Enhancing Strategies to Optimise Body Composition and Nutrition in Professional Rugby Union Players

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Thesis Abstract

Body composition and nutrition play a vital role in both health and sporting performance. Optimising energy and macronutrient requirements for a team, position, and/or individual, can enhance an athlete's preparation, performance, and recovery from training and competition. The requirements of professional Rugby Union (RU) are unique given players can be very large, strong, and powerful, or much smaller, faster, and elusive. Regardless of their size or respective playing position, players must be able to withstand numerous high-impact collisions, yet, be fit enough to play 40-80 minutes at high-intensity week after week. Therefore, positional and/or individualised body composition and fuelling requirements are required. Through a series of seven studies, this PhD thesis aimed to enhance the understanding of body composition and nutritional requirements for professional RU players.

Study One assessed the physical and fitness characteristics of elite male professional RU players from New Zealand (NZ) by primary playing position. Study Two examined the physical characteristics of elite female RU union players from NZ between and within different playing positions. Study Three assessed the body composition and anthropometrics by specific playing position and playing level among professional male and female RU players from NZ. A newly developed skinfold-based prediction equation was created to estimate body fat percentage (BF%) among male and female forwards and backs. Study Four explored the competition nutrition practices of elite male professional RU players from NZ over seven-days which included game-day (GD). Study Five examined the dietary intakes of elite male professional RU players from NZ in catered and non-catered environments, both during competition weeks which included GD. Study Six measured the resting metabolic rate (RMR) of professional male RU players from NZ and developed new RU-specific prediction equations. Finally, Study Seven evaluated the in-season energy demands of elite male professional RU players from NZ, providing specific training session and game-play energy demands by position.

In Study One, at the end of pre-season, body composition was assessed among elite male professional RU players (*n* = 39) using sum of eight-site skinfolds (Sum8SF) and Dual-energy X-ray Absorptiometry (DXA), alongside fitness (strength, power, speed, and aerobic fitness) measures. Forwards possessed significantly greater body composition measures compared to backs. Both forwards and backs within this study were taller, heavier, and leaner than players from previous studies in the northern hemisphere. Among forwards, Sum8SF demonstrated *very large* correlations with relative power and speed measures, while backs demonstrated

large correlations between Sum8SF and aerobic fitness. Fat mass and BF% demonstrated *very large* correlations with speed and aerobic fitness measures among forwards. Skinfolds, fat mass, and BF% relate strongly with key fitness characteristics required for elite male professional RU performance.

In Study Two, the body composition of elite female RU players (n = 30) was assessed using Sum8SF and DXA during the in-season period. Forwards were significantly taller, heavier, and possessed greater Sum8SF than backs. Forwards also possessed significantly greater total and regional body composition measures compared to backs. Healthy bone mineral density measures were observed among both forwards and backs. Significant differences were also present among forward positional groups.

Study Three extended on from Studies One and Two by examining the body composition (using DXA) and anthropometric (using Sum8SF) differences between specific playing positions and playing levels among professional male (n = 104) and female (n = 75) RU players. Elite players demonstrated significantly higher levels of lean mass than sub-elite players. Relationships between BF% and Sum8SF were *large* among female backs, and *very large* among male and female forwards and male backs. A new BF% prediction equation was developed using Sum8SF among male forward and back positions, and female forward and back positions.

In Study Four, elite male professional RU players (n = 34) from NZ completed dietary intakes in-season using the Snap-N-Send method during a seven-day competition week which included GD. Forwards reported significantly higher absolute energy intakes, but no significant differences were observed for mean seven-day relative carbohydrate, protein, and fat intakes. Both forwards and backs reported their highest energy and carbohydrate intakes for the week on GD, with ~62% of total kcal being consumed prior to the start of the game. Players fell short of daily sports nutrition guidelines for carbohydrate and appeared to "eat to intensity" by increasing or decreasing energy and carbohydrate intake based on the training load.

Study Five, extended on from Study Four by examining the dietary intakes of elite male professional RU players (n = 12) in catered and non-catered environments during two seven-day competition weeks which both included GD. No significant differences were observed for relative carbohydrate intake between catered and non-catered environments among forwards and backs. Whereas, mean seven-day absolute energy, relative protein, and relative fat intakes were significantly higher in the catered compared to non-catered environment among forwards.

Meanwhile, backs presented non-significantly higher energy and macronutrient intakes within a catered compared to a non-catered environment.

In Study Six, the RMR of male professional RU players (n = 108) were examined using indirect calorimetry, which were then compared to nine commonly used prediction equations. Compared to measured RMR for the group, seven of the nine commonly used prediction equations significantly under-estimated RMR, meanwhile one equation significantly over-estimated RMR. This led to the development and validation of two new RU-specific prediction equations which determined that the strongest predictors for this group were fat-free mass (FFM) alone, followed by body mass (BM) alone.

Lastly, Study Seven examined the game-play, daily, and session specific exercise energy expenditure alongside energy intake during a competition week among elite male professional RU players (n = 24). Each player's FFM was measured using DXA, which then allowed energy availability to be calculated. Changes in body mass and Sum8SF were then measured four-weeks apart to determine changes based on energy availability. This study also examined RMR on a rest day (three-days prior to GD [GD-3]) during the competition week and the morning after the game (GD+1). Significant differences between days, training sessions, game-play, and RMR between days were observed. Significant differences between energy availability groups and changes in body mass and Sum8SF were also present.

In summary, the series of studies in this thesis provide valuable insight into the body composition and nutrition requirements of professional RU players. Practical strategies are provided to help practitioners estimate BF% if laboratory-based methods are not attainable, which can then inform FFM to be used in the newly developed FFM-based RMR prediction equation. However, a BM-based RMR prediction equation was also developed in case Sum8SF and FFM measures are not attainable. Finally, when the $kcal \cdot kg \cdot min^{-1}$ factors are used to determine game-play and/or specific training session exercise energy expenditure, energy requirements can be determined specifically for professional RU players to optimise fuelling and/or body composition change strategies.

