0.8) -Ectomorphy: 0.9 vs 1.9 ($p = 0.001$, ES = 1.0) U18 Forwards vs Backs -BM: 67.3 vs 55.1 kg ($p = 0.001$, ES = 1.5) -Neck: 33.2 vs 31.5 cm ($p = 0.001$, ES = 1.2) -Endomorphy: 4.8 vs 3.5 ($p = 0.001$, ES = 1.2)

				-Mesomorphy: 4.7 vs 4.2 (p = 0.001, ES = 0.8) -Ectomorphy: 1.6 vs 2.1 (p = 0.001, ES = 1.0)
Sarkar, 2019	Forwards (n = 12): Backs (n = 13):	Indian national team	Height, BM and 4sites skinfold were collected	Forwards vs backs ($p < 0.05$) BM: 57.5 ± 7.50 vs 49.5 ± 4.93 kg Fat%: 22.7 ± 5.56 vs 17.2 ± 3.70 Sum of skinfold: 51.8 ± 10.51 vs 39.4 ± 11.39 mm MM: 23.1 ± 2.93 vs 21.1 ± 1.71 kg
Wallace, 2008	Forwards (n = 15) Backs (n = 12)	Club level	-DEXA scan: LM, FM, fat%, BMC, BMD were measured	Forwards vs Backs -BM: 77.81 ± 10.80 vs 63.22 ± 6.33kg ($p < 0.001$) -FM: 26.55 ± 8.39 vs 17.52 ± 3.98 kg ($p < 0.05$) -LM: 51.26 ± 6.80 vs 44.31 ± 4.78 kg ($p < 0.05$) Fat%: 32.47 ± 6.38 vs 27.18 ± 4.59% ($p < 0.05$)
Woodhouse, 2021	FR (n = 26) SR (n = 7) BR (n = 11) SH (n = 6) IB (n = 13) OB (n = 16)	English International squad	-BM, 8sites skinfolds through 5 seasons	FR vs SR vs BR vs SH vs IB vs OB -BM: 91.7 ± 7.3 vs 87.7 ± 4.7 vs 80.8 ± 7.6 vs 65.8 ± 1.1 vs 78.2 ± 5.6 vs 70.7 ± 5.0 kg -sum of skinfold: 97.1 ± 14.0 vs 86.9 ± 10.0 vs 83.6 ± 19.5 vs 61.7 ± 9.8 vs 79.1 ± 5.7vs 70.4 ± 6.4 mm
Yao, 2021	Forwards (n = 10) Backs (n = 12)	English premiership	BM, DEXA scan: LM, FM, fat%	Forwards vs Backs -BM: 80.4 ±12.8 vs 69.6 ± 6kg (p = 0.03, ES = 1.07) -LM: 50.1± 4.1 vs 48.9 ± 4.9kg (p = 0.543, ES = 0.25) -FM: 26.9 ± 10.6 vs 17.7 ± 5.4 kg (p = 0.17, ES = 1.08) -Fat%: 32.4 ± 8.4 vs 25.2 ± 6.3 (p = 0.035, ES = 0.95)

FR = front row; SR = second row; BR = back row; HB = half back; SH = scrum half; IB = inside back; OB = outside back; DEXA = dual-energy X-ray absorptiometry; Ave= average; BM= body mass; BF%= body fat percentage; BMI= body mass index; FM = fat mass; MM = muscle mass; LM = lean mass; FMI= fat mass index; FFM= fat-free mass; FFMI= fat-free mass Index; LST= lean soft tissue; BMA= bone mineral area; BMC= bone mineral content; BMD= bone mineral density.

Table 2.6. Summary of studies investigating physical characteristics of women's rugby union

Reference	Participants	Competition Status	Methods	Results
Hene 2011	Forwards (*n* =17) Backs (*n* =15)	South African squad (2010 World cup)	-VJ, 10m and 40m, 1RM bench press, underhand pull-ups, 1-minute pushups multistage shuttle runs were tested	Forwards vs Backs (*significant at $p < 0.01$) -VJ height: 37.50 ± 5.36 vs 44.35 ± 5.06 cm ($p = 0.007$*) -10m: 2.08 ± 0.08 vs 1.90 ± 0.07 sec ($p = 0.0002$*) -40m: 6.51 ± 0.31 vs 5.96 ± 0.19 sec ($p = 0.0001$*) -Push-ups (reps per minute): 16.46 ± 8.71 vs 24.83 ± 9.47 ($p = 0.002$*) - No significant positional differences were detected in terms of absolute and relative bench press strength, pull-ups and aerobic power.
Hene 2013	Forwards (*n* =17) Backs (*n* =15)	South African squad (2010 World cup)	-Testing was through pre-, in-season and post-season -VJ, 10m,40m, 1RM bench press, multistage shuttle runs. was tested	Forwards (pre- vs mid- vs post-) -VJ height: 37.80 ± 5.29 vs 38.40 ± 5.03 vs 39.25 ± 5.69 cm (no significant difference) -10m: 2.05 ± 0.15 vs 2.18 ± 0.10 vs 1.99 ± 0.09 sec ($p <$ 0.01, between pre- and mid-, pre- and post-, mid- and post-) -40m: 6.48 ± 0.32 vs 6.63 ± 0.27 vs 6.41 ± 0.03 sec ($p <$ 0.01, between pre- and post-, mid- and post-) -Aerobic fitness (number of shuttles): 65.6 ± 27.1 vs 53.2 ± 18.2 vs 62.6 ± 13.9 ($p < 0.01$, between pre- and mid-, mid- and post-) Backs (pre- vs mid- vs post-) -VJ height: 44.35 ± 5.06 vs 44.60 ± 5.23 vs 47.25 ± 2.92 cm (no significant difference) -10 m: 1.90 ± 0.07 vs 2.08 ± 0.08 vs 1.90 ± 0.04 sec ($p <$ 0.01, between pre- and mid-, mid- and post-)

				-40 m: 5.96 ± 0.19 vs 6.13 ± 0.16 vs 5.90 ± 0.07 sec ($p <$ 0.01, between pre- and mid-, mid- and post-) -Aerobic fitness (number of shuttles): 80.4 ± 15.3 vs 76.4 ± 10.7 vs 78.8 ± 6.7 (no significant difference)
Imbert,2023	Forwards (*n* = 229) Backs (*n* = 163)	French international	10, 20, 50 m sprint, Yo-Yo test, 1RM bench press and pull ups	-No significant differences in absolute strength -backs had significantly higher relative strength in both bench press and pull ups ($p < 0.05$)
Kirby, 1993	Forwards (*n* = 20) Backs (*n* = 19)	English regional level	Grip and back strength. Broad jump, VJ, 20 m shuttle (VO_2max)	Forwards vs Backs -Grip: 370.8 ± 41.2 vs 360.1 ± 41.2 N -Back: 1020.2 ± 1000 vs 947.6 ± 147.1 N -BJ: 187.7 ±14.3 vs 190.8 ± 14.1 cm -CJ: 35.4 ± 3.3 vs 36.9 ± 2.7 cm - VO_2max: 43.8 ± 4.8 vs 47.3 ± 4.0 (ml/kg/min)
Neto, 2021	Forwards (*n* = 9) Backs (*n* = 8)	University rugby	-Testing was through 3 seasons of pre-and post-season -Grip strength, VJ, 40m, sit and reach, push-ups, curl ups and 20 m shuttle were tested	Forwards vs Backs -Grip: 82.8 ± 11.4 vs 79.5 ± 8.5 kg -VJ power: 3,998.6 ± 560.7 vs 3,859.0 ± 287.8 W -Push-ups: 7.8 ± 3.9 vs 13.7 ± 5.6 reps (p = 0.02, ES = 0.97) -40m: 6.70 ± 0.29 vs 6.28 ± 0.35 s (p = 0.002, ES = 1.23) Pre vs Post -$\dot{V}_{O2}$ max (ml^{-1} ·kg^{-1} ·kin^{-1}) was higher at pre-season 2 (47.6) compared with postseason 1 (47.6) (p = 0.02, ES = 0.39), postseason 2 (44.6) (p = 0.01, ES = 0.55), and pre-season 3 (47.6) (p = 0.02, ES = 0.39).
Nyberg 2016	Total (*n* =19)	Scottish premiership squad	40 m (10m split), Illinois agility test, Level 1 Yo-Yo Test were tested	Forwards vs Backs -Illinois agility: 19.2 ± 0.5 vs 18.9 ± 1.3 -10m: 2.1 ± 0.1 vs 2.1 ± 0.1 -10-40m: 5.0 ± 0.2 vs 4.8 ± 0.4 -40m: 7.1 ± 0.3 vs 6.8 ± 0.5

				Estimated $\dot{V}O_2$ max: 35.9 ± 3.6 vs 35.7 ± 2.1. -There were no significant differences between positions in physical tests ($p > 0.05$)
Quarrie 1995	Senior: Forwards (*n* =35) Backs (*n* =31) U18: Forwards (*n* =13) Backs (*n* =12)	New Zealand senior women and schoolgirl grades.	-VJ, agility run, maximum push-ups, 30 m from standing start and from 5 m rolling start, 20 m multistage shuttle run, 6 repeated high intensity shuttles were tested	-Senior Forwards vs Backs Aerobic shuttle: 65.9 vs 85.6 reps (p = 0.002, ES = 0.8) Agility run: 13.3 vs 12.8 sec (p = 0.072, ES = 0.5) VJ: 39.6 vs 44.8 cm (p = 0.001, ES = 0.9) Push-ups: 12.1 vs 16.4 reps (p = 0.042, ES = 0.5) 30 m standing start: 5.3 vs 5.0 s (p = 0.005, ES = 0.6) 30 m Momentum: 428 vs 368 $kg \cdot m^{-1} \cdot s^{-1}$ (p = 0.001, ES = 1.1) -For the tests completed by both senior and U18, the multistage shuttle was the only one with significant difference ($p<0.01$; ES= 1.3).
Sarkar, 2019	Forwards (*n* =12): Backs (*n* =13):	Indian national team	-grip strength,20 m beep test, anaerobic sprint test, Illinois agility test, 30 m flying start and BJ	Forward vs Backs 30 m: 5.6 ± 0.32 vs 5.3 ± 0.45s (p = 0.161) agility: 12.7 ±0.56 vs 13.1 ±0.43 kmh (p = 0.03) BJ: 1.7 ± 0.23 vs 1.9 ± 0.11 m (p =0.01) $\dot{V}_{O2}$ max ($ml^{-1} \cdot kg^{-1} \cdot kin^{-1}$): 35.8 ± 4.65 vs 40.2 ± 4.66 (p =0.03)
Woodhouse, 2021	FR (*n* = 26) L (*n* = 7) BR (*n* = 11) SH (*n* = 6) IB (*n* = 13) OB (*n* = 16)	English International squad	-1RM bench press, SL ISO squat, SL DJ RSI, CMJ, 1200 m endurance	FR vs L vs BR vs SH vs IB vs OB -1RM bench press: 86.3 ±11.3 vs 73.9 ±4.8 vs 71.5 ± 8.4 vs 69.2 ± 8.3 vs 69.4 ± 9.2 vs 61.1 ± 6.2 kg (FR significant different from BR, SH, IB, OB, p < 0.001) -SL ISO squat PF across five seasons: FR > SH, IB, OB; L > SH, OB (p < 0.001) -CMJ JH across five seasons: OB > L, BR, IB; IB > BR

				-10 m 2019: 1.96 ± 0.06 vs 1.91 ± 0.12 vs 1.93 ± 0.10 vs 1.80 ± 0.04 vs 1.87 ±0.11 vs 1.81 ± 0.07s (FR significant slower from IB, OB, $p < 0.001$) -40 m 2019: 6.12 ± 0.08 vs 6.05 ±0.18 vs 6.03 ± 0.37 vs 5.94 ± 0.10 vs 5.82 ± 0.29 vs 5.50 ± 0.16s -Endurance 2019: 3.7 ± 0.2 vs 3.7 ±0.1 vs 3.9 ± 0.2 vs ± 4.1 ± 0.1 vs 3.9 ± 0.2 vs 4.2 ± 0.2 $m·s^{-1}$ (FR significant slower than SH, IB, OB, $p < 0.01$; L and BR significant slower than OB, $p < 0.001$)
Yao, 2021	Forwards ($n = 10$) Backs ($n = 12$)	English premiership	-10 m, 20 m, 1200 m MAS, 1RM squat, IRM bench press, CMJ, DJ, IMTP	Forwards vs Backs -10 m: 1.86 ± 0.06 vs 1.78 ± 0.05s ($p = 0.02$, ES = 1.41) -20 m: 3.33 ± 0.08 vs 3.13 ± 0.10s ($p < 0.001$, ES = 2.10) -1200 m MAS: 3.63 ± 0.42 vs 4.18 ± 0.44 $m·s^{-1}$ ($p = 0.007$, ES = -1.44) - 1RM bench press: 67.5 ± 9.20 vs 58.9 ± 7.79 ($p = 0.029$, ES = 0.98) -CMJ JH: 24.10 ± 3.14 vs 30.42 ± 5.74 ($p = 0.006$, ES = -1.29) -DJ RSI: 1.16 ± 0.3 vs 1.52 ± 0.34 ($p = 0.016$, ES = -1.15) - IMTP PF: 1426.20 ± 336.31 vs 1260.48 ± 468.29N ($p = 0.361$, ES = 0.39)

FR = front row; L = lock; SR = second row; BR = back row; HB = half back; SH = scrum half; IB = inside back; OB = outside back; BJ= standing broad jump; VJ= vertical jump; RM= repetition maximum; CMJ = countermovement jump; JH = jump height; RSI = reactive strength index; MAS = maximum aerobic speed, SL ISO squat = single leg isometric squat; IMT*P* = isometric mid-thigh pull; PF = peak force

2.3.3.2 Jump Performance

In this review, the most common jump test method used was the countermovement jump (CMJ) (Hene et al., 2011; Kirby & Reilly, 1993; Neto et al., 2021; Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021). Four studies reported backs achieved statistically significantly higher (ES = 0.9 to 1.29) jump heights (JH) than forwards (Hene et al., 2011; Quarrie et al., 1995; Yao et al., 2021). Similar results determined that outside backs jumped statistically significantly higher than all other forward positions (Woodhouse et al., 2021b). In contrast, Kirby & Reilly, (1993) reported no statistically significant differences in either CMJ JH or broad jump distance between forwards and backs. Other mechanistic and power-based variables were reported across studies. Backs were reported to have higher CMJ reactive strength index modified (RSImod) (ES = 0.67) (Yao et al., 2021) but no significant difference in CMJ power output (Neto et al., 2021; Woodhouse et al., 2021b). Besides CMJ, drop jump (DJ) testing was also presented, with backs showing statistically significantly higher DJ JH and higher reactive strength index (RSI) (ES = 1.15) (Woodhouse et al., 2021b; Yao et al., 2021).

2.3.3.3 Speed, Momentum, and Change of Direction Speed

In this review, multiple distance of speed testing was conducted including 10 m, 20 m, 30 m, 40 yd, 40 m, 50 m, and 100 m. Studies reported backs had statistically significantly faster (ES = 0.6 to 1.23) sprint times across multiple distances (Hene et al., 2011; Neto et al., 2021; Woodhouse et al., 2021b; Yao et al., 2021). In contrast, Nyberg & Penpraze, (2016) showed there were no significant differences between backs and forwards in 10 m, 10-40 m split and 40 m time. Three of the studies with speed testing also presented momentum variables with forwards presenting higher sprint momentum (ES = 0.76 to 1.1) (Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021). In change of direction ability (COD), one study reported backs demonstrated significantly faster times in the Illinois agility test (Sarkar & Dey, 2019), however, two studies reported no statistically significant differences between forwards and backs in COD speed (Nyberg & Penpraze, 2016; Quarrie et al., 1995).

2.3.3.4 Aerobic Capacity

Previous studies used 20 m multistage shuttle run and 1200m continuous run to determine aerobic performance. Studies reported there were no significant differences in estimated maximum oxygen uptake ($\dot{V}O_2$ max) values between forwards and backs (Hene et al., 2011; Kirby & Reilly, 1993; Nyberg & Penpraze, 2016). One study reported contrary results showing backs had significantly higher $\dot{V}O_2$ max (p = 0.02) (Sarkar & Dey, 2019). Two studies found backs had statistically significantly higher (ES = 1.44) maximum aerobic speed (MAS) than forwards (Woodhouse et al., 2021b; Yao et al., 2021).

2.4 DISCUSSION

Across the studies reviewed, results had demonstrated match demands, anthropometry and physical characteristics in different playing levels and region. The findings in this review identified with the differences in match demands based on positions, women's rugby union athletes display different characteristics in both anthropometry and physical profile. Furthermore, multiple testing methods can be used to identify anthropometric and physical characteristics to support practitioners in athlete development, coaching, and training.

2.4.1 Match demands

In women's rugby union, players reached a range from 5 to 6 km TD in a full game (players played 75 to 90 min including stoppage time) (Bradley et al., 2019; Busbridge et al., 2020; Sheppy et al., 2019; Suarez-Arrones et al., 2014; Woodhouse et al., 2021a). When discussing positional differences, a study in New Zealand provincial women's rugby, reported half backs covered the highest TD (6812 ± 277 m) compared to all other positions, and outside backs had significantly lower TD (5262 ± 186 m) than inside backs (5966 ± 196 m) and back rows (5952 ± 250 m) (Busbridge et al., 2020). In contrast, two international studies reported front rows (3240 ± 287 m) and half backs (3468 ± 496 m) covered the least TD (Sheppy et al., 2019; Woodhouse et al., 2021a). The differences in results can be attributed to playing time, substitution strategy, match intensity, different tactical approaches, and greater squad depth (Bradley et al., 2019; Neto et al., 2021; Sheppy et al., 2019; Suarez-Arrones et al., 2014; Woodhouse et al., 2021a). In addition, international women's rugby players might cover more distance per minute but not TD, due to the higher match intensity compared to regional or school competitions (Bradley et al., 2019). Time motion analysis in women's rugby union reported that forwards spent significantly more time and were more frequently involved in non-running exertion activities than backs, such as lineouts and scrums (Virr et al., 2014). Furthermore, forwards spend more time jogging, whereas backs spend more time walking which may be due to the positional requirements of forwards who typically follow the ball, while backs are required to maintain positioning in the backline to create attacking opportunities or avoid defensive gaps (Virr et al., 2014). Similar results were shown in GPS data, where backs spent a greater percentage of time walking and forwards spent more time jogging (Bradley et al., 2019). All studies indicate that forwards spend more time in lower intensity running compared to backs, who spend more time (and cover more distance) in high intensity runs, with a higher maximum speed also achieved (Bradley et al., 2019; Busbridge et al., 2020; Callanan et al., 2021; Suarez-Arrones et al., 2014). When looking into positional groups, Bradley et al. (2019) reported that in English premiership women's rugby, front row, second row and back row players performed greater jogging (6-12 $km \cdot h^{-1}$) and low intensity running (12-14 $km \cdot h^{-1}$) distances than outside backs, whereas outside backs achieved statistically significantly greater high intensity running (18-21 $km \cdot h^{-1}$) distances than all other positions. In contrast, Busbridge *et al.* (2020) reported in provincial women's rugby, half backs (i.e., scrum half) presented the greatest high intensity (16.1 $km \cdot h^{-1}$) distance compared to all other positions. Differences were also evident in an interprovincial women's rugby squad, with centres having significantly higher jogging (3.6-10.8 $km \cdot h^{-1}$) distance, half backs having the highest moderate intensity (10.5-18 $km \cdot h^{-1}$) running distance and outside backs having highest high speed (>18 $km \cdot h^{-1}$) running distances (Callanan et al., 2021). A study in English internationals reported similar results to interprovincial women's rugby, identifying half backs covered the highest distance per minute in moderate intensity (10.8-19.8 $km \cdot h^{-1}$) and outside backs cover significantly higher high speed (>19.8 $km \cdot h^{-1}$) distance (Woodhouse et al., 2021a). The difference between these studies besides playing level, playing time, and substitution strategy, is likely the different definition for the high intensity speed zone (>15.8 $km \cdot h^{-1}$ vs >16.1 $km \cdot h^{-1}$ vs >19.8 $km \cdot h^{-1}$ vs 18.1-21 $km \cdot h^{-1}$) (Bradley et al., 2019; Busbridge et al., 2020; Callanan et al., 2021; Sheppy et al., 2019; Woodhouse et al., 2021a). Maximum speed was reported in multiple studies with backs achieving around 24.9 ± 2.3 km·h^{-1} and outside backs to 27.9 ± 0.4 km·h^{-1} (Bradley et al., 2019; Busbridge et al., 2020). The highest maximum speed reported 2 to 4 km·h^{-1} differences compared to male rugby players (Bradley et al., 2019; Busbridge et al., 2020). However, most studies used speed zones mainly identified from men's rugby studies to identify high intensity or high-speed running from 18 to 19.8km·h^{-1} (Bradley et al., 2019; Callanan et al., 2021; Suarez-Arrones et al., 2014; Woodhouse et al., 2021a) With the maximum speed differences between men and women, the speed zone threshold might overestimate low to moderate intensity running and underestimate high intensity running of female players. Therefore, a speed zone threshold for women's rugby to elucidate match demands could support sport practitioners to plan training and monitor athletes without over or underestimation of their effort.

For work rate and player load, Virr *et al.* (2014) reported forwards had statistically significantly higher mean game HR (173 ± 10 vs. 161 ± 10 beats per minute) and a higher percentage of the game played above 80% of heart rate maximum (81 ± 14 vs. 63 ± 20%). This indicated that although forwards achieved less high-speed running in matches, they achieved greater levels of physical work due to the physicality of scrums, lineouts, and a greater number of rucks and mauls than backs (Virr et al., 2014). Similar results were reported using GPS to collect collision load in English internationals, where all forward positions had higher collision activities compared to all backs' positions (Woodhouse et al., 2021a). However, a study in the Spanish national team found backs received substantially higher impact during the match (Suarez-Arrones et al., 2014). A possible reason why forwards have higher collision loads, but lower heavy and severe impact, might be due to forwards engaging in collisions in either static (i.e.

scrum) or close quarter (line out) conditions, whereas backs run into collisions from an open space with higher running speed (Suarez-Arrones et al., 2014). However, GPS data can only report speed changes and collision load, which presents a gap to identify non-locomotive and contact aspects of play.

The research surrounding match demands in women's rugby union has increased in recent years (Woodhouse et al., 2021a). However, to the best of the author team's knowledge, there is only one time motion analysis study (Virr et al., 2014), and there are no agreed speed zone thresholds identified from women's rugby research. As such, further research should combine time motion analysis with GPS observation to identify women's rugby specific speed thresholds and on-pitch activity to support the quantification of match performance characteristics, which in return, would assist coaches and support staff (sport science, strength and conditioning and performance analyst) to design both sex and position-specific training programs.

2.4.2 Anthropometry

Across different playing levels and regions, this review identified that most studies reported forwards had significantly higher sum of skinfolds, BM, FM, LM and typically lent towards endomorphy somatotype (Escrivá et al., 2021; Harty et al., 2021; Hene et al., 2011; Kirby & Reilly, 1993; Posthumus et al., 2020b; Quarrie et al., 1995; Sarkar & Dey, 2019; Wallace & Donovan, 2008). When discussing positional groups, tight five (e.g., front row, second row) were significantly heavier than back row with higher sum of skinfolds, LM, FM, and BF % (Posthumus et al., 2020b). Similar results were reported in both English internationals and collegiate athletes, identifying front row props as significantly heavier compared to all other positions (Harty et al., 2021;

Woodhouse et al., 2021b). These general findings mirrored the match demands of forwards facing more collision activities where BM (fat and lean mass) could act as a protective buffer, whilst concurrently increasing momentum when velocity maintained (Duthie, Grant et al., 2003). However, Nyberg and Penpraze, (2016) reported no statistically significant differences between forwards and backs in anthropometry data (lean weight: 53.6 ± 6.9 vs 49.2 ± 2.2 kg; fat weight: 23.2 ± 4.9 vs 22.4 ± 8.8 kg) in the Scotland women's premiership when using the BodPod (Cosmed, Rome, Italy), a body composition assessment system based on air displacement. The reason there were no significant differences between positions might be a result of back rows were leaner than other forward positions and the small sample size from the study (Nyberg & Penpraze, 2016). The BodPod has been shown to be insufficiently sensitive when detecting female athletes, athletes with extremes of the body mass index and would over/underestimate lean or fat weight (Bentzur et al., 2008; Kasper et al., 2021). Yao et al. (2021) also reported there were no significant differences in LM between forwards and backs. However, it is worth noting the study also mentioned that 9 players from the squad were injured, and 7 players from the club were representing their respective international squads. Thus, such factors may be likely to have impacted mean data. When discussing seasonal changes, studies using a DEXA scan assessment in English premiership players found no significant differences between backs and forwards in all anthropometry variables (Curtis et al., 2021). In contrast, a study in South African rugby reported a statistically significant decrease in the sum of skinfolds in forwards from mid- to post-season (Hene & Bassett, 2013). However, in the South African study, the participant numbers changed from mid-to post-season; thus, it is hard to define if the significant change is due to players losing fat mass or because the drop in participants which caused the average score to change (Hene & Bassett, 2013). Based on the limited longitudinal anthropometry studies in women's rugby union, it is still not clear how body composition changes throughout a season.

In this review, multiple methods were used to determine body composition, with studies showing that skinfold, bioelectrical impedance analyzer and air displacement plethysmography all underestimate BF % compared to DEXA scan (Antonio et al., 2019; Sarkar & Dey, 2019) which must be taken into consideration when comparing studies. Although skinfolds are not as accurate as DEXA, studies have reported that 8-sites skinfold has the strongest relationship with DEXA results compared to a reduced number of tested sites and can monitor regional fat mass changes longitudinally (Kasper et al., 2021). This indicates that in a sport performance setting, a time and cost-effective option could be to use the 8-site skinfold measurement method. However, if a DEXA is accessible, it provides limb-specific estimations of fat mass and fat free mass, which can be useful when tracking injured athletes and the magnitude of fat loss (Kasper et al., 2021). This review identified position specific body composition demands using different methods. This will enable sports science practitioners to monitor players body composition to maximize athletes' performance and optimize nutritional strategies over the course of a competitive season.

2.4.3 Physical Characteristics

2.4.3.1 Strength

Recent studies in English women's premiership players and English internationals investigated upper body strength using the 1RM bench press and found forwards had significantly higher absolute strength (Woodhouse et al., 2021b; Yao et al., 2021). In contrast, a study in French internationals found no significant difference in 1RM bench press and pull ups, but backs demonstrated significantly greater relative strength (Imbert et al., 2023). However, for maximum repetition tests, forwards were found to perform significantly fewer push-ups than backs (Hene et al., 2011; Neto et al., 2021; Quarrie et al., 1995). The variation in results is likely due to the considerably greater body mass in forwards, which may induce more fatigue during high repetition tests (Vanderburgh & Crowder, 2006). For lower body strength, both Yao et al. (2021) and Woodhouse et al. (2021) reported there were no significant differences in isometric strength testing (IMTP and single leg isometric squat) between playing positions. However, when fixed effect pairwise comparisons were conducted across five seasons, front row forwards had significantly higher absolute peak force values compared to scrum halves, and inside- and outside backs. In addition, second row forwards also had significantly higher absolute peak force values than scrum halves and outside backs (Woodhouse et al., 2021b). Yao et al. (2021) also identified that a limitation in their study was that when data was collected, the international players were not in the club due to an international camp; thus, likely contributing to forwards and backs exhibiting no LM differences. In addition, and as a surprise, backs had significantly heavier 1RM back squat than forwards, which may also be a consequence of a number of forwards being on international duty (Yao et al., 2021). From match demands-based research (Bradley et al., 2019; Virr et al., 2014), and the contact nature of women's rugby union, possessing well-developed strength is advantageous to performing rugby-specific tasks such as tackling, rucking, scrummaging, and fending. However, there are only a limited number of studies that have reported strength characteristics in the last five years at competitive level (Woodhouse et al., 2021b; Yao et al., 2021). Further research should focus on identifying normative data for strength tests across different levels of competition (i.e., premiership vs. international). Such data would assist in providing benchmark data and better support practitioners when making informed recruitment and training decisions.

2.4.3.2 Jump Performance

Comparisons between jumping abilities highlighted that backs were able to produce greater JH during the CMJ and higher RSI scores during the DJ in English premiership women's rugby (Yao et al., 2021). Similar results were reported in English internationals, demonstrating higher JH in backs, with outside backs also producing significantly greater relative peak power output (W/kg) than all forward positions (Woodhouse et al., 2021b). Studies using the jump and reach method also found backs achieved higher JH than forwards across different playing levels (Hene et al., 2011; Kirby & Reilly, 1993; Neto et al., 2021; Quarrie et al., 1995). A number of studies in women's rugby union used jump tests but only JH was recorded, which lacks detail pertaining to the jump strategy employed by the athlete, and limits comparisons that can be made with other positional groups due to significant body mass differences not being accounted for (Barker et al., 2018; Chavda et al., 2018; Gathercole et al., 2015). Furthermore, as rugby is a collision sport that relies on a certain amount of BM, only reporting JH results might positively bias lighter athletes (often backs). Therefore, jump momentum (take off velocity x BM) may be a more suitable variable to understand both jumping abilities, and inform sprint momentum (McMahon et al., 2020). Therefore, more strategy-based variables including velocity, RSImod, momentum, and impulse should be discussed and clarified between positional groups in the future. This is because previous literature has both suggested and shown that strategy metrics are more sensitive to change after intense exercise and during the ongoing monitoring process (Bishop et al., 2021b; Gathercole et al., 2015).

2.4.3.3 Speed, Momentum, and Change of Direction Speed

With multiple distances (10 to 100 m) used during speed testing, results mainly reported backs were significantly faster than forwards across all distances. (Hene et al., 2011; Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021). A study in French internationals reported that both forwards and backs had become faster in both acceleration and top speed in the last few years (Imbert et al., 2023). These results mirror the match demands of backs, who need to perform a greater number of sprints during games with higher speeds required to create scoring opportunities or successful defensive plays (Woodhouse et al., 2021a). Besides sprint time, sprint momentum has been suggested to be a key determinant of success in the contact phases of rugby union (Tierney et al., 2019). Studies have reported forwards had higher 10 m (Yao et al., 2021) and 30 m (Quarrie et al., 1995) momentum compared to backs. Furthermore, front and second row forwards had significantly higher momentum than inside and outside backs in both 0-10 m and 20-30 m distances, and props demonstrated greater 0-10 m momentum than back row forwards (Woodhouse et al., 2021b). Despite forwards reporting significantly slower speed, they were still able to create a higher sprint momentum (Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021). The results indicate that the difference in body mass is likely to have a greater effect on sprint momentum than the difference in velocity. However, caution should be made when comparing momentum metrics given speed and body mass are both necessary for building momentum and thus, focusing on only gaining body mass might affect sprint and other sport performance.

COD speed combines the ability to accelerate and decelerate rapidly and is a fundamental component of agility in rugby (Lockie, Robert G. et al., 2016). Studies compared COD ability between forwards and backs using a custom agility run (Quarrie et al., 1995) and Illinois agility test (Nyberg & Penpraze, 2016; Sarkar & Dey, 2019). Only Sarkar & Dey (2019) found backs were significantly faster than forwards in COD tests, whereas no significant difference was found in the other two studies (Nyberg & Penpraze, 2016; Quarrie et al., 1995). The COD test used by these studies only recorded total time, which serves as a gross measures of COD speed performance and likely doesn't isolate the COD actions that occur during turns (Nimphius et al., 2016). Recent studies have used the 505 COD test in women's rugby union athletes (Lockie, Robert, 2018; Lockie, Robert G. et al., 2016) to determine COD ability and COD deficit (CODD, total 505 time -–linear speed time) fot inter-limb differences – although again, this merely represents a gross difference in time; not a true side-to-side difference in function. The results indicated that the CODD was a better variable to determine COD ability and is less affected by linear sprint speed (Lockie, Robert, 2018). However, the study did not compare COD ability between positional differences (Lockie, Robert, 2018). Future research should focus on identifying more in-depth metrics of COD testing to determine not only the finish time of a certain COD test but also the mechanics of how female rugby union athletes perform and compare positionally to support practitioners making training-based decisions.

2.4.3.4 Aerobic Capacity

Studies in New Zealand club level and Indian national team have reported backs had statically significantly higher $\dot{V}O_2$ max values using the multistage shuttle test (Quarrie et al., 1995; Sarkar & Dey, 2019). In contrast, a study in Scotland's BT Women's Premiership squad reported no significant differences in $\dot{V}O_2$ max between positions (Nyberg & Penpraze, 2016). The similarities of $\dot{V}O_2$ max between positions might be due to the athletes playing level and lack of all rugby positions in the small sample size during the study (Nyberg & Penpraze, 2016). Research have shown back rows although categorized as forwards were also required to have the ability to cover high distances at moderate speeds (Callanan et al., 2021). Furthermore, match demands-based studies have shown that back rows demonstrate statistically significantly higher average speed than front rows (Woodhouse et al., 2021a). Therefore, when athletes were only separated into forwards and backs, there might be no significant differences in $\dot{V}O_2$ max. Three recent studies used a 1200 m trial to calculate MAS to determine aerobic capacity (Imbert et al., 2023; Woodhouse et al., 2021b; Yao et al., 2021). Yao et al. (2021) showed backs had statistically significantly higher MAS than forwards. When comparing more detailed positional groups, front rows had significantly lower MAS scores than back row, scrum half, inside back and outside back, with second row and back row also demonstrating statistically significantly lower MAS scores than outside back. A longitudinal study in French internationals found using MAS can support monitoring aerobic improvements (Imbert et al., 2023). This review identified that both multistage shuttle test and continuous runs were able to determine the aerobic capacity of women's rugby union players. Although the 1200 m continuous run takes less time to accomplish than a multistage shuttle test, the longer duration of continuous running and COD might cause a disadvantage for forwards due to having higher BM (Yao et al., 2021). Further research should focus on discussing aerobic capacity with respect to positional differences across different levels of competition and multiple teams in the same competition to develop future normative data and provide training guidance for players of different positional groups.

2.5 FUTURE RESEARCH

As identified in this review, there is an increase in published literature looking at match demands, anthropometry, and physical characteristics in female rugby union players. For match demands, future research should combine GPS and time-motion analysis to identify the activity in collision load in the women's game, and to categorize match demands for each positional group. With well detailed motion categories and speed zones, it would not only improve the understanding of women's match demands but also support practitioners to make anthropometric and physical capacity changes for each positional group. It is determined that there are necessary requirements in both anthropometry and physical characteristics to become a competitive women's rugby player. With recent studies demonstrating players getting faster and stronger, it is important to not just understand positional differences but also understand characteristics in different performance categories. Firstly, anthropometry, strength and power are such critical characteristics for women's rugby, understanding the seasonal changes in these characteristics may support practitioners to adjust training plans to maximize performance during the season. Secondly, having better sprinting and COD ability are key components to become a competitive rugby player and are both critical motor skills for the sport. In addition, the differences between fast and slow female rugby players would be important to identify and characterize the kinematics to support practitioners to identify appropriate benchmarks for planning training accordingly. Lastly, the majority of studies largely focus on outcome measures (e.g., JH, sprint speed, COD speed), lacking a detailed analysis of performance strategy (e.g., how the tasks are completed). For example, future research should aim to quantify both power and mechanical variables (e.g., power output, velocity, RSImod, momentum and impulse), sprinting mechanics, and COD (deficit and mechanics) to have a more holistic understanding of women's rugby union physical performance characteristics.

2.6 CONCLUSION

This review identified differences in match demands, anthropometry, and physical characteristics in women's rugby union based on playing position. Forwards were found to spend a longer duration in low intensity running and complete a higher number of collisions. Backs were found to have longer duration in walking/standing, high speed running, sprinting, and reaching higher maximum speed. For anthropometry and physical characteristics, forwards were heavier (especially front row), stronger (especially front row), can create more momentum, and backs were leaner, faster (especially outside backs), and had more relative power and a higher aerobic capacity. The gap of anthropometry and physical characteristics and changes throughout a season should be the priority for researchers in women's rugby union to support practitioners and coaches for talent identification, training, planning seasonal plans, and nutrition guidelines.

Chapter 3: Methods, procedures, and statistics

Rugby union is a multidirectional team sport, which requires athletes to be strong, powerful, fast, and efficient throughout a competitive season. Therefore, this thesis discusses the lab and gym-based assessments, and further discussed field-based locomotive assessments (linear sprint and change of direction) in order to provide practitioners with a detailed understanding of positional and locomotive ability and how these characteristics change throughout a season (Figure 2).

In this chapter, procedures and statistical tests used in the different studies (chapter 4 to 9) of this thesis are described. This will allow the reader to comprehend the methodological rationale underpinning each analysis conducted. This chapter will be referred to throughout the thesis to avoid unnecessary repetition.

Aim	Study	Tests / Comparison
To determine the differences in anthropometry, strength and power characteristics between forwards and backs in women's rugby union athletes.	Study 1	Tests: DEXA scan, CMJ, DJ, IMTP Compared positional group differences.
To understand the trend of these characteristics during a competitive season in forwards and backs.	Study 2	Longitudinal trend across a season based on testing in study 1.
To understand speed and momentum differences between positions and to further understand the kinematics of sprinting between fast and slow athletes.	Study 3	Tests: 40 m sprints with 0-10 m split and 30-40 m split Compared both positional and speed group differences.
To observe the kinematic changes in both acceleration and top speed during a competitive season to identify mechanic changes that affect sprint performance.	Study 4	Longitudinal trend across a season based on testing in study 3.
To identify the relationship between linear speed, momentum and change of direction speed and to compare the positional differences between positions and fast and slow athletes.	Study 5	Tests: 10 m sprints and 505 COD Compared both positional and speed group differences.
To observe how change of direction ability changes throughout a competitive season and whether linear speed and momentum changes affect change of direction ability.	Study 6	Longitudinal trend across a season based on testing in study 5.

Figure 2. Thesis overview flowchart

3.1 Anthropometry assessment

The stature of each player was measured to the nearest 0.1 cm using a SECA 213 stadiometer (SECA Corp, Hamburg, Germany), and body mass (BM) was measured using a SECA 703 calibrated scale (SECA Corp) with accuracy to the nearest 0.1 kg (Yao et al., 2021). Body composition was measured using DEXA scan (Lunar Prodigy; GE Healthcare, Madison, WI), with analysis performed using GE Encore 12.20 software (GE Healthcare). Subjects were asked to wear minimal clothing (sports bra and shorts). All jewelry and metal objects were removed before each scan to improve the accuracy of the scan results (Nana et al., 2015). Variables of lean mass (LM), fat mass (FM), fat percentage (fat%), and bone mineral content (BMC) were recorded.

3.2 Power assessment

The CMJ was performed on a portable force plate (Kistler type 9260AA; Kistler Group, Winterthur, Switzerland), and data were sampled at 1000 Hz using an analysis software package (Bioware, Winterthur, Switzerland). Once familiarized with the standardized protocol, 2 trials were performed by each participant with a 3-minute rest between trials. Before each trial, the force plate was zeroed prior to the participant standing on the force plate. Once zeroed, the participant was asked to stand on the force plate with hands on their hips, at which point the data acquisition began. Subjects were told to remain motionless for at least 1-second prior to initiating the jump to obtain body weight (Chavda et al., 2018). All jumps were performed using a self-selected depth to avoid causing unwanted changes to jump coordination, and subjects were encouraged to "jump as high as possible" for each trial. All raw data were extracted as a text file and analyzed in a custom-built Microsoft Excel spreadsheet (Microsoft Corp, Redmond, WA) as outlined by Chavda et al., (2018). The detection of the initiation of the jump was calculated as the average vertical ground reaction force of the 1-second motionless period ± 5 SDs, −30 ms (Chavda et al., 2018). Jump height (JH), takeoff velocity (TOV), time to take-off (TTT), and modified reactive strength index (RSI_{mod}) were extracted utilizing the impulse momentum method (Chavda et al., 2018). Jump momentum (JM) was also calculated as TOV multiplied by body mass (BM) (McMahon et al., 2020).

The drop jump (DJ) was performed from a box height of 0.3 m in line with previous research (Marshall & Moran, 2013; Rossi et al., 2011) onto a portable force plate (Kistler type 9260AA; Kistler Group, Winterthur, Switzerland), and data were sampled at 1000 Hz using an analysis software package (Bioware, Winterthur, Switzerland). Strict instructions were given to each participant; keep hands on hips during jumps to constrain any involvement from the upper body, avoid hopping off the box, avoid a tucking motion in the air (i.e., legs kept straight), and attempt to land in the same position as takeoff. Subjects were encouraged to minimize ground contact time while also attempting to achieve maximal height during the jump. Two trials were performed with a 3-minute rest between each to avoid any residual effects of fatigue on performance. Contact time (CT) and flight time (FT) were captured from the force plate, and reactive strength index (RSI) was then calculated as FT / CT.

3.3 Strength assessment

The IMTP was performed on a portable force plate (Kistler type 9260AA), which was attached to a custom adjustable power rack (Absolute Performance, Cardiff, Wales) that allows fixation of a horizontal bar at any height. The bar was adjusted to a height that allowed the subjects to assume a position that approximated the beginning of a second pull of the clean (Wang et al., 2016). Knee angle was assessed using a handheld goniometer to verify a knee angle of 125°± 5°and a hip angle of 175°± 5°. Subjects' hands were fixed to the bar using weightlifting straps to prevent hand movement and to ensure that a maximum effort could be given without limitation of hand grip strength (Bailey et al., 2013). Each subject performed 2 warm-up trials at 50% and 75% of perceived maximal effort, followed by 1 maximal voluntary isometric contraction with a 1-minute rest between each pull. Two 3 sec maximal effort trials were performed, with a 3-minute rest between. The force plate was zeroed prior to the participant taking position between each trial. Once in position, the participant was asked to take minimal tension on the bar and stand as still as possible. Following this, a countdown was given of "3, 2, 1, Pull!" and subjects were verbally instructed to "pull against the bar with maximal effort as quickly as possible and push the feet down into the force plate". This instruction has previously been shown to optimize peak force (Thomas et al., 2015). Peak force (PF), and relative peak force (RPF) was extracted from a customized Microsoft Excel spreadsheet (Chavda et al., 2019) using an average of the motionless baseline plus 5 SD threshold to determine the onset of initiation (Chavda et al., 2019). The average of the baseline was also subtracted from the absolute force time curve to provide net force.

3.4 Sprint assessment

Two infrared timing gates (Brower Timing Systems, Draper, UT) were set at 0 and 40 m on an artificial 4G rugby pitch, with additional gates placed at 10 m and 30 m to obtain split times. Participants were instructed to start with a split stance, with their preferred foot 50 cm behind the first timing gate to prevent any false signals of the infrared beam. Sprint times were recorded using a wireless receiver (Brower Timing Systems) accurate to 0.01 second. Two smart phone high-speed video cameras (iPhone X, Apple Inc, Cupertino, Ca) were used to capture sagittal plane video images (1920 × 1080 pixels) of each 10m split at 240 Hz. Each camera was positioned 15 m from, and perpendicular to the sideline in each 10m split, to capture sagittal plane images. Video analysis was carried out using a 2D video analysis software (Kinovea – v.0.9.5). The kinematic variables of interest were determined from the toe-off and foot strike identified in the video frames. The lower body had manual digitization of the following: hip, knee, the most posterior part of the heel, and the tip of the toe.

3.5 Change of direction assessment

Two timing gates were set at the 0 m and 10 m mark, cones and a line were set at the 15 m mark. To achieve a successful trial, participants were told to sprint and make a 180° turn at the 15 m mark and sprint back to the finish line (10 m gate). Participants were instructed to start with a split stance, with their preferred foot 50 cm behind the 0 m gate to prevent any false signals of the infrared beam. Sprint times were recorded using a wireless receiver (Brower Timing Systems) accurate to 0.01 second. The 505 COD test considered the time from the 10 m gate to the 15 m contact mat and back to the 10 m gate and was completed for both left and right sides. The dominant direction (D) was identified as the turning direction with the fastest 505 performance and the opposite direction was classified as non-dominant (ND). CODD of both directions were than calculated using the equation (505 time – linear 10 m sprint time) by previous studies (Clarke et al., 2020; Freitas et al., 2018; Nimphius et al., 2016).

3.6 Statistics

Firstly, a Shapiro–Wilk test of normality revealed that all data ws normally distributed ($p > 0.05$), thus we could use parametric statistical tests. Reliability of variables within each time point was examined using: (1) a 2-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals, (2) the coefficient of variation (CV) and 95% CI, and (3) the standard error of the measurement (SEM). Average variability taken from across the ICC and CV was interpreted as small for an ICC > .67 and CV < 10%, moderate when ICC < .67 or CV > 10%, and large when ICC < .67 and CV > 10% (Bradshaw et al., 2010).

All statistical methods were analysed via SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp). An independent samples *t*-test was used to compare the difference between groups, with statistical significance set at $p < 0.05$. A one-way ANOVA was used to compare fast, moderate, and slow groups in acceleration and top speed. Longitudinal Changes at the 3 time-points (pre-, mid-, post-season) between playing positions were compared using a repeated measures ANOVA. Changes in COD ability at the 2 time-points in the season were compared using a paired sample *t*-test via SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp). Where statistically significant main effects were identified, a Bonferroni correction was applied. Hedges *g* effect sizes (ES) were calculated and interpreted as: 0 < ES < 0.2 = trivial, 0.2 < ES < 0.5 = small, 0.5 < ES < 0.8 = medium, > 0.8 = large (Nakagawa & Cuthill, 2007). Relationships between performance measures, were assessed using Pearson's *r* product-moment correlation (2-way), with values interpreted as follows: < 0.1 trivial, 0.1-0.3 = small, 0.3 – 0.5 = Moderate, 0.5 – 0.7 large, 0.7 – 0.9 = very large, 0.9-1.0 = nearly perfect, 1.0 = perfect. Statistical significance was set as $p < 0.05$ (Clarke et al., 2022).

Chapter 4: Anthropometry, strength and power characteristics in English Premiership Women's Rugby Union

Abstract

Background: Women's rugby is a collision sport that relies heavily on body composition and strength and power characteristics of strength and power to achieve competitive success.

Aim: To determine the differences in anthropometry, strength and power characteristics between forwards and backs in English Premiership Women's Rugby Union

Method: Forty-seven players were recruited from the English premiership women's rugby during the 2020–2021 season. Players were split into forwards and backs and underwent body composition testing via dual-X-ray absorptiometry, and strength and power tests (countermovement jump, drop jump, and isometric mid-thigh pull)

Results: Forwards had significantly ($p < 0.01$) higher body mass, fat mass, lean mass, bone mineral content and take off momentum, and backs had significantly higher ($p < 0.01$, $d > 0.5$) jump height, reactive strength, and shorter drop jump contact time.

Conclusion: The anthropometry, strength and power testing and characteristics shown in this study could support practitioners for talent identification having a comparable English premiership physical standards data to adjust training or nutrition plans.

4.1 INTRODUCTION

Rugby union, different from other rugby codes (e.g., rugby league and sevens), is a collision sport that is played over two 40 minutes halves with 15 players a side (Heyward et al., 2019). With the requirement of intermittent bouts of high-intensity (e.g., tackle, scrum and sprinting) and low intensity actions (e.g., walking), players rely heavily on the body composition and physical characteristics of strength and power to achieve competitive success (Hene et al., 2011; Woodhouse et al., 2021b). Players are categorized into groups of forwards and backs by specific positional demands (i.e., forwards are involved in lineouts and scrum set up) (Heyward et al., 2020). Recent women's rugby union studies have focused across different playing levels including the Spanish women's team, English premiership, US collegiate team, and New Zealand rugby union players. These studies have shown that forwards have higher body mass (Escrivá et al., 2021; Yao et al., 2021), body fat percentage (Escrivá et al., 2021; Harty et al., 2021; Yao et al., 2021) and lean mass (Harty et al., 2021; Posthumus et al., 2020b) compared to backs. However, backs have been shown to have higher relative lower body strength and jump performance in English international players (Woodhouse et al., 2021b). The results were similar to men's rugby union and women's rugby league studies, highlighting forwards are heavier and slower than backs (Jones et al., 2016; Posthumus et al., 2020b). However, despite recent women's rugby union studies investigating players over different playing levels and countries (Hene et al., 2011; Woodhouse et al., 2021b; Yao et al., 2021), a distinct lack of comparative data currently exists on the physical characteristics of competitive English premiership women's players. Therefore, it is crucial to minimize the gap in the research for coaches to understand the physical profile of the competitive women's premiership athletes to support talent identification and training.

When considering English premiership players using a cross-sectional design, Yao et al. (Yao et al., 2021) did not report positional differences in anthropometric and physical characteristics for international players in the squad. Therefore, to date, there is a distinct gap in the literature relating to detailed profiling for anthropometry and strength and power characteristics of English women's rugby union players that encompasses positional differences (i.e., forwards vs. backs), this is therefore the primary aim of this study. Based on the available studies in women's rugby union, it was hypothesized that forwards would have higher lean mass, fat mass and absolute strength performance, and backs would have higher absolute power performances.

4.2 METHOD

4.2.1 Experimental Approach to the Problem

In order to understand anthropometric profiles, strength and power characteristics of women's rugby union players, a cross-sectional study was undertaken. Playing position was the independent variable, and anthropometric, strength and power characteristics were the dependent variables. The following anthropometric and physical tests were administered: DEXA scan, isometric mid-thigh pull (IMTP), countermovement jump (CMJ), drop jump (DJ).

4.2.2 Subjects

Forty-two (*n* = 42) women's rugby union players from a single team volunteered for this study. The 42 players were separated into forwards (*n* = 24, age: 28.04 ± 5.98yrs, height: 171.75 ± 7.98cm, weight: 87.66 ± 12.60kg) and backs (*n* = 18, age: 25.77 ± 3.87yrs, height: 168.44 ± 4.67cm, weight: 70.92 ± 4.40kg). Players in this study competed in the English women's premiership, which is the highest level in English women's rugby union in the UK. All players had at least three years of experience in rugby training and strength training in a structured rugby club and took part in 2 rugby team practices and 2 individual gym sessions per week. Tests included in this study were part of the 2020-2021 annual season monitoring test battery, agreed by both the medical and strength and conditioning staff. The study was approved by the London Sport Institute research ethics subcommittee at Middlesex University. Players were informed of the benefits and risks of the investigation before signing written informed consent to participate in the study.

4.2.3 Procedures

Anthropometric and physical performance measurements were conducted on 3 separate occasions during a 9-month season, with pre-season testing in September 2020 (1 week before the season starts), mid-season testing in February 2021, and post-season testing in June 2021 (the week after the premiership final which the team participated in and won). During the three separate testing time frames, players with a medical condition or injury were excluded from the physical fitness assessment. All subjects refrained from intensive exercise in the 24-hour period prior to testing. At the beginning of laboratory-based tests, anthropometric measurements were taken for each participant. Following this, subjects underwent a standardized warm-up, consisting of 10 minutes of dynamic stretching followed by 2 practice trials for each of the strength and jump assessments. Subjects were familiar with all tests, which were also conducted during their regular annual performance monitoring and gym training programs.

4.2.3.1 Anthropometry

For the detailed testing procedures used for anthropometry refer to Chapter 3.1. Variables of body mass (BM), lean mass (LM), fat mass (FM), fat percentage (fat%), and bone mineral content (BMC) were recorded.

4.2.3.2 Power characteristics

For the detailed testing procedures used for power assessments refer to Chapter 3.2. CMJ: Jump height (JH), takeoff velocity (TOV), time to take-off (TTT), modified reactive strength index (RSI_{mod}) and jump momentum (JM); DJ: Contact time (CT), and flight time (FT) and reactive strength index (RSI) were recorded.

4.2.3.3 Strength Characteristics

For the detailed testing procedures used for strength assessments refer to Chapter 3.3. Peak force (PF), and relative peak force (RPF) was extracted.

4.2.4 Statistical Analyses

Subjects were separated into 2 groups: forwards and backs. All data were presented as mean ± standard deviation. For the detailed procedures used for normality, reliability, differences between forwards and backs using an independent sample *t*-test and Hedges *g* effect sizes (ES) can be refer to chapter 3.6.

4.3 RESULTS

All variables in this study were normally distributed when athletes were grouped into forwards and backs. Average variability for all variables demonstrated at least moderate (ICC < .67 or CV > 10%) to small (ICC > .67 and CV < 10%) variability (Table 4.1)

4.3.1 Anthropometric Characteristics

The positional differences of anthropometric characteristics across the season are shown in Table 3.2. Effect sizes are also provided to report the magnitude of difference and thus provide applied practitioners with some measure of 'practical significance' (Turner et al., 2021). There were no statistically significant differences in stature between forwards and backs throughout the season (pre-, mid-, post-season). Forwards had statistically significantly higher BM, fat%, FM, LM, and BMC ($p < 0.05$, $g = 0.76$ to 1.69) than backs throughout the 3-testing times.

4.3.2 Strength and Power Characteristics

The positional differences of strength and power characteristics across the season are shown in Table 3.3. Backs showed statistically significantly higher CMJ JH, RSImod, TOV, DJ FT, and DJ RSI throughout the 3-testing time points across the season ($p < 0.05$, $g = 0.78$ to 1.91). Forwards had significantly higher JM in post-season compared to backs ($p = 0.03$, $g = 0.77$, 95% CI = 0.05 to 1.49). There were no statistically significant differences in PF and RPF in IMTP between forwards and backs throughout the season.