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Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where explicitly defined, nor material which to a substantial extent has been submitted for the award of any other degree or diploma of university or institution of higher learning."

Logan Posthumus

May 2024

List of Abbreviations

ADP	Air displacement plethysmography
AED	Average energy demands
AFL	Australian football league
ANOVA	Analysis of variance
AU	Arbitrary units
AvgHR	Average heart rate
BC	Backs catered
BF%	Body fat percentage
BM	Body mass
BMC	Bone mineral content
BMD	Bone mineral density
BNC	Backs non-catered
BPM	Beats per minute
BR	Back row
CHO	Carbohydrate
CL	Confidence limit
CI	Confidence interval
CV	Coefficient of variation
DLW	Doubly labelled water
DXA	Dual-energy x-ray absorptiometry
EA	Energy availability
EE	Energy expenditure
EEE	Exercise energy expenditure
EI	Energy intake
EIMD	Exercise-induced muscle damage
ES	Effect size
FC	Forwards catered
FFM	Fat-free mass
FM	Fat mass
FN	Forwards non-catered
FR	Front row
GD	Game day
GPS	Global positioning system
HEA	High energy availability
HMLD	High metabolic load distance
HR	Heart rate
IB	Inside back
IC	Indirect calorimetry
IIMD	Impact-induced muscle damage
ISAK	International society for the advancement of kinanthropometry
Kcal	Kilocalories
Kj	Kilojoules

KPM	Kilocalories per kilogram per minute
LBM	Lean body mass
LEA	Low energy availability
LF	Loose forwards
LM	Lean mass
MaxHR	Maximum heart rate
MD	Mean difference
MEA	Moderate energy availability
MAPE	Mean absolute percentage error
MJ	Megajoules
NZ	New Zealand
OB	Outside back
PAL	Physical activity level
RFPM	Remote food photography method
RMR	Resting metabolic rate
RMSE	Root mean squared error
RU	Rugby union
RL	Rugby league
sRPE	Session rate of perceived exertion
SD	Standard deviation
SE	Standard error
SEE	Standard error of estimate
SPSS	Statistical package for the social sciences
Sum8SF	Sum of eight site skinfolds
SWA	SenseWear armbands
TD	Total distance
TEE	Total energy expenditure
TF	Tight five
TEI	Total energy intake

CHAPTER ONE

Thesis Overview

The primary aim of this thesis was to investigate the physical characteristics and fuelling requirements of professional male rugby union players and enhance the strategies used to optimise body composition and nutrition prescription among these athletes. A secondary aim of this thesis was to investigate the physical characteristics among elite female rugby union players.

The thesis comprises seven studies (see Figure 1) that aimed to;

- Examine the profile and relationships between physical and fitness characteristics of elite male rugby union players using Dual-energy X-ray Absorptiometry (DXA) and a range of fitness tests (Study One, Chapter Three).
- Examine the body composition requirements and bone health by playing position among elite female rugby union players using DXA in-season (Study Two, Chapter Four).
- Recruit a larger cohort of professional male and female rugby union players to determine physical characteristics by specific playing position and playing level, and to develop a new population specific prediction equation to estimate body fat percentage using skinfolds among male and female, forwards and backs (Study Three, Chapter Five).
- Understand the fuelling practices of elite male professional rugby union players during a seven-day in-season competition week, and how players fuel on game-day including pre- and post-game (Study Four, Chapter Six).
- Assess the dietary intakes of elite male professional rugby union players in both catered (hotel-setting) and non-catered (home-setting) environments during in-season competition weeks, to understand how the two settings compare to one another (Study Five, Chapter Seven).
- Assess the resting metabolic rate of professional male rugby union players to observe the accuracy of commonly used prediction equations, and to develop a new rugby union specific prediction equation if pre-existing equations were not suitable (Study Six, Chapter Eight).

- Assess in-season energy availability during a seven-day competition week, track body mass and skinfold changes over a four-week period based on energy availability groups, determine the exercise energy expenditure from all training sessions and game-play, and determine what influence a game has on resting metabolic rate to inform energy requirements among elite male professional rugby union players (Study Seven, Chapter Nine).

COVID-19 Impact Statement

It is also important to note that, in the schematic of the thesis structure (see Figure 1) between Study Six (Chapter Eight) and Seven (Chapter Nine), a 'cancelled' study can be seen. This description was included in the thesis structure because Study Seven was going to determine the in-season energy requirements of elite male professional rugby union players using the Doubly Labelled Water Method. However, due to the COVID-19 Pandemic this study was cancelled due to many access and logistical reasons. Therefore, Study Seven could not accurately provide total energy expenditure, therefore energy availability and the exercise energy expenditure from specific training sessions and game-play became the primary aim.