Table 4.1. Between-trial reliability for physical measures

		Mean ± SD	CV % (95% CI)	ICC (95% CI)	Average variability	SEM
Pre-season	IMTP PF (N)	2468.01 ± 456.24	3.05 (2.33, 3.76)	0.95 (0.90, 0.97)	small	77.12
	IMTP RPF (N)	1509.52 ± 393.85	5.38 (4.12, 6.64)	0.92 (0.86, 0.96)	small	66.57
	DJ CT (s)	0.23 ± 0.04	5.19 (3.98, 6.41)	0.83 (0.68, 0.91)	small	0.01
	DJ FT (s)	0.46 ± 0.05	3.04 (2.33, 3.76)	0.90 (0.81, 0.95)	small	0.01
	DJ RSI	2.06 ± 0.47	5.99 (4.59, 7.40)	0.91 (0.83, 0.05)	small	0.08
	CMJ JH (cm)	28.32 ± 5.88	2.17 (1.66, 2.68)	0.98 (0.73, 0.99)	small	0.99
	Time to take off (s)	0.68 ± 0.10	4.67 (3.58, 5.76)	0.77 (0.59, 0.88)	small	0.02
	RSImod	0.41 ± 0.10	4.74 (3.63, 5.85)	0.93 (0.86, 0.96)	small	0.02
	Take off velocity (m/s)	2.34 ± 0.25	1.08 (0.83, 1.33)	0.98 (0.74, 0.99)	small	0.04
	Jump momentum(kg/m/s)	184.46 ± 24.03	0.99 (0.75, 1.22)	0.99 (0.87, 0.99)	small	4.06
Mid-season	IMTP PF (N)	2427.59 ± 446.39	2.84 (2.18, 3.51)	0.96 (0.93, 0.98)	small	75.45
	IMTP RPF (N)	1386.77 ± 395.58	5.95 (4.56, 7.45)	0.90 (0.82, 0.95)	small	66.87
	DJ CT (s)	0.27 ± 0.05	7.85 (6.01, 9.68)	0.79 (0.60, 0.89)	small	0.01
	DJ FT (s)	0.47 ± 0.05	2.08 (1.60, 2.57)	0.94 (0.89, 0.97)	small	0.01
	DJ RSI	2.01 ± 0.50	8.35 (6.39, 10.31)	0.84 (0.66, 0.92)	small	0.09
	CMJ JH (cm)	27.04 ± 5.80	3.03 (2.32, 3.74)	0.97 (0.95, 0.99)	small	0.98
	Time to take off (s)	0.77 ± 0.11	6.12 (4.69, 7.56)	0.65 (0.43, 0.80)	moderate	0.02
	RSImod	0.38 ± 0.09	6.81 (5.22, 8.41)	0.90 (0.81, 0.95)	small	0.02
	Take off velocity (m/s)	2.29 ± 0.25	1.53 (1.18, 1.90)	0.97 (0.94, 0.98)	small	0.04
	Jump momentum(kg/m/s)	182.73 ± 20.67	1.53 (1.18, 1.90)	0.97 (0.94, 0.98)	small	3.49
Post-season	IMTP PF (N)	2484.35 ± 428.77	2.24 (1.72, 2.77)	0.97 (0.95, 0.99)	small	72.47
	IMTP RPF (N)	1529.03 ± 364.10	4.32 (3.31, 5.33)	0.95 (0.90, 0.97)	small	61.54
	DJ CT (s)	0.27 ± 0.06	6.23 (4.77, 7.69)	0.85 (0.69, 0.92)	small	0.01
	DJ FT (s)	0.48 ± 0.06	1.79 (1.37, 2.21)	0.96 (0.93, 0.98)	small	0.01

DJ RSI	2.02 ± 0.48	6.23 (4.77, 7.69)	0.90 (0.77, 0.96)	small	0.08
CMJ JH (cm)	27.68 ± 6.10	2.77 (2.12, 3.41)	0.97 (0.95, 0.99)	small	1.03
Time to take off (s)	0.74 ± 0.11	6.90 (5.28, 8.52)	0.66 (0.43, 0.81)	small	0.02
RSImod	0.41 ± 0.11	5.46 (4.18, 6.74)	0.94 (0.89, 0.97)	small	0.02
Take off velocity (m/s)	2.32 ± 0.26	1.39 (1.06, 1.71)	0.98 (0.95, 0.99)	small	0.04
Jump momentum(kg/m/s)	187.11 ± 22.95	1.39 (1.06, 1.71)	0.98 (0.96, 0.99)	small	3.88

CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; CMJ = countermovement jump; JH = jump height; RSImod = modified reactive strength index; DJ RSI = drop jump reactive strength index; IMTP = isometric mid-thigh pull; PF = peak force; RPF = relative peak force; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

Table 4.2. Anthropometric characteristics and differences between forwards and backs

	Variable	Forwards	Backs	*g* (95% CI)
Pre-season Forwards: n = 20 Backs: n = 16	Height (cm)	171.05 ± 7	169.16 ± 4.64	0.31 (-0.37, 1.00)
	Body mass (kg)	85.27 ± 13.7	70.58 ± 5	**1.38** (0.62, 2.14)
	Fat%	32.07 ± 9.34	24.75 ± 6.02	**0.92** (0.20, 1.64)
	Fat mass (kg)	28.3 ± 11.69	17.59 ± 5	**1.16** (0.42, 1.90)
	Lean mass (kg)	53.37 ± 5.1	49.87 ± 4.05	**0.76** (0.05, 1.47)
	BMC (kg)	3.6 ± 0.36	3.09 ± 0.33	**1.48** (0.70, 2.25)
Mid-season Forwards: n = 24 Backs: n = 18	Height (cm)	171.75 ± 7.98	168.44 ± 4.67	0.49 (-0.15, 1.13)
	Body mass (kg)	87.66 ± 12.6	70.92 ± 4.4	**1.69** (0.96, 2.43)
	Fat%	32.23 ± 7.97	24.14 ± 6.51	**1.11** (0.43, 1.78)
	Fat mass (kg)	28.98 ± 10.34	17.24 ± 5.28	**1.38** (0.68, 2.09)
	Lean mass (kg)	54.99 ± 5.06	50.55 ± 4.42	**0.93** (0.27, 1.60)
	BMC (kg)	3.67 ± 0.38	3.12 ± 0.34	**1.52** (0.80, 2.24)
Post-season Forwards: n = 23 Backs: n = 16	Height (cm)	171.58 ± 8.12	168.56 ± 4.9	0.44 (-0.23, 1.10)
	Body mass (kg)	87.68 ± 12.99	71.2 ± 4.09	**1.61** (0.85, 2.37)
	Fat%	32 ± 7.63	24.68 ± 7.11	**1.00** (0.30, 1.70)
	Fat mass (kg)	28.8 ± 10.12	17.69 ± 5.79	**1.30** (0.57, 2.03)
	Lean mass (kg)	55.23 ± 5.36	50.39 ± 4.77	**0.95** (0.26, 1.65)
	BMC (kg)	3.63 ± 0.4	3.11 ± 0.03	**1.45** (0.71, 2.91)

BMC = bone mineral content, ES = effect size, CI = confidence interval; **Bold effect size =** p **< 0.05**

Table 4.3. Strength and power characteristics and differences between forwards and backs

	Variable	Forwards	Backs	*g* (95% CI)
Pre-season Forwards: CMJ: n = 19 IMTP: n = 20 DJ: n = 19 Backs: CMJ: n = 16 IMTP: n = 15 DJ: n = 16	CMJ JH (cm)	25.00 ± 4.97	32.26 ± 4.23	**-1.58** (-2.38, -0.78)
	RSImod	0.35 ± 0.07	0.46 ± 0.08	**-1.49** (-2.27, -0.70)
	Time to take off	0.71 ± 0.12	0.69 ± 0.07	0.20 (-0.49, 0.89)
	Take off velocity	2.20 ± 0.22	2.51 ± 0.166	**-1.59** (-2.39, -0.79)
	Jump momentum	188.00 ± 29.5	180.24 ± 15.16	0.33 (-0.37, 1.02)
	IMTP PF (N)	2483.92 ± 505.54	2446.65 ± 397.36	0.08 (-0.61, 0.78)
	IMTP RPF (N)	1489.95 ± 380.5	1526.19 ± 424.16	-0.09 (-0.79, 0.60)
	DJ CT (sec)	0.24 ± 0.04	0.208 ± 0.028	**0.92** (0.20, 1.65)
	DJ FT (sec)	0.42 ± 0.06	0.478 ± 0.041	**-1.12** (-1.87, -0.38)
	DJ RSI	1.82 ± 0.43	2.329 ± 0.38	**-1.26** (-2.02, -0.50)
Mid-season Forwards: CMJ: n = 22 IMTP: n = 23 DJ: n = 22 Backs: CMJ: n = 17 IMTP: n = 16 DJ: n = 17	CMJ JH (cm)	23.55 ± 4.47	31.54 ± 3.93	**-1.90** (-2.69, -1.11)
	RSImod	0.32 ± 0.06	0.426 ± 0.089	**-1.45** (-2.19, -0.71)
	Time to take off	0.73 ± 0.10	0.75 ± 0.11	-0.19 (-0.85, 0.46)
	Take off velocity	2.14 ± 0.2	2.483 ± 0.155	**-1.91** (-2.70, -1.11)
	Jump momentum	187.34 ± 23.57	176.75 ± 14.75	0.53 (-0.14, 1.19)
	IMTP PF (N)	2485.65 ± 499.43	2344.13 ± 355.466	0.32 (-0.34, 0.98)
	IMTP RPF (N)	1399.87 ± 441.92	1347.69 ± 334.485	0.13 (-0.53, 0.79)
	DJ CT (sec)	0.25 ± 0.06	0.23 ± 0.047	0.46 (-0.21, 1.12)
	DJ FT (sec)	0.44 ± 0.05	0.503 ± 0.03	**-1.47** (-2.21, -0.73)
	DJ RSI	1.81 ± 0.45	2.263 ± 0.462	**-1.00** (-1.69, -0.30)
Post-season CMJ: n = 22 IMTP: n = 22 DJ: n = 22 Backs: CMJ: n = 14 IMTP: n = 15 DJ: n = 14	CMJ JH (cm)	25.06 ± 4.73	32 ± 5.2	**-1.43** (-2.21, -0.65)
	RSImod	0.36 ± 0.08	0.462 ± 0.09	**-1.23** (-1.99, -0.47)
	Time to take off	0.69 ± 0.09	0.70 ± 0.07	-0.12 (-0.82, 0.57)
	Take off velocity	2.20 ± 0.20	2.497 ± 0.2	**-1.50** (-2.29, -0.71)
	Jump momentum	193.88 ± 25.24	177.55 ± 13.21	**0.77** (0.05, 1.49)
	IMTP PF (N)	2576.59 ± 488.16	2343.4 ± 279.21	0.56 (-0.13, 1.26)
	IMTP RPF (N)	1549.27 ± 399.42	1477.13 ± 328.41	0.20 (-0.49, 0.88)
	DJ CT (sec)	0.25 ± 0.06	0.216 ± 0.027	**0.78** (0.06, 1.50)
	DJ FT (sec)	0.44 ± 0.05	0.509 ± 0.044	**-1.22** (-1.98, -0.47)
	DJ RSI	1.81 ± 0.42	2.387 ± 0.368	**-1.43** (-2.21, -0.65)

CMJ = countermovement jump; JH = jump height; RSImod = modified reactive strength index. IMTP = isometric mid-thigh pulls; PF = peak force; RPF = relative peak force; DJ = drop jump; CT = contact time. FT = flight time; RSI = reactive strength index; ES= effect size; **Bold effect size =** $\boldsymbol{p}$ **< 0.05**

4.4 DISCUSSION

The aim of this study was to identify anthropometric profiles and strength and power characteristics between playing positions in English women's rugby union players. To the authors' knowledge, this study was the first to show respective positional characteristics of English premiership women's rugby union players at a competitive level in a full squad capacity. When comparing positions, forwards had statistically significantly higher BM, fat%, LM, FM, BMC and JM, and backs had statistically significantly better CMJ JH, RSImod, TOV, DJ FT, DJ CT and RSI scores throughout the 3-testing times in the season.

When comparing positional differences in anthropometric profiles, there were no statistically significant differences in height. Forwards had statistically significantly higher BM, fat%, LM, FM, and BMC throughout the 3 testing timings. Similar results were presented in previous studies showing forwards had a higher sum of skinfolds BM, FM, LM, higher fat % and tend to be an endomorph somatotype (Curtis et al., 2021; Escrivá et al., 2021; Harty et al., 2021; Hene et al., 2011; Kirby & Reilly, 1993; Posthumus et al., 2020b; Quarrie et al., 1995; Wallace & Donovan, 2008; Woodhouse et al., 2021b; Yao et al., 2021). These general findings align to the match demands of forwards typically facing a greater number of collision activities (e.g., tackle, maul, ruck, scrum), where BM (fat and lean mass) could support as a protective buffer (Duthie, Grant et al., 2003). In contrast, one previous study observed positional differences in English premiership women's rugby union players, reporting only a small difference in LM between forwards and backs (Yao et al., 2021). The difference in results might be due to the number of subjects missing the pre-season testing to attend international training camps (Yao et al., 2021), thus decreasing the difference in LM between positions.

When comparing strength and power characteristics between positions, backs demonstrated statistically significantly higher scores in CMJ, and DJ compared to forwards in all three testing timeslots. Specifically, backs produced statistically significantly higher CMJ JH, TOV, RSImod, and DJ FT and RSI and lower DJ CT, compared to forwards. There were no significant differences in TTT between forwards and backs, therefore, the significantly higher RSImod scores in backs was largely driven by higher JH. This should not be seen as surprising given similar results have been previously reported whereby backs demonstrate higher CMJ JH than forwards across all playing levels (Hene et al., 2011; Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021). During the DJ, backs performed shorter DJ CT and higher FT scores which leads to RSI being significantly greater than forwards, with similar results again found in previous English international women's rugby players (Woodhouse et al., 2021b). Despite backs producing significantly higher reactive strength scores (both RSI and RSImod), unlike DJ CT, there were no significant differences in TTT between forwards and backs. The reason for longer DJ CT might be due to forwards having significantly higher FM, which is likely to serve as additional unwanted load, when the desired outcome is minimal time on the ground between landing and take-off (Daugherty et al., 2021). Therefore, during reactive strength jump testing it would be crucial to not only monitor the ratio but also report component variables (FT and CT) of RSI to further identify jump characteristics.

Momentum (mass x velocity) is an important attribute for collision sports. Players with higher sprint momentum should be able to win in collision scenarios in both offence and defense (McMahon et al., 2020). Research has reported JM to be a valuable metric to indirectly inform sprint momentum (McMahon et al., 2020). Forwards in this study created higher JM throughout the season with a statistically significant difference in post-season testing compared to the backs. Despite significantly lower TOV, forwards had significantly higher BM, which would be the confounding factor for increased JM compared to backs. Although greater BM in forwards may be considered an asset to generate higher momentum for positional specific duties, it may also have a negative effect on locomotive performances (jumping and running) (Darrall-Jones et al., 2016). Therefore, it is important for practitioners to understand how the momentum was generated and the balance between BM and TOV. To the authors' knowledge, this is the first study to determine jump momentum variables in women's rugby union. With the contact nature of collision sports, it may be practically useful to monitor JM which does not have the inherent limitations of a metric like JH, which is almost certainly biased towards lighter athletes (McMahon et al., 2020).

There were moderate differences in IMTP PF between forwards and backs in mid-season and post-season, and trivial differences in RPF. Similar results were found using isometric max strength tests (IMTP and isometric squat) in English premier 15 and international women's rugby union players showing forwards created higher PF but not when it was reported relative to body mass (Woodhouse et al., 2021b; Yao et al., 2021). RPF showing trivial to small differences might be due to the significantly higher BM and FM which does not support producing higher PF (Charlton et al., 2015). Furthermore, the dissociation between forwards having significantly higher LM but no statistically significant differences in PF output might be due to the fact that an increase in LM is not linearly correlated to a concomitant increase in force output. It can instead be suggested that changes in PF may be more closely associated with changes in neuromuscular control and output rather than predominant hypertrophy and thus changes in LM. (Reggiani & Schiaffino, 2020). Another reason might be most players were in a semi-professional setting with full time jobs, thus had remote resistance training without supervision, affecting retraining adherence and strength gains compared to being supervised (Coutts et al., 2004).

In summary, this study provided position specific anthropometric, strength and power characteristics in English premiership women's rugby. With similar results showed in three different phases of the season. The lab-based strength and power testing in this study wase able to discriminate between playing positions but not to directly assess physical changes in performance on the pitch. Therefore, further field based locomotive action testing such as sprinting and change of direction might be useful to understand differences between fast and slow athletes to identify physical abilities. In this study, some limitations must also be noted. Due to the nature of rugby as a collision sport, some athletes were injured during the testing period. The addition of these players potentially provides a greater understanding in anthropometry, strength, and power characteristics as a competitive group. Secondly, the total number per positional group was restricted in the club environment, such that forwards and backs could not be separated into more detailed rugby positional groups (i.e., front row, winger) for position analysis. Finally, subjects in this study were recruited from one rugby club and thus some caution is advised when inferring this data to the wider population of English premiership women players. Future studies should focus on anthropometric, strength and power seasonal observation in women's rugby union players and to identify position-specific locomotive characteristics and changes throughout a competitive season. This would allow practitioners to make informed recruitment and training decisions for semi-professional athletes to improve performance.

4.5 CONCLUSION

Backs produced significantly higher power-based outputs, and forwards generated higher jump momentum and absolute isometric peak force. The strength and power characteristics shown in this study could support coaches and junior women's rugby athletes to have an understanding of English premiership physical standards. For sport practitioners, isometric max strength tests and jump tests could be useful monitoring tools to understand strength and power. Furthermore, for ratio metrics such as RSImod, RSI, and JM, component variables should also be monitored to identify the strategy of the movement, which may be a useful monitoring tool.

Chapter 5: Seasonal changes in Anthropometry, Strength, and Power Characteristics in English Premiership Women's Rugby Union

Abstract

Background: To achieve competitive success in women's rugby, being strong and powerful throughout the season is necessary. However, the seasonal nature presents a variety of physical challenges that can cause fluctuations in a player's physical development.

Aim: To identify the changes in anthropometry, strength and power characteristics throughout a season in both forwards and backs in English Premiership Women's Rugby Union

Method: Forty-seven players were recruited from the English premiership women's rugby during the 2020–2021 season. Players were split into forwards and backs and underwent body composition testing via dual-X-ray absorptiometry, and strength and power tests (countermovement jump, drop jump, and isometric mid-thigh pull) in pre- mid- and post-season.

Results: There were statistically significant differences ($p < 0.01$) or moderate to large practical differences ($d > 0.5$) in lean mass, reactive strength index modified, time to take off and drop jump flight time among forwards when comparing three testing time frames. For backs, statistically significant differences ($p < 0.01$) or moderate to large practical differences ($d > 0.5$) were reported in lean mass and drop jump flight time throughout the season.

Conclusion: The seasonal changes in anthropometry, strength and power characteristics shown in this study could support practitioners to have a basic understanding of characteristic changes in English premiership women's competition

5.1 INTRODUCTION

Rugby union is a collision sport which requires players to have high level of physical fitness including strength, power body composition (Hene & Bassett, 2013). The English premiership women's rugby season is 36-40 weeks, with competitions on a weekly basis. The seasonal nature presents a variety of physical challenges that can cause fluctuations in a player's physical development during the season (Hene & Bassett, 2013); these include a decrease in resistance training load to allow for increases in the volume of technical and tactical skill training. In addition, muscle damage and inflammation following a match, potentially causing decrements in muscle performance, may be problematic for developing or maintaining muscular strength and power (Gabbett, Tim J., 2005a; Redman et al., 2021). Hence, the players' ability to acquire and maintain appropriate body composition and physical characteristics, both pre- and in-season, is of paramount importance. Regarding anthropometry, research in the South African rugby union women's international team reported significant increases in body mass from pre- to mid-season in backs, whilst no statistically significant changes were noted in forwards (Hene & Bassett, 2013). Hene & Bassett., (2013) also reported a significant drop in the sum of skinfolds for forwards when comparing pre- to post-season values (Hene & Bassett, 2013). In contrast, a study in English women's premiership rugby union players showed that body mass and bone mineral content despite being statistically significantly higher only had trivial practical increase throughout a competitive season (Curtis et al., 2021), with no meaningful changes in fat mass, lean mass, or bone mineral density were evident (Curtis et al., 2021). Furthermore, a study in university women's rugby players reported no statistically significant differences in body mass when comparing pre- and post-season among both forwards and backs (Neto et al., 2021). Although somewhat speculative, the differing results may be due to the inherent differences in competitive level, schedule, and training volume. Regardless, it is necessary to have a better understanding of anthropometric changes throughout the season to make appropriate training and nutritional adjustments for athletes.

When considering strength and power characteristics, previous women's studies have monitored upper body strength and jump performance throughout the competitive seasons (Hene & Bassett, 2013; Neto et al., 2021). For upper body strength, no statistically significant differences in 1-repetition maximum bench press in the South African team (Hene & Bassett, 2013) or grip strength in university players (Neto et al., 2021) were found across a season. When considering jump performance, studies have reported no statistically significant changes in vertical jump height across a season in either forwards or backs in both international and university level players (Hene & Bassett, 2013; Neto et al., 2021). However, previous research has shown that jump height alone is a relatively crude measure of performance, which may be less sensitive to change than some strategy-based metrics (e.g., time to take-off or reactive strength index modified (Bishop et al., 2021b; Gathercole et al., 2015). In addition, besides university (Neto et al., 2021) and international squads (Hene & Bassett, 2013) no research has focused on the English women's premiership season which might report different results due to the elevated level and the length of competition in this league.

To the authors' knowledge, there have been only three women's rugby union studies looking at changes in anthropometry or strength and power characteristics across a competitive season (Curtis et al., 2021; Hene & Bassett, 2013; Neto et al., 2021). Hene & Bassett (Hene & Bassett, 2013) reported anthropometric profiles using sum of skinfolds, and vertical jump height. Curtis et al. (Curtis et al., 2021) using dual-energy

X-ray absorptiometry (DEXA), compared a whole squad between pre- and post-season without any information regarding positional differences or data during mid-season. In addition, Neto et al. only reported body mass and height as anthropometric variables in the pre- and post-season in university level players (Neto et al., 2021). Therefore, to date, there is a distinct gap in the literature relating to understanding body composition and strength and power characteristic changes throughout a competitive rugby season; this is therefore the primary aim of this study. It was hypothesized that players including both forwards and backs would not exhibit statistically significant changes in anthropometry, strength, and power characteristics throughout the season.

5.2 METHODS

In order to monitor anthropometric profiles and physical characteristics of women's rugby union players across a season, a retrospective longitudinal design was used. Playing position and pre-, mid-, post-season testing time points were the independent variables, and anthropometric, strength, and power characteristics were the dependent variables. The following anthropometric and physical tests were administered: DEXA scan, isometric mid-thigh pull (IMTP), countermovement jump (CMJ), drop jump (DJ).

5.2.1 Subjects

Thirty-three (n = 33) women's rugby union players from a single team volunteered for this study. The 33 players were separated into forwards (n = 19, age: 28.04 ± 5.98yrs, height: 170.82 ± 7.11cm, weight: 85.25 ± 14.08kg) and backs (n = 14, age: 25.77 ± 3.87yrs, height: 169.36 ± 4.94cm, weight: 70.45 ± 3.71kg). Players in this study competed in the English women's premiership, which is the highest level in English women's rugby union in the UK. All players had at least three years of experience in rugby training and strength training in a structured rugby club and took part in 2 rugby team practices and 2 individual gym sessions per week. Tests included in this study were part of the 2020-2021 annual season monitoring test battery, agreed by both the medical, and strength and conditioning staff. The study was approved by the London Sport Institute research ethics subcommittee at Middlesex University. Players were informed of the benefits and risks of the investigation before signing written informed consent to participate in the study.

5.2.2 Procedures

Anthropometric and physical performance measurements were conducted on 3 separate occasions during a 9-month season, with the pre-season testing in September 2020 (1 week before the season starts), mid-season testing in February 2021, and post-season testing in June 2021 (the week after the premiership final which the team participated in and won). During the three separate testing time frames, players with a medical condition or injury were excluded from the physical fitness assessment. All subjects refrained from intensive exercise in the 24-hour period prior to testing. At the beginning of laboratory-based tests, anthropometric measurements were taken for each participant. Following this, subjects underwent a standardized warm-up, consisting of 10 minutes of dynamic stretching followed by 2 practice trials for each of the strength and jump assessments. Subjects were familiar with all tests, which were also conducted during their regular annual performance monitoring and gym training programs.

5.2.2.1 Anthropometry

For the detailed testing procedures used for anthropometry refer to Chapter 3.1. Variables of body mass (BM), lean mass (LM), fat mass (FM), fat percentage (fat%), and bone mineral content (BMC) were recorded.

5.2.2.2 Power characteristics

For the detailed testing procedures used for power assessments refer to Chapter 3.2. CMJ: Jump height (JH), takeoff velocity (TOV), time to take-off (TTT), modified reactive strength index (RSI_{mod}) and jump momentum (JM); DJ: Contact time (CT), and flight time (FT) and reactive strength index (RSI) were recorded.

5.2.2.3 Strength characteristics

For the detailed testing procedures used for strength assessments refer to Chapter 3.3. Peak force (PF), and relative peak force (RPF) was extracted.

5.2.3 Statistical Analysis

Subjects were separated into 2 groups: forwards and backs. All data were presented as mean ± standard deviation. For the detailed procedures used for normality, reliability, differences throughout the 3 time-points in the season and Hedges *g* effect sizes (ES) can be refer to chapter 3.6. The reliability between trials results can be found in Chapter 4 Table 4.1, with all variables having small or moderate average variability.

5.3 RESULTS

5.3.1 Anthropometric Characteristics

The seasonal changes in anthropometry characteristics in forwards and backs are shown in Tables 4.1 and 4.2. There was a statistically significant increase in LM among the forwards from pre- to mid-season (p = 0.001, g = 0.23, 95%CI = 0.09 to 0.37). For backs, there was a statistically significant increase in LM when looking at pre- vs post-season (p = 0.001, g = 0.19, 95%CI = 0.03 to 0.35). There were no other statistically significant changes in any other anthropometric variables among the forwards and backs throughout the season.

5.3.2 Strength and Power characteristics

The seasonal changes of strength and power characteristics in forwards and backs are shown in Tables 4.3 and 4.4 Among forwards, RSImod demonstrated statistically significant differences between mid- and post-season (p = 0.006, g = 0.56, 95%CI = 0.18 to 0.95). Although no other statistically significant differences were reported, TTT was shown to have a medium decrease in forwards from mid- to post-season (g = -0.56, 95%CI = -1.29 to 0.17). DJ FT was shown to have a medium increase from pre- to mid-season (g = 0.56, 95%CI = 0.05 to 1.06) and pre- to post-season (g = 0.63, 95%CI = 0.05 to 1.21). Among backs, DJ FT was shown to have statistically significant differences from pre-to mid-season (p = 0.04, g = 0.83, 95%CI = 0.02 to 1.64) and a medium difference from pre-to post-season (g = 0.76, 95%CI = 0.01 to 1.51).

Table 5.1. Forwards anthropometry characteristics changes across pre-, mid-, and post-season

Variable	**Pre-season**	**Mid-season**	**Post-season**	***g* (95% CI)**		
	***n* = 19**	***n* = 19**	***n* = 19**	**Pre- vs Mid-**	**Pre- vs Post-**	**Mid- vs Post-**
Height (cm)	170.82 ± 7.11	171.36 ± 7.84	171.36 ± 7.84	0.07 (-0.01, 0.14)	0.07 (-0.01, 0.14)	0.00 (0.00, 0.00)
Body mass (kg)	85.25 ± 14.08	85.97 ± 13.44	85.74 ± 13.38	0.05 (-0.03, 0.13)	0.03 (-0.10, 0.17)	0.00 (-0.25, 0.25)
Fat%	31.74 ± 9.47	31.04 ± 8.25	31.14 ± 7.63	-0.08 (-0.22, 0.07)	-0.07 (-0.23, 0.10)	0.01 (-0.25, 0.27)
Fat mass (kg)	28.07 ± 11.96	27.50 ± 10.84	27.48 ± 10.26	-0.05 (-0.17, 0.08)	-0.05 (-0.20, 0.10)	0.01 (-0.27, 0.25)
Lean mass (kg)	53.60 ± 5.14	54.82 ± 5.11	54.63 ± 5.20	**0.23** (0.09, 0.37)	0.19 (0.02, 0.36)	-0.01 (-0.22, 0.20)
BMC (kg)	3.58 ± 0.36	3.64 ± 0.39	3.61 ± 0.39	0.14 (-0.03, 0.31)	0.07 (-0.10, 0.25)	-0.02 (-0.14, 0.09)

BMC = bone mineral content; **Bold effect size = p < 0.05**

Table 5.2. Backs anthropometry characteristics changes across pre-mid and post-season

Variable	**Pre-season**	**Mid-season**	**Post-season**	***g* (95% CI)**		
	***n* = 14**	***n* = 14**	***n* = 14**	**Pre- vs Mid-**	**Pre- vs Post-**	**Mid- vs Post-**
Height (cm)	169.36 ± 4.94	168.68 ± 5.18	168.68 ± 5.18	-0.13 (-0.33, 0.07)	-0.13 (-0.33, 0.07)	0.00 (-0.78, 0.78)
Body mass (kg)	70.45 ± 3.71	70.53 ± 3.50	70.55 ± 3.64	0.02 (-0.30, 0.35)	0.02 (-0.24, 0.29)	0.00 (-0.77, 0.78)
Fat%	24.86 ± 5.92	23.59 ± 5.91	23.67 ± 5.94	-0.20 (-0.46, 0.06)	-0.19 (-0.42, 0.05)	0.01 (-0.76, 079)
Fat mass (kg)	17.56 ± 4.60	16.68 ± 4.53	16.72 ± 4.42	-0.18 (-0.47, 0.10)	-0.18 (-0.44, 0.09)	0.01 (-0.77, 0.79)
Lean mass (kg)	49.79 ± 4.28	50.74 ± 4.66	50.71 ± 4.67	0.20 (0.01, 0.39)	**0.19** (0.03, 0.35)	-0.01 (-0.78, 0.77)
BMC (kg)	3.07 ± 0.31	3.11 ± 0.35	3.10 ± 0.31	0.11 (-0.04, 0.26)	0.09 (-0.02, 0.21)	-0.02 (-0.80, 0.75)

BMC = bone mineral content; **Bold effect size = p < 0.05**

Table 5.3. Forwards strength and power characteristics changes across pre-, mid-, and post-season

Variable	**Pre-season** **CMJ *n* = 15** **IMTP *n* = 17** **DJ *n* = 15**	**Mid-season** **CMJ *n* = 15** **IMTP *n* = 17** **DJ *n* = 15**	**Post-season** **CMJ *n* = 15** **IMTP *n* = 17** **DJ *n* = 15**	***g* (95% CI)** **Pre- vs Mid-**	**Pre- vs Post-**	**Mid- vs Post-**
CMJ JH (cm)	24.84 ± 4.84	24.80 ± 4.58	26.14 ± 4.62	-0.01 (-0.21, 0.19)	0.26 (-0.11, 0.63)	0.28 (-0.01, 0.56)
RSImod	0.35 ± 0.07	0.33 ± 0.07	0.38 ± 0.09	-0.26 (-0.65, 0.13)	0.32 (-0.16, 0.79)	**0.56** (0.18, 0.95)
Time to take off	0.71 ± 0.13	0.74 ± 0.08	0.69 ± 0.09	0.29 (-0.24, 0.81)	-0.16 (-0.80, 0.48)	-0.56 (-1.29, 0.17)
Take off velocity	2.19 ± 0.21	2.19 ± 0.20	2.25 ± 0.19	0.01 (-0.20, 0.22)	0.28 (-0.11, 0.67)	0.28 (-0.02, 0.58)
Jump momentum	188.11 ± 22.86	187.13 ± 24.77	191.14 ± 23.65	-0.04 (-0.24, 0.16)	0.12 (-0.20, 0.45)	0.16 (-0.07, 0.38)
IMTP PF (N)	2437.97 ± 478.95	2434.06 ± 442.59	2495.18 ± 431.80	-0.01 (-0.32, 0.30)	0.12 (-0.21, 0.45)	0.13 (-0.30, 0.56)
IMTP RPF (N)	1457.95 ± 350.70	1387.35 ± 397.21	1495.53 ± 358.07	-0.18 (-0.51, 0.15)	0.10 (-0.32, 0.52)	0.27 (-0.19, 0.74)
DJ CT (sec)	0.23 ± 0.03	0.25 ± 0.05	0.24 ± 0.03	0.26 (-0.14, 0.66)	0.10 (-0.32, 0.52)	-0.19 (-0.74, 0.36)
DJ FT (sec)	0.42 ± 0.06	0.45 ± 0.04	0.46 ± 0.04	0.56 (0.05, 1.06)	0.63 (0.05, 1.21)	0.11 (-0.20, 0.41)
DJ RSI	1.82 ± 0.44	1.89 ± 0.47	1.93 ± 0.38	0.14 (-0.17, 0.45)	0.24 (-0.07, 0.56)	0.08 (-0.25, 0.42)