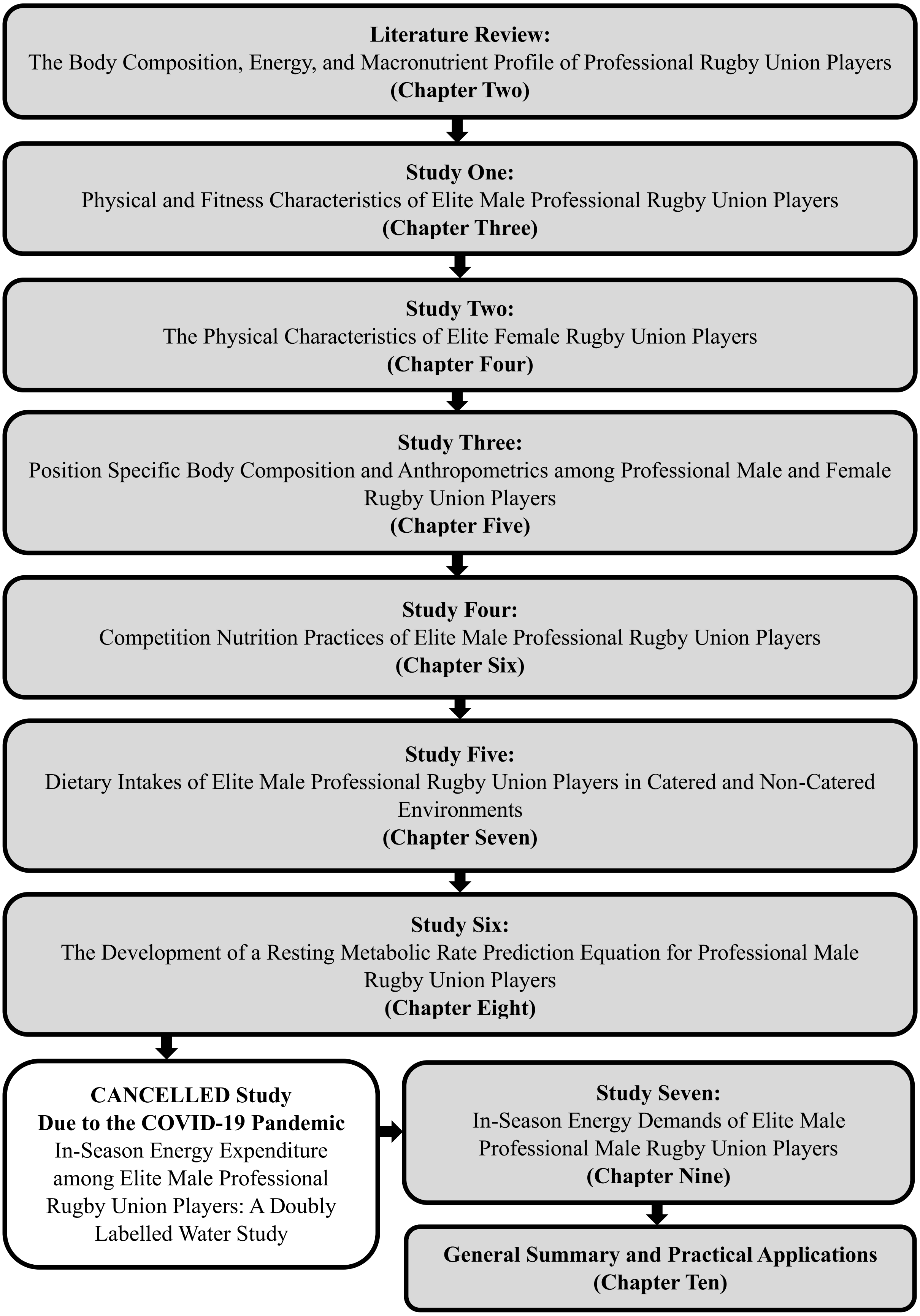

Figure 1. Schematic of the thesis structure.

Thesis Rationale

The majority of body composition research among male professional rugby union players has been carried out in the northern hemisphere and in Australia using laboratory-based equipment such as DXA, which provides great insight into the physical make-up of these athletes. It is important to use similar equipment and methods to investigate these characteristics among New Zealand professional rugby union players to further understand this group of athletes given the distinct differences in conditions and game-play between different regions of the world. However, if players or practitioners are not able to obtain DXA scans to determine more in-depth body composition methods that can be used in inform other prescription needs, such as body fat percentage and fat-free mass, then alternative strategies may need to be explored with potentially more convenient field-based measures.

The amount of scientific research among elite female rugby union players is vastly limited compared to that of their male counterparts. Prior to commencing the studies within this thesis, no research using DXA had assessed the body composition characteristics of elite female rugby union players. Insights into the fat-free mass and bone measures of athletes is important for health, performance, and screening. Although the primary aim of this thesis was to investigate body composition and nutrition among professional males, we were presented with the opportunity to also investigate the body composition characteristics of elite female players. We saw this as a great opportunity to help grow and develop research and support in this area for elite female rugby union players in both New Zealand and abroad.

Therefore, the 'body composition' aspect of the Literature Review (Chapter Two) also includes current research among elite female RU players to inform; Study Two (Chapter Four) which examined the physical characteristics of elite female rugby union players during the in-season period using DXA, and Study Three (Chapter Five) which assessed the specific playing position and playing level body composition and anthropometric characteristics among professional male and female rugby union players and led to the development of body fat percentage prediction equation using skinfolds among both male and females. Following these two studies, the secondary aim of the thesis was achieved, which was to investigate the physical characteristics among elite female rugby union players. Therefore, the remainder of the thesis (Studies Four to Seven, Chapters Six to Nine) returned to the primary aim of the thesis which was to investigate the physical characteristics and fuelling requirements of professional male rugby union players, and enhance the strategies used to optimise body composition and nutrition prescription among these athletes.

Like body composition assessment using DXA, of the three studies that have reported dietary intakes among professional male rugby union players, two of them have been carried out in the northern hemisphere by the same researchers. Both pre-season and in-season dietary intakes have been examined, but, no dietary intakes have been reported on game-day or around game-time. Therefore, analysing the nutrition practices of elite male professional rugby union players from New Zealand who are competing on game-day, would allow further understanding of the fuelling requirements. Another area to assist the fuelling requirements of professional rugby union players, is by examining their resting metabolic rates to understand how they compare to commonly used prediction equations. This is important to consider given the substantial amounts of fat-free mass that has been reported among these players and the collisions they experience from training and game-play that may increase resting metabolic rate, which has been observed in rugby league players.