CMJ = countermovement jump; JH = jump height; RSImod = modified reactive strength index; IMTP = isometric mid-thigh pull; PF = peak force; RPF = relative peak force; DJ = drop jump; CT = contact time; FT = flight time; RSI = reactive strength index; **Bold effect size = $p < 0.05$**

Table 5.4. Backs strength and power characteristics changes across a season

Variable	**Pre-season** **CMJ *n* = 11** **IMTP *n* = 10** **DJ *n* = 11**	**Mid-season** **CMJ *n* = 11** **IMTP *n* = 10** **DJ *n* = 11**	**Post-season** **CMJ *n* = 11** **IMTP *n* = 10** **DJ *n* = 11**	***g* (95% CI)** **Pre- vs Mid-**	**Pre- vs Post-**	**Mid- vs Post-**
CMJ JH (cm)	33.23 ± 4.20	32.57 ± 3.93	33.24 ± 4.75	-0.15 (-0.60, 0.30)	0.00 (-0.41, 0.42)	0.14 (-0.22, 0.50)
RSImod	0.48 ± 0.07	0.45 ± 0.08	0.48 ± 0.09	-0.29 (-0.81, 0.23)	0.05 (-0.48, 0.59)	0.31 (-0.14, 0.76)
Time to take off	0.69 ± 0.05	0.72 ± 0.08	0.69 ± 0.07	0.38 (-0.35, 1.12)	0.00 (-0.72, 0.72)	-0.34 (-0.90, 0.22)
Take off velocity	2.55 ± 0.16	2.52 ± 0.15	2.54 ± 0.18	-0.15 (-0.58, 0.29)	-0.01 (-0.44, 0.42)	0.13 (-0.24, 0.49)
Jump momentum	181.59 ± 13.52	178.35 ± 11.81	178.62 ± 13.87	-0.24 (-0.48, 0.01)	0.20 (-0.53, 0.13)	0.02 (-0.24, 0.28)
IMTP PF (N)	2334.88 ± 400.87	2359.50 ± 410.35	2291.00 ± 267.97	0.06 (-0.27, 0.38)	-0.12 (-0.33, 0.09)	-0.18 (-0.43, 0.06)
IMTP RPF (N)	1411.58 ± 401.54	1419.30 ± 398.42	1436.00 ± 330.77	0.02 (-0.47, 0.51)	0.06 (-0.32, 0.44)	0.04 (-0.32, 0.40)
DJ CT (sec)	0.20 ± 0.02	0.21 ± 0.03	0.21 ± 0.02	0.36 (-0.20, 0.93)	0.30 (-0.55, 1.14)	-0.12 (-0.86, 0.63)
DJ FT (sec)	0.48 ± 0.02	0.51 ± 0.03	0.51 ± 0.04	**0.83** (0.02, 1.64)	0.76 (0.01, 1.51)	0.10 (-0.42, 0.22)
DJ RSI	2.42 ± 0.35	2.42 ± 0.39	2.46 ± 0.36	-0.02 (-0.51, 0.48)	0.08 (-0.70, 0.86)	0.09 (-0.54, 0.73)

CMJ = countermovement jump; JH = jump height; RSImod = modified reactive strength index; IMTP = isometric mid-thigh pulls; PF = peak force; RPF = relative peak force; DJ = drop jump; CT = contact time; FT = flight time; RSI = reactive strength index; **Bold effect size =** $p < 0.05$

5.4 DISCUSSION

The aim of this study was to observe seasonal changes in English premiership women's rugby union players. To the authors' knowledge, this study was the first to show respective positional characteristics and seasonal changes of women's English premiership rugby union players at a competitive level. When observing seasonal changes, the results showed that there were statistically significant differences or moderate to large practical differences in LM (mid- > pre-season), RSImod (post- > mid-season), TTT (post- < mid-season) and DJ FT (mid- and post- > pre-season) among forwards. For backs, statistically significant differences or moderate to large differences were reported in LM (post- > pre-season) and DJ FT (mid- and post- > pre-season) throughout the season (Hene et al., 2011).

When looking at anthropometric changes across a season, forwards gained statistically significantly higher LM from pre- to mid-season, and backs gained statistically significantly higher LM comparing pre- to post- season. However, with trivial to small effect sizes reported (0.23 and 0.19), there were no practically significant differences. Similar results were previously reported in English premiership women's rugby union players (Curtis et al., 2021), whereby no statistically significant differences or significant but trivial ES in BM, FM, LM, and BMC were found when comparing pre- and post-season data. The lack of statistically significant differences found in anthropometric characteristics throughout a season were similar in men's players across different rugby codes (Duthie, G. M. et al., 2006; Gabbett, Tim J., 2005b). This might be due to the competitive phase of the season when gym training loads were reduced compared to pre-season, but whilst match loads, rugby training, and injuries were at their highest (Duthie, G. M. et al., 2006; Gabbett, Tim J., 2005b). FM and fat% were maintained throughout the season among both forwards and backs. However, Hene & Bassett (Hene & Bassett, 2013) reported forwards had statistically significantly lower sum of skinfolds when comparing pre- to post-season, and backs statistically significantly increased BM from pre- to mid-season. The differences might be caused by a drop in participant numbers (forwards from 17 in pre-season to 14 in post season). With no differences in anthropometric characteristics throughout the season, the results may reflect that the players in this study maintained their LM during a 9-month season and did not gain extra FM that might affect performance (Jones et al., 2016).

When assessing seasonal variations in jump performance, there were moderate differences in CMJ RSImod, and TTT in forwards from mid- to post-season. Similar results were shown in backs with small improvements in RSImod and TTT from mid- to post-season. This might be due to the training focus having a greater emphasis on plyometric and power training in the gym (Hene & Bassett, 2013). For DJ performance, forwards had a moderate increase in DJ FT from pre- to mid and pre- to post-season. Similar results were found in backs with statistically significantly improved DJ FT from pre- to mid-season and a moderate increase from pre- to post-season. However, there were no statistically significant differences in DJ RSI. The reason for this might be due to the small increase in backs in DJ CT (g = 0.36 to 0.30), which seems like a strategy that may have been employed, enabling more time to produce force (Flanagan & Comyns, 2008). When looking at the trend of power characteristics among forwards and backs, performance either dropped or was maintained from pre- to mid-season and improved from mid- to post-season. Similar trends were shown in academy footballers using jump tests (CMJ and DJ) to monitor performance throughout the season (Bishop et al., 2020). These results might be due to the fatigue caused by a competitive season and most women's rugby union players were semi-professional, requiring them to train and compete alongside a full-time job, which might also affect recovery and therefore affect CMJ output and altered jump mechanics (Gathercole et al., 2015). Throughout the latter phase of the season, players in this study were more focused on training for the play-offs and the final, resulting in a taper being utilized to help balance the trade-off between enhanced performance and managing fatigue.

For a collision sport, maximizing muscular strength in pre-season and maintaining it throughout the season is critical for match performance (Duthie, G. M. et al., 2006; Gabbett, Tim et al., 2009; Hene & Bassett, 2013). In this study, the IMTP PF and RPF remained constant for backs and forwards throughout the season, which was similar to a men's rugby union study using the isometric squat (Gannon et al., 2016). Similar results were reported in upper body strength using 1RM bench press (Hene & Bassett, 2013) and maximum repetition push-ups (Neto et al., 2021). This maintenance may be due to the training focus during the in season, which was periodized to perform more plyometric work, and to control training volume to prevent fatigue before match days. Furthermore, as mentioned due to the semi-professional setting and having other full-time jobs, most of the players in this study were on a remote strength and conditioning program with no direct supervision. Consequently, this is likely to have resulted in an insufficient training frequency and volume that is required to increase lower-body strength (Coutts et al., 2004). However, this, still adds important information on the ability for strength to be maintained throughout a competitive season, despite being caught up in a global pandemic and the programming being centered around power training.

In summary, this study was the first to provide a seasonal change of anthropometric, strength and power characteristics in English Premiership women's rugby union. No large practical difference was found in anthropometry characteristics across the season in both positions. Both forwards and backs jumped slower from pre-to mid-season and slightly improved from mis-to post-season. It can be assumed that players in this study maintained their physical ability through a nine-month season, with successful tapering in the playoff stage for the important matches. In this study, some limitations must also be noted. Due to some injuries in season and some players were recruited mid-season, both scenarios would have missed testing sessions. With the addition of these players potentially provides a greater understanding of seasonal change in anthropometry, strength, and power characteristics.

5.5 CONCLUSION

This study revealed that even throughout the rugby season, athletes can maintain or have small improvements in anthropometric, strength, and power characteristics. For sport practitioners, isometric max strength tests and jump tests could be useful monitoring tools to understand strength and power changes throughout the season. Furthermore, for ratio metrics such as RSImod, RSI and JM, component variables should also be monitored to identify the training needs. Reporting only the ratio might not see the true change in physical characteristics. JM and its component variable might be a crucial monitoring tool for practitioners due to having both power and body mass is beneficial for women rugby. It is also suspected that players in this study may have greater improvements in anthropometric, strength, and power characteristics throughout a season from supervised gym training program.

Chapter 6: Positional Differences in Sprint Performance and Mechanics in English Premiership Women's Rugby Union

Abstract

Background: Sprinting is an important motor skill in rugby which is carried out frequently over short distances during competition and often affects a successful defense or attacking opportunity. Furthermore, sprint momentum is an important determinant of success in rugby union to achieve dominate collision activities (e.g., carries and tackle). However, previous research has discussed only sprint time without identifying the mechanics of how high velocities are achieved.

Aim: To characterize the acceleration and top speed kinematics of English Premiership Women's Rugby Union players and to compare between positions.

Method: Twenty-nine female rugby players were recruited from the English premiership women's rugby during the 2021–2022 season. Players underwent a standardized warm up, and 2 maximal effort 40 m sprints. Timing gates and a high-speed camera was used to capture split times and slow-motion videos between 0-10 m and 30- 40 m. Sprinting variables were then split into positional (forwards and backs) and different speed groups (fast, moderate and slow) based on sprint time in 0-10 m and 30-40 m for further analysis.

Results: Backs produced statistically significantly ($p < 0.01$, $g > 0.80$) faster 10 m velocity, step rate, contact time, and step velocity. Forwards had statistically significantly higher initial momentum ($p < 0.01$, $g > 0.80$). Fast athletes had shorter

contact time ($p < 0.01$, $g > 1.64$), longer step length ($p < 0.01$, $g > 0.86$) and higher step velocity ($p < 0.01$, $g > 1.99$) in both acceleration and top speed.

Conclusion: Faster female rugby players tend to have shorter contact time to cover further distance in both acceleration and top speed. Forwards and backs although achieving different sprint velocity, had similar kinematics. Therefore, splitting athletes into speed group based on performance, may be more informative for sprint strategy and kinematic differences than based on positions.

6.1 INTRODUCTION

Sprinting is an important motor skill in rugby which is carried out frequently over short distances during competition and often affects a successful defense or attacking opportunity (Wild et al., 2022). Sprint performance is often discussed as consisting of two components: acceleration, and top speed (Gleadhill & Nagahara, 2021). The ability to improve acceleration will provide players with the opportunity to be more successful during their overall gameplay, since in rugby, the typical sprint time is between 1 and 3 seconds (Wild et al., 2018). Top speed is also considered important as rugby players frequently start sprinting with a moving start which supports athletes in achieving top speed in a shorter period of time (Barr et al., 2013). Besides identifying the significance of sprinting speed, research has also shown that due to the importance of body size in collision activities (e.g., carries and tackle), sprint momentum (BM x velocity) may also be an important determinant of success in rugby union (Barr et al., 2014b; Woodhouse et al., 2023).

Recent research in women's rugby union has identified backs achieve higher speeds than forwards in both acceleration and top speed using 40 m sprint tests (Hene et al., 2011; Woodhouse et al., 2021b; Yao et al., 2021). Furthermore, studies have shown despite backs achieving higher sprinting speed, forwards generate more sprint momentum in both acceleration and top speed (Woodhouse et al., 2021b; Yao et al., 2021). However, only sprint times have been utilized in these prior studies, without understanding the sprinting mechanics and kinematic changes throughout the sprint. To the authors knowledge, studies investigating sprinting technique in women are mainly focused on track and field sprinters (Debaere et al., 2013; Gleadhill & Nagahara, 2021; van den Tillaar, 2021). Research has shown greater changes in rate of step length and flight time; both of which were correlated with initial acceleration (during the first five steps) (Gleadhill & Nagahara, 2021). In addition, higher step frequency through shorter contact time was associated with faster running speed in the late acceleration phase (Gleadhill & Nagahara, 2021; van den Tillaar, 2021). The data from female track and field sprinters may be used to support female rugby players to improve sprinting performance, assuming some fundamental differences are acknowledged. For instance, elite sprinters reach top speed typically between 50-60 m, while rugby players achieve their top speed between 30-40 m. Therefore, changes in sprint kinematics might occur at different distances between these populations (Barr et al., 2013). Furthermore, different movement strategies associated with higher body mass might also affect sprinting technique and speed (Barr et al., 2014b; Wild et al., 2018). Finally, different task constraints such as starting position (block vs. standing), surface (track vs. pitch), anticipating changing direction due to the nature of the match demands, and footwear (spikes vs. boots) may also influence techniques adopted in the subsequent steps (Wild et al., 2018). Therefore, it is important to understand the kinematic differences in each sprinting phase among rugby players, including accounting for constraints that are specific to different playing positions.

It is currently still unknown as to how kinematic variables such as velocity, step rate, step length, contact time and flight time change as female rugby players accelerate and reach top speed. Therefore, the aim of this study was to characterize the acceleration and top speed kinematics of female rugby players and to compare the differences between positions, different speed groups and correlation between sprint output measure and kinematics. It was hypothesized that: (1) backs would achieve similar step length using shorter contact time in both acceleration and top speed running compared to forwards and, (2) slower athletes would have a larger foot strike distance than faster athletes.

6.2 METHODS

6.2.1. Subjects

Twenty-nine female rugby players, separated into forwards (*n* = 18; age: 27.22 ± 6.01 years; body mass: 83.23 ± 13.97 kg) and backs (*n* = 11; age: 24.72 ± 7.79 years; body mass: 70.00 ± 5.42 kg) volunteered to participate. Players in this study competed in the English premiership women's rugby, which is the highest level in English women rugby union in the UK. All players had at least three years of experience in rugby training and structured strength training in an elite rugby club and took part in 2 rugby team practices and 2 individual gym sessions per week. Tests included in this study were part of the 2021-2022 annual season monitoring test battery, agreed by both the medical, and strength and conditioning staff. This study was approved by the Research Ethics Sub-Committee of the London Sport Institute, Middlesex University, and both club staff and players were informed of the benefits and risks of the investigation before signing a team approved informed consent to participate in the study.

6.2.2 Procedures

Testing was conducted in pre-season and all participants refrained from intensive exercise in the 24-hour period prior to testing. Participants underwent a standardized warm up, consisting of 15 minutes of dynamic stretching followed by two 40 m sprints. After warming up, each participant accomplished 2 max effort sprints of 40 m with 4 min rest in between. Only 0-10 m and 30-40 m splits were recorded and analyzed as previous studies in rugby have identified 0-10 m as the acceleration phase (Woodhouse et al., 2021b) and 30-40 m as the top speed phase (Barr et al., 2014b). Participants were familiar with the sprint test, as they were conducted during their regular annual performance monitoring and daily training programs. Participants were informed of test procedures one week before the testing date.

6.2.2.1 Anthropometry

For the detailed testing procedures used for anthropometry refer to Chapter 3.1.

6.2.2.2 Linear speed test

For the detailed testing procedures used for sprint assessments refer to Chapter 3.4. The kinematic variables used in this study are presented in Table 6.1.

Table 6.1 Definitions of the Kinematic variables used	
	Definition
Step length (SL)	Measured in meters, and defined as the horizontal distance between the point of touchdown of one foot (furthest point) and the touchdown of the following foot
Step rate (SR)	Measured in Hz, was defined as the reciprocal of step duration (contact time + flight time)
Contact time (CT)	Measured in sec, and defined as the time taken from first point of contact to the last video frame of contact with the ground
Flight time (FT)	Measured in sec, and defined as the time taken from first video frame without ground contact, to last frame before foot strike
Step Velocity (SV)	Measured in meters per sec, and defined as the product of step length and step rate
Foot strike and toe off distance	Measured in meters as the horizontal distance between the toe and the hip during the frame of foot strike and toe off
Contact length (CL)	Measured in meters, and defined as the horizontal distance the hip travelled during contact time
Flight length (FL)	Measured in meters, and defined as the horizontal distance the hip travelled during flight time
Step Length/ Step rate ratio (LR ratio)	Calculated as a measure of each participant's sprinting kinematic strategy
Contact time/ Flight time ratio (CF ratio)	

6.2.3 Statistical Analysis

Subjects were separated into 2 groups for comparing positional differences: forwards and backs. Acceleration speed groups were created by splitting the groups into thirds based on split times of 0-10 m and top speed groups were created based on the split times of 30-40 m split time. All data were presented as mean ± standard deviation. For the detailed procedures used for normality, reliability, compared differences between positional groups and speed and correlation can be refer to chapter 3.6.

Table 6.2. Between-trial reliability for 0-10 m acceleration measures

	Mean ± SD	CV% (95% CI)	ICC (95% CI)	Average variability	SEM
Initial momentum (kg.m/s)	416.48 ± 61.78	1.17 (0.87, 1.47)	0.99 (0.64, 1.00)	small	11.47
Velocity(m/s)	5.34 ± 0.22	1.17 (0.87, 1.47)	0.91 (0.04, 0.98)	small	0.04
Time (s)	1.88 ± 0.08	1.17 (0.87, 1.47)	0.91 (0.05, 0.98)	small	0.02
CT (s)	0.17 ± 0.01	2.97 (2.20, 3.73)	0.82 (-0.02, 0.95)	small	0.00
FT (s)	0.07 ± 0.01	4.47 (3.32, 5.62)	0.85 (-0.04, 0.97)	small	0.00
CF ratio	2.48 ± 0.74	3.69 (2.74, 4.65)	0.98 (0.87, 0.99)	small	0.14
LR ratio	0.31 ± 0.03	5.38 (3.99, 6.76)	0.72 (-0.05, 0.93)	small	0.01
SR (Hz)	4.08 ± 0.18	3.67 (2.72, 4.61)	0.55 (-0.08, 0.85)	moderate	0.03
SL (m)	1.25 ± 0.08	1.71 (1.27, 2.15)	0.91 (0.08, 0.98)	small	0.02
SV (m/s)	5.12 ± 0.29	2.61 (1.93, 3.28)	0.79 (0.15, 0.93)	small	0.05
Foot strike distance (m)	0.28 ± 0.04	7.75 (5.75, 9.73)	0.64 (-0.09, 0.89)	moderate	0.01
Toe-off distance (m)	0.55 ± 0.04	3.81 (2.83, 4.79)	0.73 (-0.06, 0.92)	small	0.01
CL (m)	0.84 ± 0.06	2.75 (2.04, 3.45)	0.81 (-0.04, 0.95)	small	0.01
FL (m)	0.39 ± 0.07	5.63 (4.18, 7.08)	0.89 (0.00, 0.97)	small	0.01
Foot strike thigh angle (◦)	51.10 ± 7.25	3.53 (2.63, 4.44)	0.92 (0.11, 0.98)	small	1.35
Toe-off thigh angle (◦)	91.15 ± 7.40	2.22 (1.65, 2.79)	0.91 (0.00, 0.98)	small	1.37

CT = contact time; FT = flight time; CF ratio = contact and flight ratio; LR ratio = length and rate ratio; SL = step length; SV = step velocity; CL = contact length; FL = flight length; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

Table 6.3. Between-trial reliability for 30-40 m top speed measures

	Mean ± SD	**CV% (95% CI)**	**ICC (95% CI)**	**Average variability**	**SEM**
Top speed Momentum (kg.m/s)	569.117 ± 79.676	1.33 (0.99, 1.67)	0.98 (0.86, 1.00)	small	14.80
Velocity(m/s)	7.319 ± 0.528	1.33 (0.99, 1.67)	0.93 (0.61, 0.98)	small	0.10
Time (s)	1.37 ± 0.10	1.33 (0.99, 1.67)	0.83 (0.68, 0.91)	small	0.02
CT (s)	0.14 ± 0.01	3.10 (2.33, 3.94)	0.87 (0.00, 0.97)	small	0.00
FT (s)	0.11 ± 0.01	4.47 (3.32, 5.62)	0.85 (-0.04, 0.97)	small	0.00
CF ratio	1.19 ± 0.18	2.60 (1.93, 3.26)	0.96 (0.89, 0.98)	small	0.03
LR ratio	0.42 ± 0.05	5.22 (3.88, 6.56)	0.84 (-0.04, 0.96)	small	0.01
SR (Hz)	3.78 ± 0.25	3.84 (2.85, 4.83)	0.73 (-0.04, 0.93)	small	0.05
SL (m)	1.68 ± 0.13	1.38 (1.03, 1.74)	0.93 (0.60, 0.98)	Small	0.02
SV (m/s)	6.70 ± 0.50	3.17 (2.36, 3.99)	0.81 (0.45, 0.93)	Small	0.09
Foot strike distance (m)	0.43 ± 0.02	3.01 (2.24, 3.79)	0.73 (-0.06, 0.93)	Small	0.00
Toe-off distance (m)	0.49 ± 0.04	2.79 (2.07, 3.50)	0.84 (-0.04, 0.96)	Small	0.01
CL (m)	0.93 ± 0.05	2.65 (1.97, 3.33)	0.71 (-0.01, 0.90)	Small	0.01
FL (m)	0.75 ± 0.11	2.55 (1.89, 3.21)	0.94 (0.65, 0.98)	Small	0.02
Foot strike thigh angle (◦)	46.24 ± 10.65	4.51 (3.35, 5.67)	0.96 (0.09, 0.99)	Small	1.98
Toe-off thigh angle (◦)	89.15 ± 4.66	2.27 (1.68, 2.85)	0.83 (-0.04, 0.96)	Small	0.87

CT = contact time; FT = flight time; CF ratio = contact and flight ratio; LR ratio = length and rate ratio; SL = step length; SV = step velocity; CL = contact length; FL = flight length; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

6.3 RESULTS

All variables in this study were normally distributed (table 6.2 and 6.3) when athletes were grouped into forwards and backs and different speed groups (fast, moderate, slow).

6.3.1 Positional differences

The positional differences in acceleration between forwards and backs are shown in Table 5.4. Effect sizes are also provided to report the magnitude of effects and thus provide applied practitioners with some measure of "practical significance" (Turner et al., 2021). Backs produced statistically significantly faster 10 m velocity (p = 0.01, g = -0.85, 95% CI = -1.61 to -0.08), SR, (p = 0.049, g = -0.77, 95% CI = -1.52 to 0.00), CT (p = 0.01, g = 0.86, 95% CI = 0.08 to 1.61) and SV (p = 0.01, g = -0.88, 95% CI = -1.64 to -0.11). Forwards were shown to have statistically significantly higher BM (p = 0.001, g = 1.11, 95% CI = 0.31 to 1.89) and initial momentum (p = 0.01, g = 0.95, 95% CI = 0.17 to 1.71).

The positional differences in top speed kinematics between forwards and backs are shown in Table 6.5. During top speed, backs are shown to have statistically significantly greater velocity (p = 0.01, g = -1.02, 95% CI = -1.79 to -0.24). There were no statistically significant differences in other top speed kinematic variables between forwards and backs.

6.3.2. Speed Group Differences

The 0-10 m acceleration kinematics of different speed groups are shown in Table 6.6. Participants were separated into fast, moderate, and slow groups based on 0-10 m split time. The fast group had statistically significantly lower BM (p = 0.023, g = -1.30, 95%CI = -2.27 to -0.29), shorter CT (p = 0.002, g = -1.58, 95%CI = -2.60 to -0.52), lower CF ratio (p = 0.049, g = -0.94, 95%CI = -1.84 to -0.02) and longer SL (p = 0.039, g = 1.12, 95%CI = 0.14 to 2.07) than the slow group. The fast group was also shown to have statistically significantly faster velocity, and SV (p < 0.004, g = 2.24 to 3.73) compared to the other two groups. The moderate group also demonstrated statistically significantly faster velocity, split time and SV compared to the slow group (p < 0.009, g = 1.37 to 2.57).

When splitting different speed groups based on 30-40 m split time (Table 6.7), both fast and moderate groups had statistically significantly lower BM than the slow (p < 0.01, g = -0.15 to -0.19, 95%CI= -0.79 to -0.29) group. Fast group had statistically significantly faster velocity, split time, and SV (p < 0.018, g = 1.99 to 4.23) compared to the other two groups. Furthermore, fast group were shown to have statistically significantly shorter CT compared to the slow group (p = 0.001, g = 1.64, 95%CI= -2.64 to -0.60).

5.3.3. Correlation

When looking at correlation in acceleration measures (Table 6.8), BM had significant correlation with initial momentum (r = 0.97), 10m velocity (r = -0.49), CT (r = 0.50), FT (r = -0.53), CF ratio (r = 0.57), SL (r = -0.41), SV (r = -0.47), foot strike distance (r = 0.47), FL (r = -0.56) and toe- off thigh angle (r = -0.53). 10m velocity had significant correlation with CT (r = -0.63), CF ratio (r = -0.46), SL (r = 0.58), SV (r = 0.94), FL (r = 0.57) and toe-off thigh angle (r = 0.50). For top speed measures (Table 5.9), 30-40m split velocity had significant relationship with CT (r = -0.69), CF ratio (r = -0.47), SR (r = 0.45), SL (r = 0.49), SV (r = 0.88) and FL (r = 0.51). BM demonstrated significant relationship with top speed momentum (r = 0.90), velocity (r = -0.50), CT (r = 0.45), CF ratio (r = 0.50) and toe-off thigh angle (r = -0.41).

Table 6.4. 0-10 m acceleration kinematics and differences between forwards and backs

Variable	**Forwards (n = 18)**	**Backs (n = 11)**	***g* (95% CI)**
BM (kg)	83.23 ± 13.97	70.00 ± 5.42	**1.11** (0.31, 1.89)
Initial Momentum (kg.m/s)	437.44 ± 66.23	382.18 ± 33.85	**0.95** (0.17, 1.71)
Velocity(m/s)	5.27 ± 0.24	5.46 ± 0.15	**-0.85** (-1.61, -0.08)
Time (s)	1.9 ± 0.09	1.83 ± 0.05	**0.84** (0.07, 1.59)
CT (s)	0.18 ± 0.02	0.17 ± 0.01	**0.86** (0.08, 1.61)
FT (s)	0.07 ± 0.01	0.08 ± 0.01	0.19 (-0.54, 0.91)
CF ratio	2.60 ± 0.91	2.24 ± 0.22	0.47 (-0.27, 1.21)
LR ratio	0.31 ± 0.03	0.30 ± 0.02	0.21 (-0.52, 0.94)
SR (Hz)	4.03 ± 0.19	4.16 ± 0.15	**-0.77** (-1.52, 0.00)
SL (m)	1.24 ± 0.09	1.26 ± 0.05	-0.21 (-0.94, 0.52)
SV (m/s)	5.02 ± 0.30	5.26 ± 0.18	**-0.88** (-1.64, -0.11)
Foot strike distance (m)	0.29 ± 0.04	0.27 ± 0.03	0.62 (-0.13, 1.36)
Toe-off distance (m)	0.55 ± 0.05	0.56 ± 0.03	-0.12 (-084, 0.62)
CL (m)	0.84 ± 0.07	0.82 ± 0.04	0.31 (-0.42, 1.04)
FL (m)	0.38 ± 0.08	0.41 ± 0.03	-0.45 (-1.18, 0.30)
Foot strike thigh angle (◦)	51.36 ± 7.89	50.69 ± 6.41	0.09 (-0.82, 0.64)
Toe-off thigh angle (◦)	91.09 ± 7.75	91.26 ± 7.16	-0.02 (-0.75, 0.70)

CT = contact time; FT = flight time; CF ratio = contact and flight ratio; LR ratio = length and rate ratio; SL = step length; SV = step velocity; CL = contact length; FL = flight length. ES = effect size; **bold ES = *p* < 0.05**

Table 6.5. 30-40m top speed kinematics and differences between forwards and backs

Variable	**Forwards (n = 18)**	**Backs (n = 11)**	***g* (95% CI)**
BM (kg)	83.23 ± 13.97	70.00 ± 5.42	**1.11** (0.31, 1.89)
Top speed momentum (kg.m/s)	590.05 ± 86.48	534.87 ± 54.61	0.70 (-0.06, 1.45)
Velocity(m/s)	7.13 ± 0.55	7.63 ± 0.31	**-1.02** (-1.79, -0.24)
Time (s)	1.41 ± 0.11	1.31 ± 0.05	**1.02** (0.24, 1.79)
CT (s)	0.14 ± 0.01	0.13 ± 0.01	0.51 (-0.24, 1.24)
FT (s)	0.11 ± 0.01	0.11 ± 0.01	-0.01 (-0.74, 0.72)
CF ratio	1.25 ± 0.23	1.18 ± 0.11	0.33 (-0.41, 1.06)
LR ratio	0.42 ± 0.05	0.42 ± 0.06	0.08 (-0.65, 0.81)
SR (Hz)	3.95 ± 0.27	4.05 ± 0.26	-0.37 (-1.11, 0.3)
SL (m)	1.67 ± 0.13	1.69 ± 0.12	-0.18 (-0.91, 0.55)
SV (m/s)	6.54 ± 0.64	6.84 ± 0.32	-0.55 (-1.29, 0.20)
Foot strike distance (m)	0.43 ± 0.03	0.43 ± 0.02	0.00 (-0.73, 0.73)
Toe-off distance (m)	0.49 ± 0.04	0.50 ± 0.02	-0.17 (-0.50, 0.56)
CL (m)	0.93 ± 0.06	0.92 ± 0.04	0.03(-0.70, 0.76)
FL (m)	0.74 ± 0.13	0.76 ± 0.08	-0.18 (-0.91, 0.55)
Foot strike thigh angle (◦)	45.39 ± 10.59	47.63 ± 11.12	-0.20 (-0.93, 0.53)
Toe-off thigh angle (◦)	89.04 ± 5.15	89.31 ± 3.95	-0.06 (-0.78, 0.67)

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; ES = effect size; **Bold effect size = $p < 0.05$**

Table 6.6. 0-10m acceleration kinematics and differences between speed groups

Variable	Fast N = 10	Moderate N = 11	Slow N = 8	*g* (95% CI) Fast vs moderate	 Fast vs slow	 Moderate vs Slow
BM (kg)	69.93 ± 3.71	80.04 ± 11.62	86.06 ± 17.39	-1.10 (-1.98, -0.20)	**-1.30** (-2.27, -0.29)	-0.40 (-1.28, 0.48)
Initial momentum (kg.m/s)	388.22 ± 19.80	429.04 ± 62.41	434.47 ± 86.26	-0.83 (-1.58, 0.04)	-0.75 (-1.66, 0.19)	-0.07 (-0.94, 0.80)
Velocity (m/s)	5.55 ± 0.09	5.36 ± 0.06	5.05 ± 0.16	**2.42** (1.28, 3.52)	**3.73** (2.15, 5.27)	**2.57** (1.33, 3.78)
Time (s)	1.80 ± 0.03	1.87 ± 0.02	1.98 ± 0.07	**-2.44** (-3.55, -1.30)	**-3.49** (-4.95, -1.98)	**-2.43** (-1.22, -0.36)
CT (s)	0.16 ± 0.01	0.17 ± 0.01	0.18 ± 0.02	-0.99 (-1.86, -0.10)	**-1.58** (-2.60, -0.52)	-0.95 (-1.86, -0.01)
FT (s)	0.08 ± 0.01	0.07 ± 0.01	0.07 ± 0.02	0.22 (-0.61, 1.04)	0.63 (-0.29, 1.54)	0.54 (-0.36, 1.42)
CF ratio	2.18 ± 0.30	2.32 ± 0.28	3.01 ± 1.23	-0.47 (-1.30, 0.37)	**-0.94** (-1.84, -0.02)	-0.81 (-1.71, 0.11)
LR ratio	0.31 ± 0.02	0.31 ± 0.03	0.30 ± 0.04	0.22 (-0.61, 1.04)	0.23 (-0.66, 1.12)	0.06 (-0.81, 0.93)
SR (Hz)	4.16 ± 0.12	4.07 ± 0.16	3.99 ± 0.24	0.62 (-0.23, 1.46)	0.90 (-0.05, 1.82)	0.38 (-0.51, 1.25)
SL (m)	1.30 ± 0.06	1.24 ± 0.06	1.20 ± 0.10	0.86 (-0.02, 1.71)	**1.12** (0.14, 2.07)	0.45 (-0.44, 1.33)
SV (m/s)	5.40 ± 0.14	5.06 ± 0.15	4.81 ± 0.21	**2.24** (1.14, 3.31)	**3.22** (1.78, 4.61)	**1.37** (0.37, 2.34)
Foot strike distance (m)	0.26 ± 0.02	0.29 ± 0.05	0.31 ± 0.04	-0.67 (-1.51, 0.19)	-1.44 (-2.43, -0.41)	-0.43 (-1.30, 0.46)
Toe-off distance (m)	0.58 ± 0.03	0.54 ± 0.04	0.54 ± 0.05	0.97 (0.08, 1.83)	0.86 (-0.09, 1.78)	-0.08 (-0.79, 0.95)
CL (m)	0.84 ± 0.03	0.83 ± 0.05	0.84 ± 0.09	0.24 (-0.59, 1.06)	0.00 (-0.88, 0.89)	-0.13 (-1.00, 0.74)
FL (m)	0.43 ± 0.06	0.39 ± 0.04	0.34 ± 0.09	0.70 (-0.16, 1.54)	1.21 (0.21, 2.17)	0.81 (-0.12, 1.71)
Foot strike thigh angle (◦)	52.11 ± 6.60	48.10 ± 5.51	53.96 ± 9.28	0.64 (-0.22, 1.48)	-0.24 (0.67, 1.11)	-0.77 (-1.66, 0.15)
Toe-off thigh angle (◦)	94.46 ± 7.93	91.55 ± 5.09	86.48 ± 7.77	0.42 (-0.41, 1.25)	1.00 (0.01, 1.90)	0.76 (-0.15, 1.66)

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; **Bold effect size = $p < 0.05$**

Table 6.7. 30-40m top speed kinematics and differences between speed groups

Variable	**Fast** N = 10	**Moderate** N = 11	**Slow** N = 8	***g* (95% CI)** Fast vs moderate	Fast vs slow	Moderate vs Slow
BM (kg)	71.59 ± 3.48	72.94 ± 9.26	91.43 ± 14.30	-0.19 (-1.02, 0.66)	**-0.19** (-0.79, -0.29)	**-0.15** (-0.48, -0.25)
Top speed Momentum (kg/m/s)	563.52 ± 27.19	534.03 ± 68.08	614.33 ± 110.88	0.55 (-0.32, 1.40)	-0.62 (-0.15, 0.28)	-0.85 (-1.74, 0.07)
Velocity(m/s)	7.87 ± 0.17	7.32 ± 0.12	6.70 ± 0.34	**3.60** (2.15, 5.02)	**4.23** (2.56, 5.87)	**2.37** (1.18, 3.52)
Time (s)	1.27 ± 0.03	1.37 ± 0.02	1.50 ± 0.08	**-3.68** (-5.13, -2.21)	**-3.79** (-5.30, -2.24)	**-2.22** (-3.34, -1.07)
CT (s)	0.13 ± 0.01	0.14 ± 0.01	0.15 ± 0.01	-0.63 (-1.48, 0.24)	**-1.64** (-2.64, -0.60)	-1.13 (-2.06, 0.18)
FT (s)	0.11 ± 0.01	0.12 ± 0.02	0.11 ± 0.01	-0.39 (-1.23, 0.47)	0.40 (-0.48, 1.26)	0.55 (-0.34, 1.42)
CF ratio	1.15 ± 0.11	1.16 ± 0.16	1.37 ± 0.24	-0.07 (-0.91, 0.77)	-1.12 (-2.05, -1.70)	-0.98 (-1.89, -0.05)
LR ratio	0.42 ± 0.03	0.43 ± 0.08	0.42 ± 0.03	-0.17 (-1.01, 0.68)	0.15 (-0.71, 1.01)	0.23 (-0.63, 1.09)
SR (Hz)	4.12 ± 0.12	3.96 ± 0.40	3.88 ± 0.15	0.53 (-0.33, 1.38)	1.70 (0.65, 2.71)	0.25 (-0.62, 1.11)
SL (m)	1.73 ± 0.08	1.68 ± 0.16	1.61 ± 0.12	0.39 (-0.46, 1.24)	1.19 (0.22, 2.12)	0.48 (-0.40, 1.35)
SV (m/s)	7.14 ± 0.24	6.61 ± 0.18	6.16 ± 0.64	**2.37** (1.21, 3.49)	**1.99** (0.88, 3.05)	0.99 (0.02, 1.85)
Foot strike distance (m)	0.43 ± 0.02	0.42 ± 0.02	0.44 ± 0.03	0.34 (-0.51, 1.19)	-0.17 (-1.03, 0.70)	-0.51 (-1.38, 0.37)
Toe-off distance (m)	0.50 ± 0.02	0.48 ± 0.03	0.49 ± 0.05	0.77 (-0.12, 1.64)	0.37 (-0.50, 1.23)	-0.13 (-0.99, 0.73)
CL (m)	0.94 ± 0.05	0.91 ± 0.04	0.93 ± 0.07	0.61 (-0.26, 1.46)	0.18 (-0.69, 1.04)	-0.31 (-1.17, 0.56)
FL (m)	0.79 ± 0.05	0.77 ± 0.13	0.67 ± 0.10	0.16 (-0.68, 1.00)	1.34 (0.36, 2.30)	0.79 (-0.12, 1.68)
Foot strike thigh angle (◦)	49.41 ± 11.83	41.45 ± 8.74	48.04 ± 10.43	0.73 (-0.15, 1.60)	0.12 (-0.75, 0.98)	-0.66 (-1.54, 0.24)
Toe-off thigh angle (◦)	90.20 ± 3.49	89.55 ± 4.94	87.52 ± 5.48	0.15 (-0.70, 0.99)	0.57 (-0.32, 1.44)	0.37 (-0.56, 1.24)

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; **Bold effect size =** $p < 0.05$

Table 6.8. Pearson's Correlation between acceleration velocity and kinematics

	BM	Initial momentum	velocity	CT	FT	CF ratio	LR ratio	SR	SL	SV	Foot strike distance	Toe-off distance	CL	FL	Foot strike thigh angle	Toe-off thigh angle
BM	1	**0.97**	**-0.49**	**0.50**	**-0.53**	**0.57**	-0.26	-0.01	**-0.41**	**-0.47**	**0.47**	-0.24	0.15	**-0.56**	0.17	**-0.53**
momentum		1	-0.26	**0.37**	**-0.48**	**0.49**	-0.22	0.08	-0.29	-0.26	**0.45**	-0.17	0.18	**-0.45**	0.17	**-0.44**
velocity			1	**-0.63**	0.35	**-0.46**	0.20	0.36	**0.58**	**0.94**	-0.32	0.36	0.07	**0.57**	-0.03	**0.50**
CT				1	**-0.60**	**0.77**	0.19	**-0.52**	-0.12	**-0.56**	**0.69**	0.31	**0.68**	**-0.68**	**0.56**	-0.32
FT					1	**-0.92**	**0.57**	**-0.38**	**0.60**	**0.40**	-0.27	-0.17	-0.30	**0.93**	**-0.49**	**0.67**
CF ratio						1	-0.31	0.08	**-0.42**	**-0.44**	**0.45**	0.23	**0.46**	**-0.86**	**0.53**	**-0.59**
LR ratio							1	**-0.82**	**0.90**	0.37	0.33	**0.44**	**0.56**	**0.56**	0.18	**0.61**
SR								1	**-0.49**	0.23	**-0.51**	-0.18	**-0.47**	-0.20	-0.11	-0.33
SL									1	**0.73**	0.10	**0.53**	**0.49**	**0.71**	0.15	**0.68**
SV										1	-0.29	**0.45**	0.18	**0.64**	0.06	**0.51**
Foot strike D											1	0.02	**0.61**	**-0.37**	**0.38**	0.00
Toe-off D												1	**0.76**	-0.03	**0.51**	0.16
CL													1	-0.24	**0.64**	0.09
FL														1	**-0.37**	**0.71**
Foot strike thigh angle															1	0.02
Toe-off thigh angle																1

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; D = distance; **Bold correlation = *p* < 0.05**

Table 6.9. Pearson's Correlation between top speed velocity and kinematics

	BM	**Top speed momentum**	**velocity**	**CT**	**FT**	**CF ratio**	**LR ratio**	**SR**	**SL**	**SV**	**Foot strike distance**	**Toe-off distance**	**CL**	**FL**	**Foot strike thigh angle**	**Toe-off thigh angle**
BM	1	**0.90**	**-0.50**	**0.45**	-0.29	**0.50**	-0.07	-0.13	-0.18	-0.20	0.35	0.09	0.27	-0.36	-0.00	**-0.41**
momentum		1	-0.07	0.16	-0.29	0.33	-0.04	0.08	0.05	0.22	**0.38**	0.24	**0.40**	-0.14	-0.04	**-0.45**
velocity			1	**-0.69**	0.07	**-0.47**	0.06	**0.45**	**0.49**	0.88	-0.03	0.27	0.17	**0.51**	-0.02	0.06
CT				1	-0.11	**0.70**	0.28	**-0.63**	-0.09	**-0.60**	**0.58**	**0.37**	**0.50**	**-0.38**	0.34	-0.05
FT					1	**-0.77**	**0.83**	**-0.69**	**0.69**	-0.03	-0.26	0.03	-0.02	**0.84**	**-0.40**	0.30
CF ratio						1	**-0.40**	0.10	**-0.54**	-0.34	**0.53**	0.25	0.34	**-0.83**	**0.49**	-0.22
LR ratio							1	**-0.84**	**0.87**	0.06	0.23	**0.51**	**0.51**	**0.77**	-0.13	0.16
SR								1	**-0.47**	**0.46**	-0.23	-0.29	-0.35	**-0.38**	0.05	-0.17
SL									1	**0.52**	0.24	**0.60**	**0.57**	**0.90**	-0.12	0.06
SV										1	0.14	**0.38**	0.33	**0.45**	-0.00	-0.16
Foot strike D											1	**0.56**	**0.80**	-0.15	**0.42**	**-0.41**
Toe-off D												1	**0.88**	0.24	**0.39**	0.10
CL													1	0.17	**0.39**	-0.13
FL														1	-0.34	0.17
Foot strike thigh angle															1	0.16
Toe-off thigh angle																1

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; D = distance; **Bold correlation =** $\boldsymbol{p < 0.05}$

6.4 DISCUSSION

6.4.1 Positional Differences

6.4.1.1 Acceleration

The purpose of this study was to investigate the difference in sprint performance between forwards and backs of women's rugby and to understand which sprint kinematics differentiate faster players. Findings demonstrate that during acceleration, backs performed significantly faster 0-10 m velocity. Forwards, despite the slower 0-10 m velocity, had significantly higher momentum due to their substantially greater BM. This might be due to match demands, whereby forwards engage in more collisions (e.g., scrum and maul) and sprint shorter distance compared to backs. Therefore, players need a body mass that while not optimal for sprint velocity, is better adapted for initial momentum (Barr et al., 2014b). Similar results were found in both English women internationals and English premiership women rugby players (Woodhouse et al., 2021b; Yao et al., 2021). However, studies have shown that substantially increasing BM is likely to negatively impact sprint performance (Zabaloy et al., 2022). Therefore, it should be noted that to improve sprint momentum, there should be a balance between increasing speed and BM, as both are important for rugby match demands. A recent study in female international rugby players also found that forwards with higher initial momentum had significantly higher collision dominance and carries per minute during competition (Woodhouse et al., 2023).

When looking at acceleration kinematics, backs demonstrated significantly higher SR and SV with significantly shorter CT. Furthermore, results showed there was a moderate practical difference (g = 0.62, 95% CI = -0.013 to 1.36), whereby backs had shorter foot strike distance. Similar results were found in English premiership men's rugby, whereby backs performed faster initial acceleration in the first 3 steps with higher SR, SV with shorter CT and foot strike distance (Wild et al., 2018). However, in men's rugby, backs were also likely to have longer SL, FL, and toe-off distance compared to forwards during acceleration (Wild et al., 2018). The reason men's rugby backs can produce longer SL and FL might be due to having better ability to produce horizontal force with wider hip extension (larger toe-off distance) compared to forwards (Van Oeveren et al., 2021). In contrast, backs in this study were faster than forwards, seemingly by creating significantly faster SR, but no significant differences in SL and toe-off distance.

6.4.1.2 Top speed

In terms of top speed running, backs demonstrated significantly shorter 30-40 m split times with moderately lower top speed momentum (g = 0.70, 95% CI = -0.06 to 1.45). Similar sprinting performance outcomes were present in female international players (Hene et al., 2011; Woodhouse et al., 2021b). When discussing top speed kinematics, despite forwards having moderately longer CT (g = 0.51, 95% CI = -0.24 to 1.23) and slower SV (g = -0.55, 95% CI = -1.29 to 0.20), other variables are shown to have small to trivial differences between forwards and backs. The similarity in top speed kinematics between positions might be due to some forwards being faster than backs. In addition, the fact that backs were significantly faster at top speed might be due to them being significantly lighter in BM; thus, able to achieve shorter CT during sprinting.

6.4.2 Speed Group Differences

6.4.2.1 Acceleration

When the participants were split into thirds (fast, moderate, and slow groups) based on the 0-10 m acceleration speed, the results showed there were significant differences in split time and velocity between the groups. When comparing BM, the fast group was significantly lighter than the slow group and lighter than the moderate group with a large practical difference (g = -1.10, 95% CI = -1.98 to -0.20). For initial momentum, results showed the fast group produced lower momentum than both the slow group (g = -0.75, 95% CI = -1.66 to 0.19) and the moderate group (g = -0.83, 95% CI = -1.58 to 0.04). Only small to trivial differences were found between the moderate and slow groups in both BM and initial momentum. The results of BM and initial momentum in the current study were similar to men's rugby, which demonstrated that despite statistically significantly faster sprint times initial momentum will still favor the athletes with higher body mass (Barr et al., 2014b).

For acceleration kinematics, the fast group demonstrated smaller foot strike distances (g = -1.44, 95% CI = -2.43 to -0.41) to cover similar CL using statistically significantly shorter CT and created a longer toe-off distance (g = 0.86, 95% CI = -0.09 to 0.78) with wider toe-off thigh angle (g = -1.00, 95% CI = 0.01 to 1.90) compared to the slow group. Furthermore, the fast group produced a moderately longer FT (g = 0.63, 95% CI = -0.29 to 1.54) covering largely longer FL (g = 1.21, 95% CI = 0.21 to 2.17) to achieve a significantly longer SL than the slow group; therefore, the fast group was shown to have significantly faster SV. Similar trends were found when comparing between the moderate group and slow group, with only small practical differences in SL noted. Similar results were shown when comparing different level women sprinters, with faster sprinters covering similar SL using shorter CT and faster frequency (Economou et al., 2021). Wild et al., (2018) compared acceleration kinematics between male sprinters, forwards, and backs over the first 3 steps and found sprinters created largely faster SV using shorter CT, longer FT, shorter touchdown distance, and longer toe-off distances than forwards, supporting the findings from the present study. In contrast, a study in men's rugby showed only CT had moderate difference during 10 m acceleration with only small difference in all the other kinematics (Barr et al., 2014a). This might be due to the study in men's rugby using a median split technique, which might cause the fast and slow group to have greater similarities in kinematics despite reporting statistically significantly faster velocity; with three groups, there is at least a greater likelihood of making a clear divide between performance qualities, such that there is limited cross-over between groups consequent to arbitrary cut-offs.

CF ratio and LR ratio has been reported to categorize sprinting strategy (Van Oeveren et al., 2021; Wild et al., 2022). Both the fast (g = -0.94, 95%CI = -1.84 to -0.02) and the moderate group (g = -0.81, 95%CI = -1.71 to -0.11) showed largely lower CF ratio compared to the slow group. In running style terms, the fast and moderate group were more "bounce" runners, meaning they use less CT in the stance phase. Conversely, the slow group is identified as a "stick" runner that may spend too long in the CT phase during running (Van Oeveren et al., 2021; Wild et al., 2022). When discussing LR ratio, all three groups had similar results, but based on comparing SL and SR individually, the slow group had statistically significantly lower SL and largely slower SR (g =0.90, 95%CI = -0.05 to -1.82). Therefore, when using the LR ratio to understand an athlete's strategy, the variables of the ratio should also be recognized. These metrics may be used to identify if an athlete is reliant on step length or step rate.

This individual reliance should be considered in the context of an athlete's training to achieve a better sprinting performance (Wild et al., 2022).

6.4.2.1 Top speed

When discussing top speed performance between different groups based on 30-40 m velocity, the fast group demonstrated significantly faster velocity than the other two groups. Different from the acceleration phase, the fast group created moderately (g = 0.55, 95% CI = -0.32 to -1.40) higher top speed momentum than the moderate group, which were likely not higher due to trivial differences in BM. The fast group performed statistically significantly shorter CT and higher SV compared to the slow group. Furthermore, largely longer SL (g =1.19, 95% CI = 0.22 to 2.12), FL (g =1.34, 95% CI = 0.36 to 2.30), higher SR (g =1.70, 95% CI = 0.65 to 2.71), and moderately bigger toe-off angle (g =0.57, 95% CI = -0.32 to 1.44) was presented with small practical differences in FT between fast and slow groups. Similar top speed kinematics were presented in men's rugby when comparing the fast and slow groups, which demonstrated that faster athletes reach a higher top speed with more efficient CT to create longer horizontal distance (Barr et al., 2014a). When discussing foot strike thigh angles, the moderate group demonstrated the lowest angle with a moderate difference compared to the other two groups, and trivial differences were found between the fast and slow groups. This might be due to the angle variable itself being unable to predict top speed, and instead used only to identify a running strategy (Clark et al., 2023; Haugen et al., 2018; Van Oeveren et al., 2021).

6.4.3 Correlation

6.4.3.1 Acceleration

When looking at correlation between acceleration output measures and kinematics, results have shown BM although had a positive relationship with initial momentum (r = 0.97), there is also positive relationship with CT (r = 0.50), CF ratio (r = 0.57) and foot strike distance (r = 0.47). Furthermore, BM had negative relationship with velocity (r = -0.49), FT (r = -0.53), SL (r = -0.41), SV (r = -0.47) and toe-off thigh angle (r = -0.53). For acceleration velocity, there was positive relationship with SL (r = 0.58), SV (r = 0.94), FL (r = 0.57) and toe off thigh angle (r = 0.50) and negative relationship with CT (r = -0.63) and CF ratio (r = -0.46). The relationship between BM, velocity and acceleration kinematics supported previous results when comparing forwards and backs and between speed groups demonstrating lighter athletes were faster in acceleration by spending less CT, and generated longer FL and SL, whereas slow athletes were heavier generating longer CT, shorter SL, FL. The results also supported that substantially increasing BM is may negatively impact sprint performance (Zabaloy et al., 2022). Therefore, the relationship of BM, acceleration outcome and kinematics should take into concern when players try to increase body mass for initial momentum (Barr et al., 2014b; Woodhouse et al., 2021b; Yao et al., 2021).

Top speed velocity demonstrated significant negative relationship with BM (r = -0.50), CT (r = -0.69), CF ratio (r = -0.47) and positive relationship with SR (r = 0.4), SL (r = 0.49), SV (r = 0.88) and FL (r = 0.51). The correlation results supported the previous studies and findings in this study showing faster athletes can create longer SL by longer FL and shorter CT (Barr et al., 2014a). Surprisingly, despite FL had significant positive relationship with top speed velocity and FT, there was only trivial correlation between FT and velocity (r = 0.07). Furthermore, SL had positive relationship with CL and FL (r = 0.57 to 0.90), but CL had only trivial correlation with top speed velocity. Foot strike distance had a positive relationship with CT (r = 0.58) but trivial correlation with top speed velocity. Therefore, despite knowing fast athletes demonstrate faster top speeds with certain kinematics traits, concerns are raised when trying to improve one specific sprint kinematic to improve top speed performance.

In summary, having shorter CT and generating longer or similar SL is important for both acceleration and top speed running, which is similar to results from male and female sprinters and men's rugby players (Debaere et al., 2013; Economou et al., 2021; Gleadhill & Nagahara, 2021; Wild et al., 2018). Furthermore, when athletes were split into speed groups based on performance, sprint strategy and characteristics may be more informative than when players are split into forward and back positional groups.

Despite this important and largely novel information for female rugby union players, some limitations must also be noted. Only a limited amount of lower body kinematics were discussed. However, underlying mechanical differences in terms of leg joint kinematics and kinetics during sprinting might be able to further explain some of the variance between sprint mechanics and performance determinants. Secondly, both acceleration and top speed were determined using average kinematics through 10 m segments, which might miss some kinematic information compared to analyzing through shorter segments or each step. Thus, future research may wish to take a more granular approach to analyzing sprint performance, in an attempt to better explain how sprint strategy explains sprint performance.

6.5 CONCLUSION

To the author's knowledge, this is the first study to identify both acceleration and top speed kinematics in women's rugby union. Identifying the kinematics, speed, and momentum may be a more holistic approach to support practitioners to understand what rugby athletes' need to improve sprinting performance; this in turn will likely improve training design to support this. Future studies should observe how kinematics change throughout a season, and which kinematics are sensitive to training fatigue and thus might affect sprinting performance.

Chapter 7: Seasonal Differences in Sprint Performance and Mechanics in English Premiership Women's Rugby Union

Abstract

Background: Sprinting is an important motor skill in rugby which is carried out frequently over short distances during competition and often affects a successful defense or attacking opportunity. Sprint performance may be affected by acute or chronic fatigue, due to the challenging nature of a women's rugby season. However, previous research discussed only seasonal changes of split times without identifying if sprinting strategy changes throughout a rugby season.

Aim: To observe the seasonal changes in both acceleration and top speed kinematics in English Premiership Women's Rugby Union players

Method: Seven female rugby players were recruited from the English premiership women's rugby during the 2021–2022 season. Players underwent a standardized warm up, and 2 max effort 40 m sprints were undertaken, with timing gate and high-speed camera capturing split time and slow-motion video analysis of 0-10 m and 30- 40 m split.

Results: During acceleration, statistically significant reductions were found from pre- to mid-season in momentum, velocity, toe-off distance, and flight length, whereas velocity was maintained from mid- to post-season. Similar results in top speed were found, with velocity, step velocity, step length, toe-off distance, and foot strike distance all statistically significantly decreasing from pre- to mid-season and improving from mid-to post season.

Conclusion: Seasonal changes in both acceleration and top speed performance were noted across multiple kinematics. Practitioners should monitor sprint kinematics to adjust training plans accordingly to adjust for fatigue or to improve performance.

7.1 INTRODUCTION

The ability to sprint fast is important for all rugby positions. Recent women's rugby studies in English and French international players have reported noticeable improvements in over-arching fitness (e.g., sprint and jump ability) in the last few years (Imbert et al., 2023; Woodhouse et al., 2021b). More importantly, the ability to be able to maintain high performance and be able to sprint fast over the whole season is crucial for creating successful defense or attacking opportunities in every game (Hene & Bassett, 2013; Neto et al., 2021). Two longitudinal studies in women's rugby union have discussed sprint performance (Hene & Bassett, 2013; Neto et al., 2021). A study in South African women rugby players found both forwards and backs significantly decreased their 10 m and 40 m velocity from pre- to mid-season and increased from mid-to post-season (Hene & Bassett, 2013). When looking at pre- and post-season changes, collegiate forwards were reported to have significantly decreased 5 m velocity (Neto et al., 2021). In contrast, it was noted that forwards had a significant improvement in both 10 m and 40 m sprint time when comparing pre- to post-season performances (Hene & Bassett, 2013). In addition, the contrasting results in previous studies demonstrate that it is still unclear as to how female rugby union players' sprint performance changes throughout a season, which may be expected given changes in physical capacity, such as changes in strength and power, along with changes in fat and lean mass (Hene & Bassett, 2013). Furthermore, the aforementioned studies only reported sprint time (the outcome metric), without discussing the kinematic changes during the sprint (the strategy-based metrics), which limits the understanding of how sprinting as a motor skill changes through the rugby season. Understanding the changes in sprint strategy may support practitioners to identify the sprint kinematics that are sensitive to fatigue and therefore adjust training and recovery plans. Sprinting may be defined as a combination of stride frequency and stride length, and the contact phase represents one of the most crucial parameters, with faster sprinters applying greater horizontal force in a shorter contact time than slow sprinters (Mattes et al., 2014). A study in sprinters and jumpers found that despite reaching similar speeds across six training periods, significant differences were found in step velocity, stride length, stride frequency and contact time (Mattes et al., 2014). Despite the importance of sprinting in rugby, no longitudinal studies have been conducted in women's rugby union to identify kinematic changes throughout a rugby season. Therefore, the aim of this study was to observe both acceleration and top speed kinematic changes throughout the course of a competitive rugby season. It was hypothesized that female rugby union players would get slower from pre- to mid-season due to fatigue, with a longer contact time based on slow athletes' characteristics in chapter 5 and improve from mid-to post-season.