Finally, assessing and or predicting the resting metabolic rate and exercise energy expenditure from specific training sessions and game-play, alongside the assessment of body composition to determine fat-free mass, and dietary intake to assess energy and macronutrient intakes, can allow energy availability and fuelling requirements to be optimised which can have favourable outcomes on both health and performance in professional rugby union players.

Chapter Organisation

The thesis comprises a total of ten chapters. Each of the studies in Chapters Three to Nine are written as standalone chapters that are either published, accepted, under review, or in the submission process with a journal. Each chapter incorporates standard manuscript format (abstract, introduction, methodology, results, and discussion) and are therefore specific to the aims of the chapter. Chapters Three, Four, and Six to Eight appear in the same format as required by the individual journals that they were submitted to.

Chapter Two provides a literature review identifying the research that existed among professional rugby union players prior to the commencement of the studies within this thesis, followed by future recommendations which this thesis sought to address in Chapters Three to Ten. Chapters Three to Nine consist of original studies aimed to further the understanding of body composition and fuelling requirements among professional rugby union players. In Chapter Ten, a general summary of the thesis is provided, including a practical applications section which demonstrates how the findings from this thesis can be implemented to optimise the prescription of body composition and fuelling requirements among professional rugby union players.

Due to the structure of the thesis, with each chapter submitted as a standalone piece of research work for publication, there is a degree of repetition throughout the thesis. There is a single reference list of citations included at the end of the thesis, for consistency and readability.

Research Outputs Arising from this PhD Thesis

Peer Reviewed Journal Publications

Posthumus, L., Macgregor, C., Winwood, P., Darry, K., Driller, M., & Gill, N. (2020). Physical and fitness characteristics of elite professional rugby union players. *Sports*, *8*(6), 85. https://doi.org/10.3390/sports8060085

Posthumus, L., Macgregor, C., Winwood, P., Tout, J., Morton, L., Driller, M., & Gill, N. (2020). The physical characteristics of elite female rugby union players. *International Journal of Environmental Research and Public Health*, *17*(18), 6457. https://doi.org/10.3390/ijerph17186457

Posthumus, L., Fairbairn, K., Darry, K., Driller, M., Winwood, P., & Gill, N. (2021). Competition nutrition practices of elite male professional rugby union players. *International Journal of Environmental Research and Public Health*, *18*(10), 5398. https://doi.org/10.3390/ijerph18105398

Posthumus, L., Driller, M., Darry, K., Winwood, P., Rollo, I., & Gill, N. (2022). Dietary Intakes of Elite Male Professional Rugby Union Players in Catered and Non-Catered Environments. *International Journal of Environmental Research and Public Health*, *19*(23), 16242. https://doi.org/10.3390/ijerph192316242

Posthumus, L., Driller, M., Winwood, P., & Gill, N. (2024). The Development of a Resting Metabolic Rate Prediction Equation for Professional Male Rugby Union Players. *Nutrients, 16*(2), 271. https://doi.org/10.3390/nu16020271

Manuscripts Under Review for Publication

Posthumus, L., Driller, M., Winwood, P., & Gill, N. (2024). Position Specific Anthropometrics and Body Composition Among Professional Male and Female Rugby Union Players. *(Study Three, Chapter Five)*

Posthumus, L., Driller, M., Darry. K., Winwood, P., Rollo, I., & Gill, N. (2024). In-Season Energy Demands of Elite Male Professional Rugby Union Players. *(Study Seven, Chapter Nine)*

Peer Reviewed Conference Presentations

Posthumus, L., MacGregor, C., Driller, M., & Gill, N. (2019). *Body Composition and Symmetry Characteristics of Professional Rugby Union Players.* Presented at the European College of Sport Science Congress, Prague, Czech Republic. (Oral Presentation).

CHAPTER TWO

Literature Review – The Body Composition, Energy, and Macronutrient Profile of Professional Rugby Union Players

Prelude

This literature review will examine the current body composition, energy, and macronutrient profile of professional rugby union players and will highlight the future research required to better understand the requirements for this population group. Although this review is primarily focused on male professional rugby union players, the opportunity to examine the body composition characteristics of elite female rugby union players arose. Given the limited research in this area, a secondary aim of this review is to highlight future research required to better understand the body composition profile of elite female rugby union players.

Demands of Professional Rugby Union

Rugby Union (RU) is a high contact field-based team-sport which consists of an 80-minute game made up of two 40-minute halves separated by a break no longer than 15-minutes [1]. Each team has 15-players on the field at a time comprising eight forwards (numbers 1-8) and seven backs (numbers 9-15). Players contest by gaining and retaining possession of the rugby ball and accumulating points by; scoring tries across the opponent's goal-line and by kicking conversions, penalty kicks, and drop/field goals.

The eight forwards are made up of; Front-Row comprising Props (Loose-Head [number 1] and Tight-Head [number 3]) and a Hooker (number 2); Second-Row comprising Locks (numbers 4 and 5); and the Back-Row/Loose-Forwards comprising Blind-Side [number 6] and Open-Side [number 7] Flankers, and the Number-Eight (number 8). The backs are made up of; Inside-Backs comprising the Half-Back/Scrum-Half (number 9) and First-Five Eighth/Fly-Half (number 10); Midfielders comprising Second-Five Eighth/Inside-Centre [number 12] and Centre/Outside-Centre [number 13]; Outside-Backs comprising Left (number 11) and Right (number 14) Wingers, and Full-Back (number 15).

Each team also has eight reserves on the side line (bench) who can be substituted only once during the game unless blood or head injuries occur requiring a substitution [2]. Forwards generally have a larger body mass and a higher strength emphasis in order to gain and retain possession of the ball, scrummage with greater force and tolerate more frequent and impactful collisions [3]. Backs on the other hand, require greater speed and agility to control possession of the ball and create try scoring opportunities from more wide open-spaces which generally favours a slightly lower body mass and more efficient muscle to fat mass ratio [1].