7.2 METHODS

7.2.1 Subjects

Seven female rugby players (n = 7; age: 24.52 ± 3.2 years; body mass: 73.92 ± 17.88 kg) volunteered to participate in the present study. Players competed in the English women's premiership, which is the highest level in English women rugby union in the UK. All players had at least three years of experience in rugby training and strength training in a structured rugby club and took part in 2 rugby team practices and 2 individual gym sessions per week. Tests included in this study were part of the 2021-2022 annual season monitoring test battery, agreed by both the medical, and strength and conditioning staff. This study was approved by the Research Ethics Sub-Committee of the London Sport Institute, Middlesex University, and both club staff and players were informed of the benefits and risks of the investigation before signing a team approved informed consent to participate in the study.

7.2.2 Procedures

Testing was done in pre-, mid-, and post-season and during all testing time frames all participants refrained from intensive exercise in the 24-hour period prior to testing. Participants underwent a standardized warm up, consisting of 15 minutes of dynamic stretching followed two 40 m sprints. After warming up, each participant accomplished 2 max effort sprints of 40 m with 4 min rest in between. Only 0-10 m and 30-40 m split was recorded and analyzed due to previous studies in rugby having identified 0-10 m as the acceleration phase (Woodhouse et al., 2021b) and 30-40 m as the top speed phase (Barr et al., 2014b). Participants were familiar with the sprint test, as they were conducted during their regular annual performance monitoring and daily training programs. Participants were informed of test procedures one week before the testing date.

7.2.2.1 Anthropometry

For the detailed testing procedures used for anthropometry refer to Chapter 3.1.

7.2.2.2 Linear speed test

For the detailed testing procedures used for sprint assessments refer to Chapter 3.4. The The kinematic variables used in this study are presented in Table 6.1.

7.2.3 Statistical analyses

Subjects were separated into 2 groups for comparing positional differences: forwards and backs. Acceleration speed groups were created by splitting the groups into thirds based on split times of 0-10 m and top speed groups were created based on the split times of 30-40 m split time. All data were presented as mean ± standard deviation. For the detailed procedures used for normality, reliability, and longitudinal changes can be refer to chapter 3.6.

Table 7.1. Between-trial reliability for seasonal 0-10 m acceleration measures

		Mean ± SD	CV % (95% CI)	ICC (95% CI)	Average variability	SEM
Pre-season	Initial momentum (kg.m/s)	388.22 ± 19.80	0.53 (0.25, 0.80)	0.99 (0.96, 1.00)	small	31.25
	Velocity(m/s)	5.55 ± 0.09	0.53 (0.25, 0.80)	0.99 (0.56, 0.99)	small	0.10
	Time (s)	1.80 ± 0.03	0.53 (0.25, 0.80)	0.98 (0.57, 0.99)	small	0.04
	CT (s)	0.16 ± 0.01	1.98 (0.95, 3.02)	0.84 (0.27, 0.97)	small	0.00
	FT (s)	0.08 ± 0.01	2.86 (1.36, 4.35)	0.98 (0.43, 0.99)	small	0.01
	CF ratio	2.18 ± 0.30	2.83 (1.35, 4.31)	0.99 (0.95, 0.99)	small	0.43
	LR ratio	0.31 ± 0.02	3.39 (1.61, 5.16)	0.81 (-0.06, 0.97)	small	0.01
	SR (Hz)	4.16 ± 0.12	2.22 (1.06, 3.38)	0.77 (-0.08, 0.96)	small	0.07
	SL (m)	1.30 ± 0.06	1.17 (0.56, 1.78)	0.92 (0.37, 0.99)	small	0.02
	SV (m/s)	5.40 ± 0.14	0.97 (0.46, 1.48)	0.95 (0.67, 0.99)	small	0.12
	Foot strike distance (m)	0.26 ± 0.02	1.18 (0.56, 1.81)	0.96 (0.02, 0.99)	small	0.01
	Toe-off distance (m)	0.58 ± 0.03	1.25 (0.60, 1.90)	0.92 (0.04, 0.99)	small	0.01
	CL (m)	0.84 ± 0.03	1.70 (0.81, 2.59)	0.82 (-0.06, 0.97)	small	0.01
	FL (m)	0.43 ± 0.06	2.69 (1.28, 4.09)	0.98 (0.21, 0.99)	small	0.03
	Foot strike thigh angle (◦)	52.11 ± 6.60	2.34 (1.12, 3.57)	0.96 (0.15, 0.99)	small	2.55
	Toe-off thigh angle (◦)	94.46 ± 7.93	1.50 (0.71, 2.28)	0.98 (0.16, 0.99)	small	3.95
Mid-season	Initial momentum (kg.m/s)	370.27 ± 70.80	1.08 (0.51, 1.64)	0.99 (0.83, 1.00)	small	26.76
	Velocity(m/s)	5.04 ± 0.24	1.08 (0.51, 1.64)	0.92 (0.16, 0.99)	small	0.09
	Time (s)	1.99 ± 0.09	1.08 (0.51,1.66)	0.92 (0.13, 0.99)	small	0.03
	CT (s)	0.18 ± 0.01	1.37 (0.65, 2.09)	0.76 (-0.05, 0.96)	small	0.00
	FT (s)	0.06 ± 0.01	5.65 (2.69, 8.60)	0.87 (-0.03, 0.98)	small	0.04
	CF ratio	3.03 ± 0.64	4.35 (2.07, 6.62)	0.95 (0.16, 0.99)	small	0.24
	LR ratio	0.29 ± 0.03	4.53 (2.16, 6.90)	0.83 (-0.06, 0.97)	small	0.01

	SR (Hz)	4.08 ± 0.17	2.65 (1.26, 4.04)	0.65 (-0.09, 0.94)	moderate	0.06
	SL (m)	1.18 ± 0.11	1.88 (0.90, 2.87)	0.95 (0.22, 0.99)	small	0.04
	SV (m/s)	4.81 ± 0.47	1.55 (0.74, 2.36)	0.97 (0.83, 0.99)	small	0.18
	Foot strike distance (m)	0.31 ± 0.06	3.82 (1.82, 5.82)	0.96(0.03, 0.99)	small	0.02
	Toe-off distance (m)	0.44 ± 0.02	3.15 (1.50, 4.80)	00.74 (-0.06, 0.96)	small	0.01
	CL (m)	0.76 ± 0.08	2.05 (0.98, 3.12)	0.95 (0.11, 0.99)	small	0.03
	FL (m)	0.32 ± 0.07	4.76 (2.27, 7.25)	0.89 (0.48, 0.98)	small	0.02
	Foot strike thigh angle (◦)	52.01 ± 7.12	2.61 (1.24, 3.98)	0.96 (0.13, 0.99)	small	2.69
	Toe-off thigh angle (◦)	88.11 ± 12.03	1.65 (0.79, 2.51)	0.98 (0.12, 0.99)	small	4.55
Post-season	Initial momentum (kg.m/s)	374.85 ± 74.01	0.62 (0.30, 0.94)	0.99 (0.87,1.00)	small	27.97
	Velocity(m/s)	5.05 ± 0.23	0.62 (0.29, 0.94)	0.97 (0.22, 0.99)	small	0.09
	Time (s)	1.98 ± 0.09	0.62 (0.29, 0.94)	0.97 (0.22, 0.99)	small	0.03
	CT (s)	0.17 ± 0.01	2.12 (1.01, 3.23)	0.82 (-0.06, 0.97)	small	0.00
	FT (s)	0.07 ± 0.01	3.87 (1.84, 5.90)	0.92 (0.05, 0.99)	small	0.00
	CF ratio	2.54 ± 0.46	2.93 (1.40, 4.50)	0.97 (0.83, 0.99)	small	0.18
	LR ratio	0.30 ± 0.03	2.64 (1.26, 4.02)	0.94 (0.01, 0.99)	small	0.01
	SR (Hz)	4.11 ± 0.23	2.64 (1.26, 4.02)	0.83 (-0.02, 0.98)	small	0.09
	SL (m)	1.21 ± 0.08	1.86 (0.88, 2.83)	0.90 (0.11, 0.99)	small	0.03
	SV (m/s)	4.96 ± 0.22	1.39 (0.66, 2.12)	0.87 (0.44, 0.98)	small	0.08
	Foot strike distance (m)	0.28 ± 0.02	5.41 (2.58, 8.24)	0.51 (-0.09, 0.90)	moderate	0.01
	Toe-off distance (m)	0.53 ± 0.05	3.06 (1.46. 4.66)	0.87 (-0.04, 0.98)	small	0.02
	CL (m)	0.81 ± 0.05	3.09 (1.47, 4.71)	0.73 (-0.08, 0.96)	small	0.02
	FL (m)	0.37 ± 0.05	1.92 (0.91, 2.92)	0.98 (0.42, 0.99)	small	0.02
	Foot strike thigh angle (◦)	48.00 ± 5.59	2.93 (1.40, 4.47)	0.93 (0.01, 0.99)	small	2.11
	Toe-off thigh angle (◦)	83.27 ± 7.74	1.94 (0.92, 2.96)	0.96 (0.02, 0.99)	small	2.93

CT = contact time; FT = flight time; CF ratio = contact and flight ratio; LR ratio = length and rate ratio; SL = step length; SV = step velocity; CL = contact length; FL = flight length; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

Table 7.2. Between-trial reliability for seasonal 30-40 m top speed measures

		Mean ± SD	CV % (95% CI)	ICC (95% CI)	Average variability	SEM
Pre-season	Initial momentum (kg.m/s)	522.12 ± 113.87	1.36 (0.65, 2.08)	1.00 (0.70, 1.00)	small	43.04
	Velocity(m/s)	7.10 ± 0.49	1.36 (0.65, 2.08)	0.96 (0.12, 0.99)	small	0.19
	Time (s)	1.41 ± 0.10	1.36 (0.65, 2.08)	0.95 (0.11, 0.99)	small	0.04
	CT (s)	0.14 ± 0.01	3.95 (1.88, 6.03)	0.69 (-0.09, 0.95)	small	0.04
	FT (s)	0.11 ± 0.01	7.37 (3.51, 11.23)	0.69 (-0.06, 0.99)	small	0.00
	CF ratio	1.35 ± 0.24	3.81 (1.81, 5.80)	0.93 (0.43, 0.99)	small	0.09
	LR ratio	0.40 ± 0.03	4.18 (1.99, 6.37)	0.75 (-0.03, 0.96)	small	0.01
	SR (Hz)	4.00 ± 0.15	5.43 (2.58, 8.27)	0.79 (-0.02, 0.95)	small	0.05
	SL (m)	1.60 ± 0.07	1.41 (0.67, 2.15)	0.90 (-0.03, 0.99)	small	0.03
	SV (m/s)	6.28 ± 0.59	4.02 (1.91, 6.13)	0.52 (-0.07, 0.90)	moderate	0.12
	Foot strike distance (m)	0.44 ± 0.02	1.77 (0.84, 2.70)	0.75 (0.01, 0.95)	small	0.01
	Toe-off distance (m)	0.49 ± 0.04	1.63 (0.78, 2.48)	0.94 (0.04, 0.99)	small	0.01
	CL (m)	0.92 ± 0.06	1.47 (0.70, 2.25)	0.94 (0.00, 0.99)	small	0.02
	FL (m)	0.67 ± 0.09	1.04 (0.49, 1.58)	0.99 (0.74, 1.00)	small	0.04
	Foot strike thigh angle (◦)	53.07 ± 12.91	3.18 (1.52, 4.85)	0.98 (0.18, 1.00)	small	4.88
	Toe-off thigh angle (◦)	89.67 ± 4.11	1.54 (0.73, 2.34)	0.88 (-0.04, 0.98)	small	1.55
Mid-season	Initial momentum (kg.m/s)	481.46 ± 84.54	1.60 (0.76, 2.43)	0.99 (0.75, 1.00)	small	31.95
	Velocity(m/s)	6.58 ± 0.37	1.69 (0.76, 2.43)	0.88 (0.06, 0.98)	small	0.14
	Time (s)	1.52 ± 0.09	1.60 (0.76, 2.43)	0.90 (0.07, 0.99)	small	0.03
	CT (s)	0.15 ± 0.01	2.51 (1.20, 3.83)	0.77(-0.08, 0.96)	small	0.00
	FT (s)	0.10 ± 0.02	4.17 (1.98, 6.35)	0.91 (0.32, 0.99)	small	0.01
	CF ratio	1.49 ± 0.30	2.76 (1.32, 4.21)	0.97 (0.86, 1.00)	small	0.11
	LR ratio	0.33 ± 0.04	5.26 (2.51, 8.02)	0.83 (-0.04, 0.98)	small	0.02

	SR (Hz)	4.02 ± 0.24	3.26 (1.55, 4.96)	0.76 (-0.05, 0.96)	small	0.09
	SL (m)	1.34 ± 0.09	2.01 (0.95, 3.06)	0.90 (0.08, 0.98)	small	0.03
	SV (m/s)	5.36 ± 0.25	1.98 (0.94, 3.02)	0.85 (0.42, 0.97)	small	0.09
	Foot strike distance (m)	0.35 ± 0.03	1.31 (0.63, 2.00)	0.96 (0.62, 0.99)	small	0.01
	Toe-off distance (m)	0.44 ± 0.01	2.32 (1.10, 3.53)	0.61 (-0.08, 0.93)	small	0.01
	CL (m)	0.79 ± 0.04	1.24 (0.59, 1.89)	0.91 (0.30, 0.99)	small	0.01
	FL (m)	0.54 ± 0.09	0.68 (0.33, 1.04)	1.00 (0.93, 1.00)	small	0.04
	Foot strike thigh angle (◦)	44.29 ± 6.67	2.58 (1.23, 3.93)	0.96 (0.22, 1.00)	small	2.52
	Toe-off thigh angle (◦)	85.33 ± 2.65	1.46 (0.69, 2.22)	0.77 (-0.07, 0.96)	small	1.00
Post-season	Initial momentum (kg.m/s)	499.32 ± 107.06	1.22 (0.58, 1.85)	1.00 (0.76, 1.00)	small	40.46
	Velocity(m/s)	6.72 ± 0.28	1.22 (0.58, 1.85)	0.92 (0.02, 0.99)	small	0.11
	Time (s)	1.49 ± 0.06	1.22 (0.58, 1.85)	0.91 (0.04, 0.99)	small	0.02
	CT (s)	0.15 ± 0.01	1.98 (0.94, 3.01)	0.81 (-0.07, 0.97)	small	0.00
	FT (s)	0.10 ± 0.01	4.39 (2.09, 6.69)	0.86 (0.00, 0.98)	small	0.01
	CF ratio	1.44 ± 0.26	3.37 (1.60, 5.13)	0.95 (0.63, 0.99)	small	0.10
	LR ratio	0.40 ± 0.04	2.92 (1.39, 4.44)	0.91 (0.01, 0.99)	small	0.02
	SR (Hz)	4.01 ± 0.21	2.92 (1.39, 4.44)	0.68 (-0.09, 0.95)	small	0.08
	SL (m)	1.59 ± 0.09	0.64 (0.31, 0.98)	0.99 (0.16, 1.00)	small	0.04
	SV (m/s)	6.35 ± 0.24	2.27 (1.08, 3.46)	0.60 (-0.12, 0.92)	moderate	0.09
	Foot strike distance (m)	0.41 ± 0.02	2.22 (1.06, 3.38)	0.72 (-0.09, 0.95)	small	0.01
	Toe-off distance (m)	0.51 ± 0.03	1.51 (0.72, 2.30)	0.90 (0.02, 0.99)	small	0.01
	CL (m)	0.93 ± 0.04	1.63 (0.77, 2.48)	0.88 (-0.03, 0.98)	small	0.02
	FL (m)	0.65 ± 0.08	1.81 (0.86, 2.76)	0.98 (0.26, 1.00)	small	0.03
	Foot strike thigh angle (◦)	41.19 ± 9.98	5.15 (2.45, 7.85)	0.94 (0.17, 0.99)	small	3.77
	Toe-off thigh angle (◦)	88.24 ± 4.71	2.04 (0.97, 3.11)	0.85 (-0.04, 0.98)	small	1.78

CT = contact time; FT = flight time; CF ratio = contact and flight ratio; LR ratio = length and rate ratio; SL = step length; SV = step velocity; CL = contact length; FL = flight length; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

7.3 RESULTS

Between trial reliability can be found in Table 7.1 and 7.2 with all metrics reported to have small to moderate variability.

Changes in acceleration kinematics throughout a season are shown in Table 7.3. There were statistically significant decreases in initial momentum, velocity, split time, toe-off distance, and FL ($p < 0.028$, $g = 1.33$ to 3.68) from pre-season to mid-season. From mid- to post-season, result showed there were statistically significant decrease in CF ratio ($p = 0.023$, $g = 1.39$) and increases in FT and toe-off distance ($p < 0.008$, $g =$ -1.76 to -2,95). The changes in top speed kinematics throughout a season are shown in Table 6.4. From pre- to mid-season, there were statistically significant decreases in top speed momentum, velocity, time, LR ratio, SL, SV, CL, FL, and both foot strike and toe-off distance ($p < 0.009$, $g = 1.00$ to 4.99). From mid- to post-season, there were statistically significant increase in LR ratio, SL, SV, CL, FL and both foot strike and toe-off distance ($p < 0.024$, $g = -0.46$ to -20.79). Result also shown that velocity, split time and foot strike thigh angle had a statistically significant decrease when comparing pre- to post-season ($p < 0.041$, $g = 1.11$ to 1.35).

Table 7.3. 0-10 m acceleration kinematics changes throughout a season

Variable	**Pre-season**	**Mid-season**	**Post-season**	***g* (95% CI)**		
	***n* = 7**	***n* = 7**	***n* = 7**	**Pre- vs Mid**	**Pre vs Post**	**Mid vs Post**
BM (kg)	73.92 ± 17.88	73.60 ± 15.14	74.53 ± 16.54	0.10 (-0.60, 0.79)	-0.18(-0.88, 0.53)	-0.45 (-1.17, 0.30)
Initial Momentum (kg.m/s)	387.99 ± 82.68	370.27 ± 70.80	374.85 ± 74.01	**1.33** (0.30, 2.32)	0.63 (-0.17, 1.39)	-0.25 (-0.95, 0.47)
Velocity(m/s)	5.27 ± 0.27	5.04 ± 0.24	5.05 ± 0.23	**1.34** (0.30, 2.33)	**1.81** (0.58, 3.01)	-0.05 (-0.74, 0.65)
Time (s)	1.90 ± 0.10	1.99 ± 0.09	1.98 ± 0.09	**-1.36** (-2.36, -0.32)	**-1.87** (-3.09, -0.61)	0.05 (-0.65, 0.74)
CT (s)	0.17 ± 0.01	0.18 ± 0.01	0.17 ± 0.01	-1.38 (-2.39, -0.33)	-0.15 (-0.85, 0.55)	0.90 (0.02, 1.73)
FT (s)	0.07 ± 0.02	0.06 ± 0.01	0.07 ± 0.01	0.66 (-0.14, 1.43)	-0.21 (-0.91, 0.50)	**-1.76** (-2.93, -0.54)
CF ratio	2.72 ± 1.14	3.03 ± 0.64	2.54 ± 0.46	-0.48 (-1.21, 0.28)	0.21 (-0.50, 0.91)	**1.39** (0.33, 2.40)
LR ratio	0.29 ± 0.02	0.29 ± 0.03	0.30 ± 0.03	-0.11 (-0.81, 0.59)	-0.45 (-1.17, 0.30)	-0.25 (-0.95, 0.47)
SR (Hz)	4.17 ± 0.18	4.08 ± 0.17	4.11 ± 0.23	0.51 (-0.26, 1.23)	0.33 (-0.40, 1.03)	-0.18 (-0.88, 0.53)
SL (m)	1.20 ± 0.06	1.18 ± 0.11	1.21 ± 0.08	0.18 (-0.54, 0.88)	-0.37 (-1.07, 0.37)	-0.35 (-1.06, 0.38)
SV (m/s)	4.99 ± 0.32	4.81 ± 0.47	4.96 ± 0.22	0.65 (-0.15, 1.41)	0.15 (-0.55, 0.85)	-0.39 (-1.10, 0.36)
Foot strike distance (m)	0.28 ± 0.02	0.31 ± 0.06	0.28± 0.02	-0.61 (-1.36, 0.18)	0.08 (-0.78, 0.62)	0.44 (-0.31, 1.15)
Toe-off distance (m)	0.54 ± 0.03	0.44 ± 0.02	0.53 ± 0.05	**3.68** (1.54, 5.82)	0.21 (-0.50, 0.90)	**-2.95** (-4.71, -1.18)
CL (m)	0.81 ± 0.03	0.76 ± 0.08	0.81 ± 0.05	0.53 (-0.24, 1.26)	-0.05 (-0.77, 0.64)	-0.43 (-1.14, 0.32)
FL (m)	0.36 ± 0.07	0.32 ± 0.07	0.37 ± 0.05	**1.58** (0.45, 2.68)	-0.28 (-0.98, 0.44)	1.09 (0.14, 1.96)
Foot strike thigh angle (◦)	50.96 ± 6.75	52.01 ± 7.12	48.00 ± 5.59	-0.17 (-0.86, 0.54)	0.41 (-0.33, 1.13)	0.70 (-0.12, 1.47)
Toe-off thigh angle (◦)	89.86 ± 10.46	88.11 ± 12.03	83.27 ± 7.74	0.43 (-0.32, 1.14)	**1.33** (0.30, 0.23)	0.69 (-0.13, 1.45)

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; ES = effect size; Bold effect size = $p < 0.05$

Table 7.4. 30-40 m Top speed kinematics changes throughout a season

Variable	**Pre-season**	**Mid-season**	**Post-season**	***g*** **(95% CI)**		
	n **= 7**	***n*** **= 7**	***n*** **= 7**	**Pre- vs Mid**	**Pre vs Post**	**Mid vs Post**
BM (kg)	73.92 ± 17.88	73.60 ± 15.14	74.53 ± 16.54	0.10 (-0.60, 0.79)	-0.18 (-0.88, 0.53)	-0.45 (-1.17, 0.30)
Top speed Momentum (kg.m/s)	522.12 ± 113.87	481.46 ± 84.54	499.32 ± 107.06	**1.00** (0.09, 1.86)	0.60 (-0.19, 1.35)	-0.61 (-0.14, 0.18)
Velocity(m/s)	7.10 ± 0.49	6.58 ± 0.37	6.72 ± 0.28	**1.43** (0.36, 2.45)	**1.11** (0.16, 2.02)	-0.68 (-1.45, 0.13)
Time (s)	1.41 ± 0.10	1.52 ± 0.09	1.49 ± 0.06	**-1.52** (-2.59, -0.41)	**-1.22** (-2.16, -0.23)	0.67 (-0.14, 1.43)
CT (s)	0.14 ± 0.01	0.15 ± 0.01	0.15 ± 0.01	-0.62 (-1.38, 0.17)	-0.29 (-1.00, 0.43)	0.27 (-0.45, 0.97)
FT (s)	0.11 ± 0.01	0.10 ± 0.02	0.10 ± 0.01	0.35 (-0.38, 1.06)	0.72 (-0.10, 1.50)	-0.06 (-0.75, 0.64)
CF ratio	1.35 ± 0.24	1.49 ± 0.30	1.44 ± 0.26	-0.71 (-1.48, 0.11)	-0.82 (-1.63, 0.03)	0.22 (-0.50, 0.91)
LR ratio	0.40 ± 0.03	0.33 ± 0.04	0.40 ± 0.04	**2.19** (0.78, 3.56)	0.11 (-0.59, 0.80)	**-2.46** (-3.96, -0.92)
SR (Hz)	4.00 ± 0.15	4.02 ± 0.24	4.01 ± 0.21	-0.06 (-0.75, 0.64)	-0.03 (-0.72, 0.67)	0.07 (0.63, 0.76)
SL (m)	1.60 ± 0.07	1.34 ± 0.09	1.59 ± 0.09	**4.99** (2.16, 7.82)	0.31 (-0.42, 1.01)	**-0.46** (-7.27, -1.99)
SV (m/s)	6.28 ± 0.59	5.36 ± 0.25	6.35 ± 0.24	**1.66** (0.49, 2.79)	-0.13 (-0.82, 0.57)	**-3.76** (-6.42, -1.10)
Foot strike distance (m)	0.44 ± 0.02	0.35 ± 0.03	0.41 ± 0.02	**2.95** (1.17, 4.70)	1.15 (0.19, 2.07)	**-1.38** (-2.39, -0.33)
Toe-off distance (m)	0.49 ± 0.04	0.44 ± 0.01	0.51 ± 0.03	**1.87** (0.61, 3.08)	-0.81 (-1.61, 0.04)	**-3.67** (-5.79, -1.53)
CL (m)	0.92 ± 0.06	0.79 ± 0.04	0.93 ± 0.04	**3.38** (1.39, 5.36)	-0.39 (-1.10, 0.39)	**-3.13** (-4.98, -1.27)
FL (m)	0.67 ± 0.09	0.54 ± 0.09	0.65 ± 0.08	**1.88** (0.61, 3.10)	0.55 (-0.23, 1.29)	**-1.41** (-2.43, -0.34)
Foot strike thigh angle (◦)	53.07 ± 12.91	44.29 ± 6.67	41.19 ± 9.98	0.91 (0.03, 1.74)	**1.35** (0.31, 2.34)	0.32 (-0.41, 1.02)
Toe-off thigh angle (◦)	89.67 ± 4.11	85.33 ± 2.65	88.24 ± 4.71	1.10 (0.16, 2.00)	0.23 (-0.48, 0.93)	-0.89 (-0.17, -0.02)

BM = body mass; CT = contact time; FT = flight time; CF ratio = contact time and flight time ratio; LR ratio = step length and step rate ratio; SR = step rate; SL = step length; SV = step velocity; CL = Contact length; FL = flight length; ES = effect size; Bold effect size = $p < 0.05$

7.4 DISCUSSION

7.4.1 Acceleration performance

The purpose of this study was to investigate sprint performance and kinematics across a competitive season in England premiership women's rugby union athletes. When assessing seasonal variations in acceleration performance, there was a significant decrease in velocity and momentum from pre-to mid-season and with a maintenance from mid to post-season. Similar results were shown in South African female rugby players from pre- to mid-season, where 10 m speed decreased with no significant changes in BM (Hene & Bassett, 2013). In contrast, South African female rugby players improved significantly in acceleration from mid-to post-season and forwards got significantly faster when comparing pre-to post-season (Hene & Bassett, 2013). The variation in results might be due to differences in testing schedules for international players, performing their post-season testing 2-weeks after the season, which creates additional time for recovery (Hene & Bassett, 2013). Furthermore, participants in this study were primarily semi-professional, which might affect in-season recovery due to some players also being full-time students or having full-time jobs. In support of this, decreases in acceleration performance from pre-to post season have been previously similarly shown in female university players and male U19 rugby players (Neto et al., 2021; Zabaloy et al., 2022).

7.4.2 Acceleration kinematics

Acceleration kinematics showed a large increase in CT (g = -1.38, 95% CI = -2.36 to -0.32) and a moderate decrease in FT (g = 0.66, 95% CI = -0.14 to 1.43), with moderately lower SR (g = 0.51, 95% CI = -0.26 to 1.23) and SV (g = 0.65, 95% CI = -

0.15 to 1.41). Despite longer CT, CL also showed a moderate decrease (g = 0.53, 95% CI = -0.24 to 1.26) with FL being significantly shorter from pre- to mid-season. Furthermore, the increase in foot strike distance might be the reason SL showed only trivial differences. Similar kinematic results were presented in female footballers, identifying that when fatigued, CT increased, step frequency decreased, but SL remained similar (van den Tillaar, 2021). The decrease in acceleration performance might be caused by a cumulative build-up of fatigue throughout the competitive season; thus, affecting the acceleration kinematics (Barr et al., 2014a). When comparing mid- to post-season, although no differences were found in velocity, the acceleration strategy changed. From mid- to post-season, a large decrease in CT (g = 0.90, 95% CI = 0.02 to 1.73) and significantly higher FT created a significant decrease in CF ratio, and most of the kinematic variables showed only trivial to small differences when compared to pre-season. Therefore, it is assumed that players in this study improved the efficiency in acceleration from mid- to post-season and were similar to pre-season despite no statistically significant improvement in velocity. However, this is the first study to understand acceleration kinematics in women's rugby throughout the season, therefore, more evidence is needed to fully understand the kinematics changes and the underpinning physiological reasons behind it.

7.4.3 Top speed performance

When looking at top speed performance across the season, despite only trivial to small changes in BM, 30-40 m velocity and top speed momentum significantly worsened from pre- to mid-season and showed a moderate improvement (g = -0.68 and -0.61, 95% CI = -1.45 to 0.13 and -0.14 to 0.18, respectively) from mid-to post-season. However, top speed velocity in pre-season still presented the fastest scores. The decrease in top speed performance in-season might be due to the fatigue of having rugby match weekly adding up to the semi-professional setting (i.e. training while having full-time jobs). The improvement of top speed at post-season compared to mid-season might be caused by the decrease in training load to taper for the final therefore, athletes in this study were well recovered. A similar trend was found in South African female rugby players in 40 m sprint time, whereby slower sprint times were recorded in mid-season and improved from mid to post-season in both forwards and backs (Hene & Bassett, 2013).

7.4.4 Top speed kinematics

In top speed kinematics during pre-season, players demonstrated moderately shorter CT (g = -0.62, 95% CI = -1.38 to 0.17) compared to mid-season and moderately longer FT (g = 0.72, 95% CI = -0.10 to 1.50) compared to post-season, resulting in the CF ratio being lowest in pre-season. In addition, during a rugby season it is possible to identify how female rugby players' top speed performance could be affected by external factors like running strategy (Wild et al., 2022). Despite SR showing trivial differences across the season (due to significantly longer SL in pre-and post-season), the result showed statistically higher LR ratio compared to mid-season. Both pre- and post-season demonstrated significantly longer SL, CL, FL, foot strike and toe off-distance, and higher SV than mid-season despite having similar SR. These top speed kinematic changes might again, be due to being fatigued in season, although using similar time to accomplish each step, the length was shorter (Economou et al., 2021; Nagahara et al., 2014). The trend of decreasing speed performance from pre-to mid-season in both acceleration and top speed, and either maintaining or improving from mid-to post-season, might be also due to the training focus at different stages of the season. Coming from pre-season to in-season, training load reduced, game fatigue increased, and gym training's main lift went from a more strength focused (i.e. squat) to more speed-strength (i.e. loaded jump) focused, with a taper before the final few games. The difference in gym training focus might also be a reason the changes in sprint performance throughout a season with acceleration being more strength biased and top speed being more speed strength biased (Barr et al., 2013).

In summary, this chapter reported similar results to study 3 (chapter 4) discussing longitudinal changes in strength and power characteristics. Results revealed a decrease in performance from pre- to mid-season and an increase from mid-to post-season. English premiership women's rugby union athletes decreased sprint performance in both acceleration and top speed from pre- to post- were able to maintain or slightly improve it from mid-to post-season. In this study, some limitations must also be acknowledged. The total number of participants was limited due to some players being injured, recruited into the club mid-season, or away on international duty, therefore, only 7 female rugby players completed all three-speed tests throughout the season. The addition of these missing players would potentially provide a greater understanding of sprint performance and kinematic changes throughout a season in English premiership women's rugby athletes.

7.5 CONCLUSION

This is the first study to examine sprint performance and kinematic changes throughout an English premiership women's rugby season. Despite the low number of participants, results still identified sprint performance would fluctuate during the season.

Furthermore, similar sprinting velocities may be underpinned by different sprinting strategies. Future research should identify positional differences as well as separating players based on sprint times (fast, moderate and slow). These results may support practitioners to determine speed monitoring protocols using both outcome (velocity) and kinematics (strategy) measures to inform individualized training.

Chapter 8: Positional Differences in Change of Direction Performance in English Premiership Women's Rugby Union

Abstract

Background: Change of direction ability is particularly important in rugby due to the sport's multidirectional nature and provides the mechanical and physical basis underpinning agility. In addition, athletes frequently change movement pace and direction to avoid contact from opposing players to obtain scoring opportunities and get into positional advantage to make dominate tackles.

Aim: The purpose of this study was to understand change of direction ability between positions and different speed group using a 505 test in English Premiership Women's Rugby Union

Method: Twenty-seven female rugby players were recruited from the English premiership women's rugby during the 2019–2020 season. Players underwent a standardized warm up, 2 max effort 40 m sprints and 4 max effort 505 tests were accomplished. Athletes were then split into forwards and backs and speed group based on 505 test time for analysis.

Results: Forwards had statistically significantly higher body mass and initial momentum (g = 1.60 and 1.15). Backs demonstrated statistically significantly faster 10 m sprint time, velocity, and 505 time on both dominant and non-dominant sides (g = 0.93 to 1.21). Athletes with faster 505 time had lower body mass, linear sprint time, and faster 505 times on the non-dominant side.

Conclusion: Backs and the faster 505 group are generally lighter and faster in linear speed. Forwards and the slow 505 group are generally heavier and slower in linear

speed. However, both can have similar change of direction deficits. Therefore, the combination of gathering anthropometry and linear speed may support practitioners to identify what type of COD training an athlete needs to improve COD performance.

8.1 INTRODUCTION

Rugby union is a team sport that requires repeated high intensity efforts in contact and non-contact activities (Freitas et al., 2018). Athletes are categorized into forwards and backs based on match position and demands, with forwards having more collision activities (e.g., scrum, maul, ruck), while backs are involved in more high-speed running (Bradley et al., 2019; Busbridge et al., 2020; Woodhouse et al., 2021a). Change of direction (COD) ability is particularly important in rugby due to the sport's multidirectional nature and provides the mechanical and physical basis underpinning agility. This is a fundamental physical ability in rugby athletes, as they frequently change movement speed and direction to avoid contact from opposing players, to obtain scoring and passing opportunities, and get into positions that enable dominant tackles (forcing the ball carrier backwards) (Dos' Santos et al., 2021; Freitas et al., 2018; Nyberg & Penpraze, 2016; Quarrie et al., 1995). COD can be split into four phases, acceleration, deceleration, COD foot plant, and reacceleration (Dos' Santos et al., 2021). Most COD tests use total time to evaluate COD performance, making it difficult to identify true COD ability, since the majority of time is a function of linear running (Freitas et al., 2023; Lockie, Robert, 2018; Nimphius et al., 2016). The COD deficit (CODD) has been proposed as a practical measure to isolate COD ability, independent of sprint speed. Recent studies have used the CODD to gain a better understanding of COD ability in multiple sports (Bishop et al., 2021b; Freitas et al., 2023; Lockie, Robert, 2018; Nimphius et al., 2016).

Studies in female rugby union players regarding COD performance have used different testing methods including the agility run (Quarrie et al., 1995), Illinois agility test (Nyberg & Penpraze, 2016) and the 505 (Lockie, Robert, 2018). A study in New

Zealand female rugby players using the agility run reported backs had significantly faster finishing times compared to forwards (Quarrie et al., 1995). In contrast, a study in Scottish female rugby players found no significant difference in the Illinois test between forwards and backs. However, both tests only reported the metric of 'total time' for the COD test, and with the amount of linear running in both tests, it is difficult to isolate the COD ability between legs and between positions (Lockie, Robert, 2018). Lockie, (2018) conducted a COD ability study in university level female rugby union athletes and found that using the 505 test to identify CODD did not correlate with linear speed running. However, no positional comparison was conducted; thus, COD ability across positions in female rugby union players still remains unclear. Results in women's rugby league showed backs performed significantly faster 505 times compared to forwards (Jones et al., 2016), while a study in men's rugby union found no significant difference between positions in all 505 testing variables (Bishop et al., 2021a). Results in a women's rugby sevens study showed no correlation between sprint momentum and CODD, but linear speed had a strong positive relationship with CODD (r = 0.78) (Freitas et al., 2023). In contrast, a study in men's rugby found CODD and sprint momentum had a strong positive relationship (r = 0.85), most likely due to the higher braking force needed to overcome the greater inertia; thereby, affecting the CODD for those with heavier body masses (Freitas et al., 2021b). Both studies identified that the faster the sprint velocity, the harder it is for athletes to change direction, therefore CODD would be greater (Freitas et al., 2021b; Freitas et al., 2023). In light of these findings, further research on the COD ability in women's rugby union may help coaches develop more efficient and tailored training plans. Consequently, the purpose of this study was to understand COD ability between positions and fast and slow groups.

8.2 METHODS

8.2.1 Experimental approach to the problem

In order to understand the COD ability of female rugby union players, a cross-sectional design was used. Playing position, speed group (defined as slow, moderate, and fast) were the independent variables, while BM, COD speed, CODD, and momentum were the dependent variables.

8.2.2 Subjects

Twenty-seven (*n* = 27) female rugby union players from a single team volunteered for this study. The 27 players were separated into forwards (*n* = 12, age: 26.25 ± 5.50 yrs, height: 170.46 ± 9.24 cm, weight: 84.77 ± 12.33 kg) and backs (*n* = 15, age: 24.67 ± 3.85 yrs, height: 166.37 ± 5.05 cm, weight: 69.60 ± 5.70 kg). Players in this study competed in the English premiership women's rugby union, which is the highest level in women's rugby union in the UK. All players had at least three years of experience in rugby training and strength training in a structured rugby club and took part in 2 rugby team practices and 2 individual gym sessions per week. Tests included in this study were part of the 2020-2021 annual season monitoring test battery, agreed by both the medical, and strength and conditioning staff. The study was approved by the London Sport Institute research ethics subcommittee at Middlesex University. Players were informed of the benefits and risks of the investigation before signing written informed consent to participate in the study.

8.2.3 Procedures

Linear speed and COD performance measurements were conducted during mid-season. During the testing time frames, players with a medical condition or injury were excluded from the physical fitness assessment. All subjects refrained from intensive exercise in the 24-hour period prior to testing. Anthropometric measurements were taken for each participant before the testing session started. Players underwent a standardized warm-up, consisting of 10 minutes of dynamic stretching followed by 1 practice trials for each of the linear speed and COD assessments. Subjects were familiar with all tests, which were also conducted during their regular annual performance monitoring and running sessions.

8.2.3.1 Anthropometry

For the detailed testing procedures used for anthropometry refer to Chapter 3.1.

8.2.3.2 Linear speed test

For the detailed testing procedures used for sprint assessments refer to Chapter 3.4.

8.2.3.3 505 COD test

For the detailed testing procedures used for sprint assessments refer to Chapter 3.5. The dominant direction (D), non-dominant (ND) and CODD of both directions were recorded.

8.2.4 Statistical Analysis

Subjects were separated into 2 groups for comparing positional differences: forwards and backs. COD speed groups were created by splitting the groups into thirds based on the finish time of the D side 505. All data were presented as mean ± standard deviation. For the detailed procedures used for normality, reliability, compared positional of speed group and correlation can be refer to chapter 3.6.

8.3 RESULTS

All variables in this study were normally distributed with athletes grouped into forwards and backs, and into different speed groups (slow, moderate, and fast). Average variability for all variables demonstrated at least moderate (ICC < .67 or CV > 10%) to small (ICC > .67 and CV < 10%) variability (Table 8.1).

8.3.1 Positional differences

The positional differences in COD ability between forwards and backs are shown in Table 7.2. ES data are also provided to report the magnitude of effects and thus, provide applied practitioners with some measure of "practical significance" (Turner et al., 2021). Forwards generated statistically significantly higher BM and initial momentum (g = 1.60, 95% CI = 0.73 to 2.44 and g = 1.15, 95% CI = 0.34 to 1.94). Backs demonstrated statistically significantly faster 10 m velocity and 505 time in both D and ND side (g = -1.17, 95% CI = -1.96 to -0.36 and g = 1.06, 95% CI = 0.26 to 1.84).

8.3.2 Speed Group differences

The COD ability differences in across speed groups are shown in Table 8.3. The speed group split is based on D 505 time and demonstrates that faster athletes have statistically significantly lower BM (g = -1.35, 95% CI = -2.33 to -0.34), 10m sprint time (g = -2.15, 95% CI = -3.28 to -0.98), and ND 505 time (g = -1.83, 95% CI = -2.89 to -0.73), with a largely lower initial momentum (g = -0.87, 95% CI = -1.79 to 0.07). Despite statistical significance, the fast and moderate group had only small practical difference (g = -0.24, 95% CI = -0.36 to -1.16). The fast group also had largely lower D CODD (g = -1.23, 95% CI = -2.19 to -0.24), ND 505 time (g = -0.94, 95% CI = -1.87 to -0.01), and ND CODD (g = -0.82, 95% CI = -1.73 to 0.12), but trivial differences in linear sprint velocity (g = 0.07, 95% CI = -0.81 to -0.95) compared to the moderate group. The moderate group had statistically significantly higher sprint speed than the slow group, however, the slow group had faster D and ND CODD (moderate to large practical differences; g = 0.77, 95% CI = -0.16 to 1.68 and g = 1.01, 95% CI = 0.05 to 1.94).

8.3.3 Correlations

Correlations between COD ability and acceleration performance are shown in table 8.4 and 8.5. The D 505 time is correlated with BM (r = 0.67) and 10 m sprint (r = 0.69) in forwards. D CODD is correlated with 10 m sprint and initial momentum in both forwards (r = -0.62 and 0.58) and backs (r = -0.58 and 0.60). Only forwards ND 505 time is correlated with D 505 time (r = 0.81). Backs ND CODD is correlated with 10 m sprint (r = -0.70). ND CODD is correlated with D CODD in both forwards (r = 0.78) and backs (r = 0.69).

Table 8.1. Between-trial reliability for COD measures

	Mean ± SD	CV % (95% CI)	ICC (95% CI)	Average variability	SEM
Initial momentum (kg.m/s)	394.07 ± 54.39	1.41 (1.03, 1.78)	0.98 (0.96, 0.99)	small	10.47
Velocity(m/s)	5.178 ± 0.27	1.41 (1.03, 1.78)	0.89 (0.77, 0.95)	small	0.05
Time (s)	1.94 ± 0.10	1.41 (1.03, 1.78)	0.88 (0.75, 0.94)	small	0.02
505 left turn (s)	2.49 ± 0.11	0.51 (0.37, 0.65)	0.82 (-0.02, 0.95)	small	0.02
CODD left turn (s)	0.52 ± 0.12	5.22 (3.83, 6.62)	0.75 (0.52, 0.88)	small	0.02
505 right turn (s)	2.45 ± 0.09	0.38 (0.28, 0.49)	0.97 (0.04, 0.99)	small	0.02
CODD right turn	0.49 ± 0.10	4.93 (3.61, 6.24)	0.84 (0.68, 0.92)	small	0.02

COD = change of direction; CODD = change of direction deficit; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

Table 8.2. COD ability differences between forwards and backs

Variable	Forwards (n = 12)	Backs (n = 15)	*g* (95% CI)
BM (kg)	84.77 ± 12.33	69.60 ± 5.70	**1.60** (0.73, 2.44)
Height (cm)	170.46 ± 9.24	166.37 ± 5.05	0.55 (-0.21, 1.30)
10m sprint (s)	1.99 ± 0.11	1.89 ± 0.07	**1.21** (2.00, 3.88)
10m velocity (m/s)	5.03 ± 0.28	5.31 ± 0.18	**-1.17** (-1.96, -0.36)
Initial Momentum (kg/m/s)	425.33 ± 58.19	369.79 ± 35.46	**1.15** (0.34, 1.94)
D 505 time (s)	2.48 ± 0.09	2.40 ± 0.07	**0.93** (0.14, 1.70)
D CODD (s)	0.48 ± 0.08	0.52 ± 0.08	-0.42 (0.33, 1.17)
ND 505 time (s)	2.56 ± 0.11	2.47 ± 0.06	**1.06** (0.26, 1.84)
ND CODD (s)	0.57 ± 0.11	0.58 ± 0.08	-0.15 (-0.89, 0.59)

COD = change of direction; CODD = change of direction deficit; D = dominate side; ND = non-dominate side; **Bold effect size = $p < 0.05$**

Table 8.3. COD ability differences between fast, moderate and slow athletes.

Variable	**Fast** **N = 9**	**Moderate** **N = 9**	**Slow** **N = 9**	***g* (95% CI)** **Fast vs moderate**	**Fast vs slow**	**Moderate vs Slow**
Height (cm)	166.79 ± 3.77	169.06 ± 8.31	168.72 ± 9.45	-0.34 (-0.12, 0.56)	-0.26 (-1.14, 0.63)	0.04 (-0.85, 0.92)
BM (kg)	69.32 ± 4.52	74.72 ± 8.40	84.99 ± 14.98	-0.76 (-0.17, 0.17)	**-1.35** (-2.33, -0.34)	-0.81 (-1.72, 0.13)
10m sprint (s)	1.88 ± 0.06	1.89 ± 0.09	2.03 ± 0.07	-0.09 (-0.97, 0.79)	**-2.15** (-3.28, -0.98)	**-1.69** (-2.73, -0.62)
Velocity (m/s)	5.32 ± 0.18	5.31 ± 0.24	4.92 ± 0.18	0.07 (-0.81, 0.95)	**2.13** (0.96, 3.25)	**1.72** (0.64, 2.76)
Initial Momentum (kg/m/s)	369.00 ± 27.21	396.63 ± 49.04	417.80 ± 70.25	-0.66 (-1.56, 0.26)	-0.87 (-1.79, 0.07)	-0.33 (-1.22, 0.56)
D 505 time (s)	2.34 ± 0.05	2.44 ± 0.03	2.52 ± 0.03	**-0.24** (-0.36, -1.16)	**-4.14** (-5.79, -2.45)	**-2.52** (-3.73, -1.27)
D CODD (s)	0.46 ± 0.05	0.56 ± 0.09	0.49 ± .007	-1.23 (-2.19, -0.24)	-0.45 (-1.33, 0.46)	0.77 (-0.16, 1.68)
N 505 time (s)	2.44 ± 0.08	2.52 ± 0.09	2.58 ± 0.06	**-0.94** (-1.87, 0.01)	**-1.83** (-2.89, -0.73)	-0.75 (-1.66, 0.18)
N CODD (s)	0.55 ± 0.09	0.63 ± 0.09	0.55 ± 0.07	-0.82 (-1.73, 0.12)	0.09 (-0.79, 0.97)	1.01 (0.05, 1.94)

BM = body mass; D = dominate side; CODD = change of direction deficit; ND = non-dominate; **Bold effect size = *p* < 0.05**

Table 8.4. Pearson's Correlation between forwards' COD ability and acceleration performance

Variable	Height	BM	10m sprint	Velocity	Initial Momentum	D 505 time	D CODD	ND 505 time	ND CODD
Height (cm)	1	0.82	-0.20	0.19	0.18	0.06	0.34	-0.10	0.11
BM (kg)		1	.29	-0.30	**0.93**	**0.67**	0.32	0.43	0.16
10m sprint (s)			1	**-1.00**	-0.08	**0.69**	**-0.62**	0.56	-0.45
Velocity (m/s)				1	0.06	**-0.70**	**0.60**	-0.57	0.43
Initial Momentum (kg/m/s)					1	0.44	**0.58**	0.24	0.34
D 505 time (s)						1	0.14	**0.81**	0.16
D CODD (s)							1	0.12	**0.78**
ND 505 time (s)								1	0.49
ND CODD (s)									1

BM = body mass; D = dominate side; CODD = change of direction deficit; ND = non-dominate. **Bold correlation =** $\boldsymbol{p < 0.05}$.

Table 8.5. Pearson's Correlation between backs' COD ability and acceleration performance

Variable	Height	BM	10m sprint	Velocity	Initial Momentum	D 505 time	D CODD	ND 505 time	ND CODD
Height (cm)	1	0.37	**-0.57**	**0.56**	**0.52**	-0.40	0.13	-0.31	0.24
BM (kg)		1	-2.3	**0.24**	**0.94**	0.19	0.35	0.09	0.26
10m sprint (s)			1	**-1.00**	-0.56	0.23	**-0.58**	0.16	**-0.70**
Velocity (m/s)				1	**0.56**	-0.26	**0.60**	-0.15	**0.71**
Initial Momentum (kg/m/s)					1	0.08	**0.52**	0.02	0.47
D 505 time (s)						1	**0.62**	0.51	0.15
D CODD (s)							1	0.30	**0.69**
ND 505 time (s)								1	**0.60**
ND CODD (s)									1

BM = body mass; D = dominate side; CODD = change of direction deficit; ND = non-dominate. **Bold correlation =** $p < 0.05$.

8.4 DISCUSSION

The main purpose of the present study was to assess acceleration, initial momentum, COD ability, and CODD of women's rugby union players, discriminating between position, and D 505 time (using a third split analysis to separate fast, moderate, and slow athletes). Similar to previous studies in women's rugby, backs had statistically significantly lower BM and initial momentum, but produced faster acceleration and velocity (Quarrie et al., 1995; Woodhouse et al., 2021b). For COD ability, backs performed statistically significantly faster 505 times in both the D and ND side. Similar results were reported in women's rugby league (Jones et al., 2016). In contrast, a study in men's rugby reported no statistically significant differences between forwards and backs in 505 time on both sides (Bishop et al., 2021a). Differences between male and female studies might be due to only the backs in the female study and current study were reported to have significantly faster acceleration times than forwards (Jones et al., 2016). Furthermore, the backs had less momentum to overcome braking forces compared to forwards; this therefore benefited the acceleration and reacceleration phases in the 505 test (Nimphius et al., 2016). When comparing CODD, there were no significant differences in either D or ND side, which is similar to men's rugby whereby when split into positional groups, there were no significant differences in CODD in multiple COD tests (Freitas et al., 2018).

When comparing COD ability in different speed groups based on D 505 time, the results showed that slower athletes are statistically significantly higher in BM, generating differences classed as moderate to large in initial momentum, with slower acceleration velocity. Similar to results when comparing forwards and backs, athletes that were slower in both D and ND 505 time are also largely heavier and slower in linear acceleration (Jones et al., 2016). Results also demonstrated that fast athletes had largely lower CODD in both D and ND sides than the moderate group. These results contrast with previous studies reporting faster athletes display larger CODD, which indicates that they are less efficient in COD (Freitas et al., 2022; Freitas et al., 2023). The difference in results might be due to the COD tests in those studies being done in an indoor court compared to the current study on rugby pitch with boots. Athletes performing COD tests in boots might be able to create more traction for acceleration and deceleration therefore does not display larger CODD. Furthermore, the fast athletes in the current study might have better COD skills and lower BM, therefore, can create a more successful turn despite having higher linear speed. Different from the fast group, the moderate group despite being statistically significantly faster in acceleration and D 505 time, and faster in N505 time to a large effect compared to the slow group, demonstrated moderate to largely higher CODD on both sides. The results presented by the moderate group might be due to having similar linear speed to the fast group but moderately higher BM and initial momentum, therefore needing to apply more braking force to overcome the greater inertia negatively affecting CODD (Freitas et al., 2021b). Astonishingly, the slow group demonstrated moderate to largely lower CODD in both D CODD and ND CODD compared to the moderate group and showed trivial to small differences compared to the fast group. The slow group having lower CODD than the moderate group might be due to despite only small practical difference in initial momentum between groups, the slow group had statistically significantly slower linear speed and 505 time, therefore, less inertia needed to be overcome by the slower entry speed before the turn (Freitas et al., 2023). The difference between speed groups might be due to large anthropometric and physical differences in women's rugby union (Woodhouse et al., 2021b; Yao et al., 2021). In addition, initial momentum may affect

COD ability, however, both variables that generate momentum (velocity and mass) need to be taken into consideration separately to support understanding COD ability.

When discussing the relationship between COD, acceleration, and BM, forwards reported BM had significant positive relationships with initial momentum and D 505 time, but no significant relationships were found in backs between initial momentum and D 505 time. The results support previous comparisons between speed groups, showing slow D 505-time athletes had statistically significantly slower linear acceleration and a largely greater BM than the moderate group. D CODD had a positive relationship with linear acceleration velocity and initial momentum in both forwards and backs. This matches the results found in the moderate group in the current study and previous studies in both women's and men's rugby, indicating that the faster acceleration might create more initial momentum therefore demonstrating a large D CODD (Freitas et al., 2021b; Freitas et al., 2023). When looking at ND CODD in both forwards and backs, a significant positive relationship was shown with D CODD, however, only in backs results showed a significant positive relationship between ND CODD and velocity. Furthermore, only backs reported a significant positive relationship between 505 times and CODD on both sides. Similar results were found in women's sevens athletes showing in lighter athletes, the main factor influencing CODD was linear acceleration velocity, whereas body mass is more decisive in heavier athletes (Freitas et al., 2023).

In summary, backs in this study generated higher speed in both linear and 505 time with less BM and initial momentum; forwards only generated higher initial momentum. Therefore, the results suggest that to understand COD ability in female rugby union players, using different speed groups is a better way to characterize COD and CODD.

The results identified that in women's rugby union, athletes can be separated into fast and light, heavy and fast, and heavy and slow groups based on body mass and COD ability. Therefore, the differences in linear speed and BM should be taken into account when suggesting COD training. In this study, some limitations must also be noted. Firstly, due to the COVID pandemic affecting semi-professional sport, and injury in-season, some players missed the testing of COD ability, therefore the numbers could not split into further positional differences. The addition of these players potentially provides a greater understanding of seasonal change and COD ability as a competitive group. More studies should focus on understanding COD ability and technique in women's rugby union player due to the large variation of speed and body composition across positions. This would allow practitioners to make informed decisions to improve performance via more specific training or adjusting body composition.

8.5 CONCLUSION

The current study is the first study to identify COD ability in female rugby union players across position and speed differences. Both momentum and linear sprint had strong positive relationships with change of direction deficit in both forwards and backs. Backs and a faster D 505 group are mainly lighter and faster in linear speed and ND 505. Forwards and slow D 505 group are mainly heavier and slower in linear speed and ND 505. However, both can have similar CODD. Therefore, the combination of gathering anthropometry and linear speed may support practitioners to identify what type of COD training an athlete need to improve COD performance.

Chapter 9: Seasonal changes in change of direction performance in English premiership women's rugby union

Abstract

Background: Change of direction ability is a motor skill crucial for multidirectional sports such as rugby. Performance change throughout a rugby season may provide valuable information to practitioners.

Aim: The purpose of this study was to understand seasonal changes in change of direction ability using the 505 test in English Premiership Women's Rugby Union

Method: Seven female rugby players (age: 25.28 ± 4.07 years; body mass: 75.78 ± 14.81 kg) were recruited from the English premiership during the 2019–2020 season. During mid- and post-season, players underwent a standardized warm up, 2 max effort 40 m sprints and 4 max efforts for 505 testing, were accomplished.

Results: There were large practical increases in body mass and initial momentum (g= -0,71 and -0.79) from mid- to post-season. There was also a small practical increase in both dominate and non-dominate side 505 time from mid-to post season (g = -0.37 and -0.41).

Conclusion: The increase in body mass and momentum could have an effect on change of direction speed. When monitoring Change of direction ability, linear velocity and momentum should be considered as well in women's rugby.

9.1 INTRODUCTION

Physical profiling of rugby athletes, particularly longitudinal investigations of physical characteristics can provide valuable training information to practitioners (Hene & Bassett, 2013; Woodhouse et al., 2021b). Change of direction (COD) ability is defined as the ability to accelerate, rapidly decelerate, turn, and reaccelerate which is particularly important in rugby due to the sport's multidirectional nature (Freitas et al., 2023). In addition, to isolate COD ability from linear speed, recent studies had proposed change of direction deficit (CODD) as a practical measure (COD test total time – linear sprint time) across multiple sports (Bishop et al., 2021b; Freitas et al., 2023; Lockie, Robert, 2018; Nimphius et al., 2016).