The game itself is composed of intermittent exercise where short periods of maximal or high intensity activity (e.g. sprinting, tackling, rucking, scrummaging, mauling) lasts between five and 15 s, interspersed with activity of lower intensities (e.g. standing, walking, jogging) of up to 40 s [4, 5]. During a game, players may cover approximately 6,500 to 7,500 m with an average heart rate around 172 bpm [6, 7]. When total distance covered is expressed as a percentage of activity it shows; walking accounts for 37%, jogging 28%, and sprinting 34% of total distance covered [1, 7, 8]. It is apparent that high-intensity activities such as speed and repeated sprint ability are crucial for match outcomes [9] and appear to be even more important in international rugby competition [10]. However, distance and intensity of movements alone may not reflect the true nature of rugby union, appropriate monitoring of high-impact collisions, as well as static scrumming, rucking, and mauling activities are important when determining match demands and the physical load on players [7, 11].

For training, it is suggested that frequent maximal intensity efforts rather than steady-state exercise is desired [1]. It appears that during pre-season, players cover greater distances compared to in-season training [12, 13]. Pre-season is a period of training where players prepare for the competitive season ahead by focusing on; high-volume, high-intensity conditioning work to optimise body composition (increase lean muscle mass and decrease fat mass) and increase speed, strength, power, aerobic fitness, and anaerobic fitness [14]. Comparatively, there is generally a decrease in the amount of intensive conditioning work during the in-season to allow more rugby-specific training, such as skill and tactical sessions [12-14]. During a typical training week, players often participate in 8-10 training sessions made up of field, gym, and recovery sessions to prepare for the intense demands of game-play and the competitive season [12, 13].

Regarding competition, a RU season in New Zealand (NZ) can be lengthy especially for Super Rugby and International players (elite level) [15]. The Super Rugby Championship is the highest level of professional club rugby in NZ which starts in February and includes ~18-20 rounds of game-play, with each team playing ~15-16 games and a further three if they qualify for quarter-finals, semi-finals, and finals. The Super Rugby Championship is contested across five countries creating a large travel and logistical demand. Following the Super Rugby Championship competition, players then either compete in; the National Provincial Union or International (NZ All Blacks) competition depending on selection.

The National Provincial Union competition is the second highest level of professional club rugby (sub-elite level) in NZ who compete in ~11 rounds of game-play followed by an additional three-games if they qualify for quarter-finals, semi-finals, and finals. The NZ professional club season finishes near the end of October, where players have a brief off-season period before commencing pre-season for the Super Rugby Championship near the end of November. International RU is the highest level of rugby competition in the world, with the World Cup being the pinnacle event every four years which has been won by the All Blacks three times (1987, 2011, 2015). The international RU season for the NZ All Blacks usually starts in June and finishes in December consisting of ~14 games in NZ and abroad.

Indeed, NZ professional RU players have a lengthy season and have limited off-season and pre-season periods to enhance physical and fitness characteristics. Therefore, further enhancements need to be prioritised during the in-season periods to continue the development of physical and fitness characteristics over consecutive seasons. Although Super Rugby and international players may not take part in every game during the long professional NZ season, they are still training vigorously throughout the entire season which places great demand on the athlete both physically and mentally [15, 16]. Given the long professional season, it is important for players to fuel appropriately to allow high-quality training outputs and recovery so physical, fitness, and skill development can continue to improve over the entire season and future seasons.

Body Composition Profile of Professional Male and Elite Female Rugby Union Players

The assessment of body composition is performed to further understand how an individual's body mass (BM) is comprised. The main tissues of interest when determining body composition among professional RU players are; lean mass ([LM] muscle tissue only), fat-free mass ([FFM] all body mass excluding fat mass), fat mass [FM], and bone mineral content (BMC)/bone mass (see Table 1). The body composition of professional RU players is often assessed given its importance to both health and performance. It is useful when prescribing individual and/or positional goals and tracking progress alongside fitness and/or game-play key performance indicators [9]. Larger players, particularly heavier forwards and taller backs have been associated with greater team success in world cup competitions [17, 18]. The need for continued physical development is imperative given the rate at which professional RU players continue to increase in size [19]. Therefore, further understanding of how body composition is comprised among these athletes, particularly by specific playing position and different locations around the world is required.

Determining LM and FFM is important when assessing body composition in RU given its distinguishing differences between elite and non-elite players [20]. The promotion of LM and FFM is desired for RU performance given the high-contact nature of the sport [1] and due to the contractile properties and force generating capability of muscle mass [21]. Meanwhile, minimising fat mass is desired given this tissue does not directly contribute to force production. Therefore, optimising an individual's body mass to comprise predominantly contractile and force generating tissue (LM) with minimal amounts of non-contractile tissue (FM), may improve a range of fitness characteristics. Additionally, the determination of FFM allows the practitioner to assess energy availability (EA) [22, 23] and predict resting metabolic rate

(RMR) using FFM-based prediction equations to further optimise individual and positional fuelling requirements [24, 25]. Furthermore, being able to explore the composition between different regions of the body and examining bone measures for health and performance is of benefit when prescribing both nutritional and exercise interventions [26].

Table 1. Summary of previous research examining body composition among professional male and elite female rugby union players.

Study	Location	Phase	Method	Sample (*n*)	LM (kg)	FM (kg)	BMC (kg)	BF%	BMD	FFM	SumSF (mm)
Professional Males											
Baker et al. [27]	Wales	n/s	Predicted BF%	F = 8	n/a	13.0 ± 6.0	n/a	14.0 ± 2.0	n/a	n/a	n/a
			Sum7SF	B = 8		9.0 ± 7.0		12.0 ± 2.0			
Duthie et al. [28]	Australia	In-Season	Sum7SF (ISAK)	F = 40	n/a	n/a	n/a	n/a	n/a	n/a	84.0 ± 19.0
				B = 32							60.0 ± 13.0
Fontana et al. [29]	Italy	In-Season	Predicted BF%	F = 191	n/a	n/a	n/a	19.1 ± 5.9	n/a	85.5 ± 7.3	n/a
			Sum6SF	B = 171				12.4 ± 4.6		76.8 ± 6.9	
Higham et al. [30]	Australia	Pre-Season	DXA (Hologic)	F = 21	~ 87.4 ± 6.8	~ 15.9 ± 4.1	~ 3.7 ± 0.5	n/a	n/a	n/a	n/a
				B = 17	~ 75.2 ± 5.8	~ 9.7 ± 2.8	~ 3.2 ± 0.3				
Smart et al. [20]	New Zealand	Pre- & In-Season	Predicted BF%	F = 279	n/a	n/a	n/a	14.0 ± 3.5	n/a	94.1 ± 6.2	n/a
			Sum8SF	B = 231				10.5 ± 2.5		83.1 ± 5.9	
Bradley et al. [13]	United Kingdom	Pre-Season	Predicted BF%	F = 25	n/a	n/a	n/a	12.6 ± 3.2	n/a	95.4 ± 4.5	90.4 ± 25.9
			Sum7SF (ISAK)	B = 20				8.9 ± 2.2		83.5 ± 5.4	66.1 ± 14.4
Zemski et al. [3]	Australia	In-Season	DXA (Hologic),	F = 20	92.2 (89.5-94.9)	16.1 (14.9-17.3)	4.5 (4.3-4.7)	14.2 (13.4-15.0)	n/a	n/a	73.1 (67.7 - 78.4)
			Sum7SF (ISAK)	B= 17	79.1 (76.7-81.6)	9.9 (9.2-10.7)	3.9 (3.7-4.0)	10.7 (10.0-11.4)			49.0 (45.4 - 52.5)
Lees et al. [31]	United Kingdom	In-Season	DXA (Lunar)	F = 20	85.5 ± 5.4	21.4 ± 5.1	4.6 ± 0.4	20.0 ± 4.0	n/a	n/a	n/a
				B = 15	74.7 ± 5.5	14.2 ± 3.8	4.3 ± 0.4	15.9 ± 3.8			
Zemski et al. [32]	Australia	In-Season	DXA (Hologic), Sum7SF (ISAK)	All = 43	87.5 ± 8.8	14.2 ± 4.2	4.3 ± 0.5	13.2 ± 2.9	n/a	n/a	68.8 ± 22.5
Zemski et al. [33]	Australia	Pre-Season	DXA (Hologic)	F = 11	92.0 ± 5.6	18.4 ± 3.9	4.4 ± 0.4	n/a	n/a	n/a	n/a
				B = 11	76.5 ± 6.7	12.5 ± 2.3	3.6 ± 0.4				
Zemski et al. [34]	Australia	In-Season	DXA (Hologic)	F = 23	n/a	17.4 ± 4.0	n/a	n/a	n/a	96.5 ± 6.3	80.6 ± 22.1
			Sum7SF (ISAK)	B = 16		10.8 ± 2.2				82.8 ± 5.9	53.2 ± 13.4
Zemski et al. [35]	Australia	Pre-Season	DXA (Hologic)	F = 17	86.5 ± 4.8	17.1 ± 3.6	4.3 ± 0.3	15.8 ± 2.9	n/a	n/a	n/a
				B = 13	75.7 ± 4.4	10.1 ± 1.7	3.8 ± 0.4	11.3 ± 1.9			
				FR = 7	84.7 ± 3.9	19.1 ± 2.7	4.3 ± 0.2	17.7 ± 1.9			
				SBR = 10	87.7 ± 5.2	15.7 ± 3.5	4.3 ± 0.4	14.5 ± 2.8			
Elite Females											
Hene et al. [36]	South Africa	Pre-Season	Predicted BF%	F = 16	n/a	n/a	n/a	30.8 ± 4.6	n/a	n/a	137.4 ± 30.1
			Sum7SF	B = 15				26.1 ± 3.8			106.7 ± 19.1
Nyberg et al. [37]	Scotland	In-Season	ADP	All = 11	51.2 ± 5.2	22.8 ± 7.0	n/a	29.8 ± 6.4	n/a	n/a	n/a
			(BodPod)	F = n/s	53.6 ± 6.9	23.2 ± 4.9					
				B = n/s	49.2 ± 2.2	22.4 ± 8.8					

Mean (confidence interval), Mean ± standard deviation. LM = lean mass, FM = fat mass, BMC = bone mineral content = BF% = body fat percentage, BMD = bone mineral density, FFM = fat-free mass, SumSF = total sum of skinfolds, Sum6SF = sum of six-site skinfolds, Sum7SF = sum of seven-site skinfolds, Sum8SF = sum of eight-site skinfolds, n/s = not stated, n/a = not applicable, F = forwards, B = backs, DXA = duel-energy x-ray absorptiometry, ISAK = international society for the advancement of anthropometry, ADP = air displacement plethysmography, F = forwards, B = backs, FR = front row, SBR = second and back row.

Body Composition Assessment Methods Among Professional Rugby Union Players

A summary of the most common field- and laboratory-based methods used to assess body composition among professional RU players can be observed in Table 2.

Field-Based Methods

The most common and simple field-based method used among professional RU players is skinfolds (also known as surface anthropometry), whereby a certain number of sites are located, marked, and measured using a set of calibrated hand-held callipers to measure the thickness of the skinfold site, providing an indication of how much subcutaneous adipose tissue is located underneath the skin. The measurements from these sites are then totalled providing a total sum of skinfolds where a higher number would indicate higher levels of FM. Additionally, these sites can be entered into prediction equations [26] to provide an estimate of body fat percentage (BF%) and therefore, an estimate of FM and FFM. However, when skinfold-based prediction equations have been used to estimate BF% in other settings [26] and in professional RU players [32], poor agreement has generally been observed.