When discussing COD ability throughout a season, studies in men's academy football and female softball report improvements in 505 time, especially in the nondominant leg from pre- to post-season (Bishop et al., 2023; Nimphius et al., 2012). In contrast, a study in youth female footballers found decrements in 505 time from mid- to post-season (Emmonds et al., 2020). However, to the authors knowledge no longitudinal studies have been conducted to observe COD ability in women's rugby union. Due to the difference in sex, the length of the season, physical and anthropometry demands, caution should be made when trying to interpret the results into female rugby union players (Freitas et al., 2021a; Freitas et al., 2022). Recent studies have discussed the relationship between sprint momentum and COD ability. Results in a women's rugby sevens study showed no correlations between sprint momentum and CODD, but linear speed had a strong positive relationship with CODD (Freitas et al., 2023). In contrast, study in men's rugby found CODD and sprint momentum had a strong positive relationship, most likely due to the higher braking force needed to overcome the greater inertia which effects CODD in heavier individuals (Freitas et al., 2021b). The author suggested that the difference in result might be due to women's rugby seven's players being much lighter than men's rugby players, generating correlation between sprint momentum and deficits (Freitas et al., 2023). Both studies identified that the faster the sprint velocity, the harder it is for athletes to COD, therefore CODD would be greater (Freitas et al., 2021b; Freitas et al., 2023). In study 6 (Chapter 7), results showed that BM had a positive relationship with dominant side (D) 505 time in forwards, and linear sprint velocity had positive relationship with D CODD in both forwards and backs. In light of these findings, further research on seasonal changes in COD ability, BM and linear sprint speed in women's rugby union may help coaches develop more efficient seasonal training plans. Therefore, the purpose of this research was to examine the longitudinal changes in COD ability throughout mid-and post- season in premiership women's rugby.

9.2 METHODS

In order to monitor the COD ability of women's rugby union players across a season, a longitudinal design was used. Mid- and post-season testing time points were the independent variables, and BM, COD speed, CODD, and momentum were the dependent variables.

9.2.1 Subjects

Seven (*n* = 7) women's rugby union players (age: 25.28 ± 4.07 years; body mass: 75.78 ± 14.81 kg) from a single team volunteered for this study. Players in this study competed in the English women premiership, which is the highest level in English women's rugby union in the UK. All players had at least three years of experience in rugby training and strength training in a structured rugby club and took part in 2 rugby team practices and 2 individual gym sessions per week. Tests included in this study were part of the 2019-2020 annual season monitoring test battery, agreed by both the medical, and strength and conditioning staff. The study was approved by the London Sport Institute research ethics subcommittee at Middlesex University. Players were informed of the benefits and risks of the investigation before signing written informed consent to participate in the study.

9.2.2 Procedures

Linear speed and COD performance measurements were conducted during mid-season and post-season. During the two separate testing time frames, players with a medical condition or injury were excluded from the physical fitness assessment. All subjects refrained from intensive exercise in the 24-hour period prior to testing. Anthropometric measurements were taken for each participant before the testing session started. Players underwent a standardized warm-up, consisting of 10 minutes of dynamic stretching followed by 1 practice trials for each of the linear speed and COD assessments. Players were familiar with all tests, which were also conducted during their regular annual performance monitoring and running sessions.

9.2.2.1 Anthropometry

For the detailed testing procedures used for anthropometry refer to Chapter 3.1.

9.2.2.2 Linear speed test

For the detailed testing procedures used for sprint assessments refer to Chapter 3.4.

9.2.2.3 505 COD test

For the detailed testing procedures used for sprint assessments refer to Chapter 3.5. The dominant direction (D), non-dominant (ND) and CODD of both directions were recorded.

9.2.3 Statistical Analysis

Subjects were separated into 2 groups for comparing positional differences: forwards and backs. COD speed groups were created by splitting the groups into thirds based on D505 time. All data were presented as mean ± standard deviation. For the detailed procedures used for normality, reliability, and longitudinal changes can be refer to chapter 3.6.

9.3 RESULTS

All variables in this study were normally distributed when athletes were grouped into mid- and post-season. Average variability for all variables demonstrated at least moderate (ICC < .67 or CV > 10%) to small (ICC > .67 and CV < 10%) variability (Table 9.1 and 9.2).

The differences in COD ability, BM and linear speed between mid- and post-season are in Table 9.3. Results showed a large practical increase in BM and initial momentum (g= -0,71 and -0.79). There is also a small practical increase in both D and ND 505 time from mid-to post season (g = -0.37 and -0.41).

Table 9.1. Between-trial reliability for mid-season COD measures

	Mean ± SD	CV% (95% CI)	ICC (95% CI)	Average variability	SEM
Initial momentum (kg.m/s)	391.76 ± 67.84	1.31 (0.62, 1.99)	0.97 (0.92,1.00)	small	22.41
Velocity(m/s)	5.19 ± 0.22	1.31 (0.62, 1.99)	0.91 (0.57, 0.99)	small	0.113
Time (s)	1.93 ± 0.08	1.31 (0.62, 1.99)	0.90 (0.52, 0.98)	small	0.04
505 left turn (s)	2.44 ± 0.10	0.43 (0.21, 0.66)	0.99 (0.93, 1.00)	small	0.046
CODD left turn (s)	0.51 ± 0.05	2.05 (0.97, 3.12)	0.98 (0.91, 1.00)	small	0.04
505 right turn (s)	2.51 ± 0.05	0.36 (0.17, 0.54)	0.98 (0.94, 1.00)	small	0.04
CODD right turn	0.58 ± 0.08	1.86 (0.89, 2.84)	0.92 (0.61, 0.99)	small	0.02

COD = change of direction; CODD = change of direction deficit; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

Table 9.2. Between-trial reliability for post-season COD measures

	Mean ± SD	CV% (95% CI)	ICC (95% CI)	Average variability	SEM
Initial momentum (kg.m/s)	402.01 ± 72.35	0.37 (0.18, 0.57)	0.99 (0.94, 0.99)	small	24.41
Velocity(m/s)	5.21 ± 0.24	0.37 (0.18, 0.57)	0.99 (0.94, 0.99)	small	0.12
Time (s)	1.92 ± 0.09	0.37 (0.18, 0.57)	0.99 (0.94, 0.99)	small	0.05
505 left turn (s)	2.48 ± 0.13	0.32 (0.15, 0.49)	0.99 (0.94, 0.99)	small	0.05
CODD left turn (s)	0.55 ± 0.10	2.36 (1.12, 3.59)	0.98 (0.87, 0.99)	small	0.05
505 right turn (s)	2.54 ± 0.15	0.29 (0.14, 0.44)	0.99 (0.97, 0.99)	small	0.06
CODD right turn	0.62 ± 0.12	2.44 (1.16, 3.71)	0.98 (0.89, 1.00)	small	0.05

COD = change of direction; CODD = change of direction deficit; CV = coefficient of variations; ICC = intra-class correlation coefficient; CI = confidence interval; SEM = standard error mean. Average variability: small (ICC>0.67, CV<10%), moderate (ICC<0.67 or CV>10%) and large (ICC<0.67, CV>10%)

Table 9.3. COD ability differences between mid-and post season.

Variable	**Mid-season N = 9**	**Post-season N = 9**	***g* (95% CI) Mid- vs post-**
BM (kg)	75.59 ± 14.82	77.46 ± 16.26	-0.79 (-1.59, 0.05)
10 m sprint (s)	1.93 ± 0.08	1.92 ± 0.09	0.27 (-0.45, 0.97)
Velocity (m/s)	5.19 ± 0.22	5.21 ± 0.24	-0.29 (-0.99, 0.43)
Initial Momentum (kg/m/s)	391.76 ± 67.84	402.01 ± 72.35	-0.71 (-1.48, 0.11)
D 505 time (s)	2.44 ± 0.10	2.48 ± 0.13	-0.37 (-1.08, 0.37)
D CODD (s)	0.51 ± 0.05	0.55 ± 0.10	-0.17 (-0.86, 0.54)
ND 505 time (s)	2.51 ± 0.12	2.54 ± 0.15	-0.41 (-1.13, 0.33)
ND CODD (s)	0.58 ± 0.08	0.62 ± 0.12	-0.14 (-0.83, 0.57)

BM = body mass; D = dominate side; CODD = change of direction deficit; ND = non-dominate; **Bold effect size = *p* < 0.05**

9.4 DISCUSSION

The main purpose of the present study was to observe the seasonal changes in COD ability in women's rugby union. When comparing seasonal changes from mid-to post-season, results demonstrated that there was a large practical increase in BM and initial momentum with only a small practical improvement in 10 m velocity. 505 time in both D and ND side reported a small practical increase. Different results were shown in men's football and women softball, where both studies showed moderate to large improvements from mid to post season in 505 time (Bishop et al., 2023; Nimphius et al., 2012). The difference in results might be due to the large increase in BM and momentum, therefore despite the CODD having only a trivial increase, the changes in BM might have affected COD ability (Emmonds et al., 2019; Kukić et al., 2020). The results presented through mid- to post-season were also similar to the findings in different speed groups as described in chapter 7, identifying when athletes have similar linear acceleration speed, the ones with greater BM and momentum typically have slower 505 times. The increase in BM from mid- to post-season might be due to the impact of the COVID pandemic the athletes had to face during this season. Quarantine restrictions, limited gym usage and shorter team training, might have caused the athletes in this study to gain BM during the later stage of the season, which is in contrast to results found in study 3 (Chapter 4) demonstrating athletes were able to maintain their BM throughout a competitive rugby season.

COD is a motor skill that would be affected not just by linear speed and BM, but also the COD technique on the specific task, such as foot placement, and body angle before and after the turn (Dos' Santos et al., 2021). Therefore, caution is needed when observing seasonal differences and trying to adjust training plans to improve COD ability because the changes in COD ability might come from changing BM or linear speed, with or without improving efficient COD technique. In this study, some limitations must also be noted. Firstly, due to the COVID pandemic affecting semi-professional sport, the study missed the pre-season testing of COD testing. Secondly, due to the low participants in the longitudinal study, the athletes couldn't be split into positional groups or speed groups. The addition of these covariates would potentially provide a greater understanding of seasonal change and COD ability as a competitive group. More studies should focus on understanding COD ability and technique in female rugby union players due to the large variation of speed and body composition across positions which might affect CODD or 505 time. This information would allow practitioners to make informed decisions in improving performance by specific training or adjusting body composition.

9.5 CONCLUSION

This is the first study to examine longitudinal changes in COD ability, linear speed and momentum in women's rugby union. When monitoring COD ability using 505 and CODD in women's rugby, linear speed and momentum should also be taken into consideration to understand the reason behind changes in COD performance.

Chapter 10 General Discussion

10.1 Thesis Overview

The main aims of the research presented in this thesis were to (1) understand the match demands, anthropometry and physical characteristics of women's rugby union and (2) determine the anthropometry and physical characteristics in English premiership women's rugby union. Lastly, (3) to observe the physical profile changes throughout a season. To meet these aims, this thesis consists of a systematic review (Chapter 2), and three within-subject research studies (Chapters 4, 6 and 8) comparing positional differences in anthropometry, strength, power, speed and COD performance. Furthermore, three longitudinal research studies (Chapter 5, 7 and 9) which were conducted to observe the characteristics and performance changes throughout the women's rugby season.

10.2 Discussion of the results

Through the systematic review, the match demands of women's rugby union are clearly demonstrated. Through the separation of positions in women's rugby, forwards were involved in more low intensity running and higher collision loads, and backs were involved in more high intensity running and sprinting, having higher maximum speed. The total distance and moderate intensity running distance coved will be based on playing time, substitution strategy, match intensity, different tactical approaches, and greater squad depth (Bradley et al., 2019; Busbridge et al., 2020; Neto et al., 2021; Sheppy et al., 2019; Suarez-Arrones et al., 2014; Woodhouse et al., 2021a).

The anthropometry characteristics of women's rugby union was clarified in this thesis (Chapter 4). The results in Chapter 4 identified anthropometry characteristics three times in a season and found similar results to the systematic review (Chapter 2). Forwards across region and competition level were recorded to have statistically significantly higher body mass, fat%, fat mass, and lean mass. The review also identified when separated to more detailed positional groups, front row props were the heaviest in the whole squad (Harty et al., 2021; Woodhouse et al., 2021b). These general findings matched the findings of match demands that forwards face more collision activities (tackle, maul, ruck, scrum), for which increased BM (fat and lean mass) could support as a protective buffer, whilst concurrently increasing momentum (Duthie, Grant et al., 2003). When discussing seasonal changes in anthropometry characteristics (Chapter 5), despite statistically significantly increases in lean mass in forwards (pre- to mid-season) and backs (pre- to mid-season), only trivial to small practical differences were shown (g = 0.19, 95% CI = 0.03 to 0.35; g = 0.23, 95% CI = 0.09 to 0.37). Therefore, results have shown (Chapter 5) that it is possible to maintain physical status from pre- to post-season throughout a 9-month women's rugby union season.

Strength characteristics had been reported using multiple methods in this thesis (Chapter 2). For upper body strength, recent studies reported forwards had statistically significant heavier 1RM bench press (Woodhouse et al., 2021b; Yao et al., 2021) compared to backs. When discussing upper body relative strength, only one out of the four studies reported backs had statistically significantly higher relative strength in 1RM bench press and 1RM pull ups (Imbert et al., 2023). For grip strength, no significant differences between forwards and backs were found (Kirby & Reilly, 1993;

Neto et al., 2021; Sarkar & Dey, 2019). For maximum repetition tests, forwards were found to perform statistically significantly fewer push-ups than backs (ES = 0.5 to 0.97) (Hene et al., 2011; Kirby & Reilly, 1993; Neto et al., 2021; Quarrie et al., 1995). These upper body strength results might be caused by the statistically significantly higher lean mass and fat mass in forwards. Having higher absolute strength supports forwards' match demands, requiring higher collision loads according to the systematic review (Chapter 2). However, due to the higher fat mass in forwards, it creates the difficulty in demonstrating relative strength or achieving higher scores in max repetition tests (Hene et al., 2011; Imbert et al., 2023). From the systematic review (Chapter 2) and Chapter 4 discussing lower body strength differences between forwards and backs, no statistically significant differences between forwards and backs in absolute strength using IMTP and 1RM back squat were revealed (Yao et al., 2021). A study in English international women's players found only front row players were statistically significantly stronger than all the backs positions using the SL ISO squat test, and inside backs had similar absolute strength with locks and back row players (Woodhouse et al., 2021b). This might explain why chapter 4 and previous studies showed no significant difference in absolute lower body strength when only separating positions into categories of forwards and backs.

For power characteristics, including the systematic review as well as empirical research, the most common test method used was the CMJ (Hene et al., 2011; Kirby & Reilly, 1993; Neto et al., 2021; Quarrie et al., 1995; Woodhouse et al., 2021b; Yao et al., 2021). All recent studies reported backs demonstrated statistically significantly higher jump height compared to forwards. (Hene et al., 2011; Quarrie et al., 1995; Yao et al., 2021). Similar results determined that outside backs jumped statistically significantly higher than all other forward positions (Woodhouse et al., 2021b). Other mechanistic and power variables were reported in different studies as well including time to take off, take off velocity, jump momentum, and power output. Backs were reported to have higher CMJ RSImod (ES = 0.67) (Yao et al., 2021) but no significant difference in CMJ power output (Neto et al., 2021; Woodhouse et al., 2021b). Similar results were found in Chapter 4, forwards and backs showed no statistically significant differences in time to take off during CMJ, but backs achieved statistically significantly higher scores in JH, take off velocity and RSImod. Besides CMJ, DJ testing was also presented, with backs showing statistically significantly higher drop jump JH and higher (RSI) (ES = 1.15) (Woodhouse et al., 2021b; Yao et al., 2021). In Chapter 4, backs were also found to have statistically significantly shorter CT in the drop jump. Therefore, results demonstrated in CMJ and DJ, backs can produce higher JH with shorter or similar CT.

In this thesis, linear speed has been discussed in multiple distance including 10 m, 20 m, 30 m, 40 yd, 40 m 50 m and 100 m. In Chapter 6, backs were reported to have statistically significantly faster acceleration and top speed in 40 m sprints, which is similar to previous studies across different playing levels (Hene et al., 2011; Neto et al., 2021; Woodhouse et al., 2021b; Yao et al., 2021). Three studies also presented sprint momentum since it has been identified to be crucial for women's rugby union and it was found that players who have higher sprint momentum dominated carry and tackle statistics within a match (Woodhouse et al., 2023). Results of Chapter 6 found similar results, showing that despite having slower sprint speeds, forwards can still produce statistically significantly higher sprint momentum. Furthermore, Chapter 6 is the first research to discuss kinematic characteristics in women's rugby union and found that backs created faster acceleration utilising statistically significantly shorter CT, longer FT, higher SR and SL. For top speed mechanics, Chapter 6 reported there were only moderate practical difference in CT (g = 0.51, 95% CI = -0.24 to 1.24) and SV (g = -0.55, 95% CI = -1.29 to 0.20). When separating female rugby players into different speed groups based on 10 m sprint time, fast athletes were found in this thesis to have statistically significantly lighter BM, shorter CT, smaller CF ratio, and faster SV. Furthermore, moderately higher FT (g = 0.63, 95% CI = -0.29 to 1.54), largely higher SR, longer SL, toe-off distance, FL, and wider toe-off thigh angle were presented when comparing fast to slow athletes in acceleration kinematics. Similar characteristics were found in top speed kinematics with fast group athletes used statistically shorter CT to generate largely higher SR (g = 1.70, 95% CI = 0.65 to 2.71), SL (g = 1.19, 95% CI = -0.22 to 2.12) and FL (g = 1.34, 95% CI = 0.36 to 2.30) resulting with statistically significantly faster SV. The correlation results in Chapter 6 also supports the finding between speed group, demonstrating to reach a faster velocity in acceleration and top speed, multiple sprint kinematics may affect performance, not one specific. This is the first study to identify sprint kinematics in women's rugby union and to identify the differences between positions and between athletes in different speed. The results of having shorter CT and generating longer or similar SL is important for both acceleration and top speed running which is similar to results from male and female sprinters and male rugby players (Debaere et al., 2013; Economou et al., 2021; Gleadhill & Nagahara, 2021; Wild et al., 2018). This thesis suggested that besides sprint time (outcome measure), monitoring sprint kinematics (strategy measure) may provide a more holistic picture into the sprint performance of female rugby union players.

Regarding longitudinal changes in linear sprint throughout a season, findings in Chapter 7 found in both acceleration and top speed performance, there was a statistically significant decrease in velocity and momentum from pre-to mid-season and maintenance or moderate improvements from mid to post-season. Similar to previous studies showing female rugby union athletes decreased sprint velocity from pre-to mid-season and increased from mid-to post-season (Hene & Bassett, 2013). In contrast, South African female rugby players improved significantly in acceleration from mid-to post-season, and forwards got significantly faster when comparing pre-to post-season (Hene & Bassett, 2013). Not having significant improvements in sprint velocity from mid-to post-season might be due to participants in Chapter 7 being mainly semi-professional, which may affect in-season recovery due to also being a full-time student or having a full-time job besides training and competing in rugby.

In acceleration kinematics from pre-to mid-season, a large increase in CT (g = -1.38, 95% CI = -2.36 to -0.32) and a moderate decrease in FT (g = 0.66, 95% CI = -0.14 to 1.43) with moderately lower SR (g = 0.51, 95% CI = -0.26 to 1.23) and SV (g = 0.65, 95% CI = -0.15 to 1.41) was reported in Chapter 7. The decrease in acceleration performance might be caused by the fatigue throughout a competitive season, therefore affecting the acceleration kinematics (Barr et al., 2014a) with similar results also presented in women footballers (van den Tillaar, 2021). When comparing mid- to post-season, although no differences were found in velocity, the acceleration strategy changed by largely decreasing CT (g = 0.90, 95% CI = 0.02 to 1.73) and statistically significantly increasing FT, thus creating a significant decrease in CF ratio; most of the kinematic variables showed only trivial to small differences when comparing to pre-season. Therefore, it is assumed that players in this study due to a tapered training load in preparation for the final, improved the efficiency in acceleration from mid- to post-season and were similar to pre-season despite no statistically significant improvements in velocity. In top speed kinematics, athletes in pre-season demonstrated moderately shorter CT (g = -0.62, 95% CI = -1.38 to 0.17) compared to mid-season and moderately longer FT (g = 0.72, 95% CI = -0.10 to 1.50) compared to post-season therefore, thus the CF ratio was the lowest in pre-season. In addition, it is possible to identify during a rugby season, that female rugby athletes' top speed performance could be affected by external factors like running strategy (Wild et al., 2022). The trend of decreasing speed performance from pre-to mid-season in both acceleration and top speed, and either maintaining or improved from mid-to post-season might also be due to the training focus at different stage of the season. Coming from pre-season to in-season, training load decreased, game fatigue increased, and gym training went from more strength focused to more speed-strength focused, with a taper before the final few games. In addition, the performance outcome matches the training focus, with acceleration being more strength focused and top speed being higher impulse in a short period of time (Barr et al., 2013). Chapter 6 and 7 are the first studies to investigate women's rugby sprint kinematics and longitudinal changes, therefore, it is known that using kinematics may be able to understand how an athlete performs the sprint and may be useful for long term monitoring for training improvements or fatigue management.

COD ability in women's rugby union was discussed in Chapter 8. For COD ability, backs performed statistically significantly faster 505 time in both D and ND side. It was shown in Chapter 4 and 8 that backs performed statistically significantly faster acceleration but generated statistically significantly lower initial momentum. Therefore, it is assumed that backs in this thesis had significantly faster acceleration time and less momentum to overcome braking forces compared to forwards, who were therefore advantaged in the acceleration and reacceleration phase in the 505 test (Nimphius et al., 2016). Results in Chapter 8 also found based on 505 time, the fast group had statistically significantly smaller initial momentum, and higher linear acceleration. The moderate group had similar linear speed but higher BM and CODD than the fast group. The slow group had the highest BM with the slowest speed but similar CODD with the fast group. Furthermore, the slow group although having similar initial momentum with the moderate group, had statistically significantly slower linear speed, therefore the moderate group needs to apply more braking force to overcome the greater inertia negatively affecting CODD (Freitas et al., 2021b). The difference between speed groups might be due to large anthropometrical and physical differences in women's rugby union (Woodhouse et al., 2021b; Yao et al., 2021). Chapter 8 also assessed the correlation in forwards and backs between COD ability, BM, and linear speed, and found similar results, demonstrating forwards with higher initial momentum or linear speed had significantly positive relationships with DCODD. In backs, players with higher linear speed had significantly positive relationships with both D and ND CODD. The longitudinal COD study in this thesis (Chapter 9) found that there was a large increase (g = -0.71, 95% CI = -1.48 to 0.11) in initial momentum due to BM increased. The 505 time on both D and ND side had a small increase with trivial differences in CODD from mid- to post-season. In addition, initial momentum may affect COD ability, however, both variables that generate momentum (velocity and mass) need to both take into account separately to support understanding COD ability.

10.3 Overall Summary

In conclusion, the results presented in this thesis have demonstrated the anthropometric and physical characteristics for English premiership women's rugby union players. Forwards were generally heavier with higher lean mass and fat mass. Backs were leaner, faster, and relatively stronger. Faster athletes sprint faster by using shorter CT to generate similar to bigger toe- off distance, creating bigger toe-off thigh angle, to generate higher SR and SV. In COD, fast athletes had higher linear speed with less BM. This thesis also identified when comparing locomotive skills such as sprinting or COD, just splitting into forwards and backs might not be clear to identify positional characteristics due to previous studies showing overlap between back rows and inside centres. In addition, when this thesis separated the squad based on performance test outcomes, the moderate group also had different sprinting and COD characteristics. Furthermore, this thesis also demonstrated that with only outcome measures, it would be difficult to understand the strategy the athletes used. Therefore, when reporting physical characteristics such as JH, speed, COD, adding strategy measures such as time to take-off, CT, kinematics, CODD, may help practitioners to have a better understanding of the performance outcome. The thesis also demonstrated during longitudinal studies in power, speed, and COD that despite outcome measures being similar, the strategy measures might demonstrate a significant change, therefore caution should be exercised when trying to adjust outcome measures in the absence of strategy data for individual athletes.

10.4 Practical implications

The current data presented multiple ways to monitor and understand anthropometry and physical characteristics in women's rugby union. With the dramatic anthropometric characteristic differences between positions, it would be beneficial to monitor anthropometry throughout the season, therefore, it is suggested to use DEXA scan assessments as the most accurate, and skinfold as the most budget friendly way. Furthermore, if skinfold is used, the more sites measured the more accurate the predicted fat% will be. Secondly, for power characteristics, strategy measures should also be noted to inform outcome measures. Including both outcome and strategy measures during testing may support monitoring long term athlete development throughout a season or across seasons of performance changes. Thirdly, when monitoring locomotive skill such as COD and sprinting, splitting athletes based on different speed groups or kinematic groups may be more beneficial for training interventions to observe change rather than positional groups. Additionally, this thesis provides practitioners a basic understanding of athletes' physical standards in English premiership women's rugby union. This will allow practitioners to make informed recruitment and training decisions for junior or semi-professional athletes to improve performance. Lastly, with an understanding of seasonal changes, in both anthropometric and physical characteristics, training intervention studies should be incorporated to elicit significant changes in the performance variables throughout the season.

10.5 Managing performance and anthropometry characteristics in female athletes

From this thesis, results have shown higher BM and BF% may have a negative impact on physical performance including slower jump strategy, linear sprints, COD ability and aerobic capacity. Despite the match demands required, female rugby athletes likely must have a certain amount of FM to face collisions and forwards-based activity such as scrums. Therefore, managing BF% may support female rugby athletes to increase physical performance. However, studies have shown females with higher FM (overweight or obese) may also suffer from eating disorders and low energy availability due to weight-related teasing and other behaviors that could affect negatively their self-esteem and thus energy intake (Torres-McGehee et al., 2021; Veses et al., 2011). Therefore, for practitioners trying to manage female rugby athletes' anthropometry characteristics, it is important to go through nutritional education with the athletes regarding the importance of fueling to meet the energy demands of training and competition. Furthermore, understanding each athlete's psychological needs and tailoring feedback on an individual basis will likely show better results when managing FM in female (Guglielmi et al., 2024).

10.6 Future investigations

The present body of work provides a thorough investigation of the anthropometric and physical characteristics in women's rugby union. However, a number of aspects of the study design and general limitations of the current research opens avenues for future investigation. Moreover, the findings of the current research offer potential for future inquiry. Specifically, future studies should expand on this research to look at more than one English premiership women's team, therefore, more detailed positional groups can be examined to identify positional differences. Furthermore, it may decrease the limitation of using participants from the same team, which might affect the results based on the players recruited and team playing strategy.

Future studies should also investigate the relationship between match performance outcome metrics (i.e. dominated tackle, winning scrums) and physical characteristics to support practitioners understanding the key performance indicators (KPI). With the understanding of match KPIs and physical characteristics, training interventions may be implemented to support performance gains. Lastly, physiological differences in female athletes (i.e. menstrual cycle) were not monitored in this thesis but may also affect training and competition performance. Future studies should consider understanding how the menstrual cycle affects female rugby athletes' performance and how to effectively monitor and implement training adjustments. Collectively, these studies will provide a better understanding of women's rugby, and thus will allow new monitoring or training hypotheses to be formulated to assist future research and practitioners to support athletes to improve overall performance.

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Appendices

Ethics approve form for the whole thesis.

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01/06/2020

APPLICATION NUMBER: 7701

Dear Xiang Yao and all collaborators/co-investigators

Re your application title: Players characteristics in Womens Rugby Union

Supervisor:

Co-investigators/collaborators:

Thank you for submitting your application. I can confirm that your application has been given APPROVAL from the date of this letter by the London Sport Institute REC.

The following documents have been reviewed and approved as part of this research ethics application:

Document Type	File Name	Date	Version
Amendments	approved Letter	01/06/2020	1

Although your application has been approved, the reviewers of your application may have made some useful comments on your application. Please look at your online application again to check whether the reviewers have added any comments for you to look at.

Also, please note the following:

1. Please ensure that you contact your supervisor/research ethics committee (REC) if any changes are made to the research project which could affect your ethics approval. There is an Amendment sub-form on MORE that can be completed and submitted to your REC for further review.

2. You must notify your supervisor/REC if there is a breach in data protection management or any issues that arise that may lead to a health and safety concern or conflict of interests.

3. If you require more time to complete your research, i.e., beyond the date specified in your application, please complete the Extension sub-form on MORE and submit it your REC for review.

4. Please quote the application number in any correspondence.

5. It is important that you retain this document as evidence of research ethics approval, as it may be required for submission to external bodies (e.g., NHS, grant awarding bodies) or as part of your research report, dissemination (e.g., journal articles) and data management plan.

6. Also, please forward any other information that would be helpful in enhancing our application form and procedures - please contact MOREsupport@mdx.ac.uk to provide feedback.

Good luck with your research.

Yours sincerely

Page 1 of 2

Chanda Cole

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01/06/2020

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Co-investigators/collaborators: Mr Xiang Yao

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Amendments	new_Methods	01/06/2020	1
Amendments	(LSI) Participation Information Sheet (PIS)	01/06/2020	1
Amendments	GateKeeper Letter (Data)	01/06/2020	1
Amendments	Gatekeeper letter (Intrusive)	01/06/2020	1
Amendments	Letter	01/06/2020	1
Amendments	Scan 2019-04-23-12-26-53	01/06/2020	1
Amendments	Scan 2019-04-23-12-28-27	01/06/2020	1

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Good luck with your research.