Another limiting factor regarding the use of skinfolds is the lack of consistency in protocols, measuring devices (callipers), site location, or number of sites being measured [38]. This makes comparison between studies difficult when sum of six (Sum6SF) [39], seven (Sum7SF) [3, 13, 27, 28, 32, 34, 36, 40], and eight-site skinfolds (Sum8SF) [20] have been reported among professional RU players. To enable comparison and consistent profiling of professional RU players around the world, adhering to protocols such as the International Society for the Advancement of Kinanthropometry (ISAK) using calibrated callipers that apply a constant closing pressure of 10 $g \cdot mm^2$ throughout the range of measurements, should be implemented [41, 42].

When following ISAK protocols, skinfold assessments are cost-effective, convenient, simple to standardise, and generally possess acceptable error [43]. However, the intra- and inter-rater error for skinfolds can increase among less experienced assessors and particularly if sites are not correctly located and measured [43]. Although the most common number of sites measured when using the ISAK protocol among professional RU players is Sum7SF, Sum8SF is widely used in NZ and is what ISAK describe during accreditation [41]. Notably, ISAK skinfolds are performed on the right-side of the body and only provide an indication of FM. For the assessment of other tissues (e.g. LM, FFM, BMC) and to determine differences between limbs and/or regions of the body, laboratory-based methods are required.

Laboratory-Based Methods

The use of Dual-energy X-ray Absorptiometry (DXA) has become increasingly popular for assessing body composition among professional RU players [3, 30-35], as presented in Table 1. Additionally, DXA is commonly used as a reference method when developing and validating skinfold-based prediction equations to estimate BF% [38]. Implementing DXA as an assessment tool allows for the determination of whole-body and regional LM, FM, FFM, BF%, BMC, and BMD [44-46]. This allows for greater screening, tracking, and goal setting by monitoring multiple body composition measures rather than just an indication of FM alone [26]. This may enhance player engagement, given the positive affirmation around the building of muscle mass, addressing asymmetries and/or imbalances, and not just the reduction of FM [47, 48]. Utilising DXA is also valuable given it can provide a gold-standard measure of BMD [45, 49-51] and a precise measure of FFM [46] in a single assessment, which are important measures when examining other health and performance outcomes such as EA [22, 23].

In the pursuit of collecting valid and reliable DXA results, best practice methods to standardise testing conditions are strongly encouraged [44, 52]. Some of these standardised conditions can be difficult to implement in high performance sporting environments due to the disruption on the athletes competition preparation by having to travel to a laboratory in a standardised fasted and rested state [52]. Solutions have been presented around the standardisation of meals for DXA scanning in the attempt to help minimise disruption among elite athletes [53]. Like skinfolds, DXA possess important limitations to consider regarding protocol and the device used. Body composition results reported using DXA can vary substantially between different machines, manufacturers, beam technologies, scan speeds, and software versions [44]. This can lead to discrepancies when tracking player progress over time and/or comparing results between different studies. Additionally, DXA scan duration can vary greatly between devices, with fan-beam devices providing faster whole-body scans (~3 mins), compared to pencil-beam (~8-15 mins, depending on scan mode) [54]. This is a considerable difference in duration when scanning entire squads across multiple time-points. Furthermore, athletic populations are generally larger than the typical dimensions of the scanning beds, and therefore require specific or standardised protocols [55].

Another laboratory-based method that has been implemented in a sample of elite female RU players is Air Displacement Plethysmography (ADP). Of the laboratory-based methods, ADP is the least common method for determining body composition among professional RU players.

Although this method can reliably determine FM and FFM, results can be substantially different to DXA [56] and therefore, caution should be taken when comparing results between methods. Provided that both ADP and DXA are laboratory-based methods where availability, accessibility, cost, standardisation, and the need for experienced technicians is required, DXA is generally selected. This is due to DXA providing more valuable measures (e.g. soft tissue, bone, and regional composition) than ADP for a similar investment in cost, accessibility, time, and effort [56].

When examining the skinfolds and body composition currently reported among professional RU players, it is evident that forwards possess significantly greater total sum of skinfolds (SumSF), LM, FM, FFM, and BF% compared to backs (see Table 1). It is also clear that considerable differences exist among professional RU players based on the region they are from, with southern hemisphere demonstrating lower Sum7SF, FM, and BF%, but greater LM than northern hemisphere players.

Although field-based measures such as Sum8SF have been conducted in male professional RU players from NZ [20], no laboratory-based methods such as ADP or DXA have been performed in NZ elite male professional RU players. Additionally, no studies among elite female RU players from NZ or world-wide have been conducted using Sum8SF or DXA. Interestingly, body composition analysis using DXA has predominantly examined forward and back positional groups only, and not specific playing positions and/or specific positional groups.

Limited position specific body composition has been examined among professional RU players. One study among professional Australian RU players examined the body composition of Front-Row and Second-Row forwards, demonstrating considerable differences [35]. In professional Rugby League (RL) players, considerable differences between specific playing positions were observed [57], indicating the need for position specific body composition assessment in addition to generalised forward and back position groups. It is also important to note that no BMD has been reported in professional RU players. Indeed, fitness characteristics (e.g. strength, speed, power, aerobic, and anaerobic capacity) among professional RU players have been reported [14, 20, 58, 59] and differences between playing levels highlighted [20, 58], yet no relationships between physical (e.g. FM, LM, FFM, BF%, BMC, and BMD) and fitness characteristics have been examined among elite professional RU players.

Table 2. Description of the most common methods for assessing body composition among professional rugby union players.

Method	Description	Duration	Pros	Cons
Field-Based				
ISAK Skinfolds	All measures taken on right hand-side of the body at the triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, mid-anterior thigh, mid-medial calf. Skin pinched and measured using calibrated callipers with a constant closing pressure of 10 g·mm^2. Measures are taken in duplicate and repeated a third time if the second measure is not within 5% of the first.	• ~5 mins • Less duration if collecting less sites	• Portable and travel well • Cost-effective • Accurate when following ISAK protocols • Can be monitored frequently • Access to many assessors • Easier to standardise and is less sensitive than laboratory-based methods regarding food, hydration, exercise	• Invasive for some individuals • Results can change drastically if measurement site is off by as little as 1 cm or more • Inter-rater error can be high • Larger players and players with higher levels of fat mass are generally more difficult for in-experienced assessors
Laboratory-Based				
DXA	Technical Description: Pencil- and/or fan-beam DXA machine passes both high and low energy x-ray photons through regions of the body. These photons detect differences in density between the different tissues. Scans are then analysed using computer software to locate regions / landmarks. Standardised Protocol: Scan carried out in an overnight fasted-state in tight-fitting clothing or underwear, with jewellery or any metal/obstructive objects removed. Standardised/repeatable training load, nutrition, and hydration status.	Fan-beam: • ~3 mins for whole-body scan • ~8 mins for whole-body and clincal-sites scan Pencil-beam: • ~8-15 mins depending on scan mode	• Gold-standard accuracy for BMC and BMD • Provides accurate and reliable LM, FFM, FM, and BF% if standardised appropriately • Provides additional insight into regional body composition • May enhance athlete engagement as monitoring does not only include FM, but includes LM, limb symmetry and regional insight • Some may find this less invasive than skinfolds • Low radiation dose (~0.5 µSv) considered background level, safe for longitudinal monitoring	• Specialised equipment • Expensive & poor portability • Limited machines and/or laboratories • Lack of convenience, players generally required to travel to laboratory • Trained and experienced operators required • Low radiation dose • Results can vary depending on the; machine, manufacturer (e.g. Hologic, Lunar), beam technology (e.g. pencil- vs fan-beam), software version, and algorithm • Strict standardised conditions required (fasted and rested state, training load and food intake standardised)

ISAK = international society for the advancement of kinanthropometry, DXA = dual-energy x-ray absorptiometry, BMC = bone mineral content, BMD = bone mineral density, LM = lean mass, FFM = fat-free mass, fat mass, BF% = body fat percentage. Literature cited [41, 43-45].

Energy Profile of Professional Male Rugby Union Players

Energy Balance

The dietary intakes of professional RU players need to be well-designed to meet the demands of training and game-play by closely matching energy intake (EI) with energy expenditure (EE). Not meeting energy demands may inhibit training adaptations [60, 61]. Moreover, consistently achieving an un-supervised energy deficient state during training and game-play may lead to unfavourable losses in LM, strength, and bone mineral content [22, 62]. Additionally, increased susceptibility to illness, injury, disturbances in endocrine and immune function, as well as an increased risk of overtraining may occur [60, 61].

Currently, the only research available on energy balance (EB) within elite professional RU players was conducted in the northern hemisphere (see Table 3) during the in-season period [12]. The results of this study demonstrated that EE exceeded EI during the first three-days of the training week in both forwards and backs. However, EI met or exceeded EE two days prior to game-day (GD) and one day post-game (GD was not assessed) for both positions. Although it was reported that EI and EE differ on a day to day basis, mean weekly EI and EE were similar for forwards (~3965 and ~3798 $kcal\cdot day^{-1}$, respectively) and backs (~3392 and 3344 $kcal\cdot day^{-1}$, respectively) [12]. It appears that, although players may fail to meet energy requirements on certain training days, specifically earlier in the week, weekly energy requirements are generally met by EI meeting or exceeding EE on light training days and/or rest days. Additionally, players appear to increase EI closer to GD to optimise fuel stores, which coincides with a decrease in training load, allowing players to feel rested and prepared for GD [12]. What is of interest, is whether players would perform and recover more efficiently from training and game-play by meeting all daily energy requirements and not just weekly. As suggested, not meeting daily energy requirements may increase susceptibility to illness, injuries, and disturbances to endocrine and immune function [60]. Furthermore, by meeting daily energy requirements players may enhance energy stores for future training sessions, which may lead to a greater stimulus in training and thus better adaptation and performance [16].

It is clear that achieving an energy sufficient and appropriately distributed dietary intake with as many wholesome food sources as possible, will provide athletes with the optimal nutritional requirements needed to promote health and performance [60, 61]. The next step which is often difficult to assess, involves measuring the EI and EE (energy balance) of athletes to make sure energy needs are being fulfilled. Measuring energy balance can often be time consuming, expensive, and labour intensive on both the athlete and practitioner which often leads to infrequent dietary analysis [63]. As a result, athletes with inadequate or poor dietary intakes that are not meeting energy requirements, may go unnoticed or receive delayed support which could compromise health and performance. Measuring EB can be prone to significant error depending on what methods are used and how skilled/familiar the practitioner and athletes are with the method. When choosing methods for assessing both EI and EE, validity and reliability are important, along with ease of use and minimal disruption to both the athlete and practitioner [64-66].

Energy Availability

Aside from EB, another important aspect for practitioners and players to be aware of is EA. Having an optimal EA means that an individual has enough energy remaining at the end of the day (>40 $kcal \cdot kg^{FFM} \cdot day^{-1}$ for males) after exercise energy expenditure (EEE) has been taken into account (EI – EE (kcal) / FFM (kg)) to support optimal physiological function [23]. In high-performance sporting environments where intense training and competition demands are present, athletes can be at risk of low energy availability (LEA) which is defined as <30 $kcal \cdot kg^{FFM} \cdot day^{-1}$ and may lead to unfavourable health outcomes and sports performance [22].

The health issues associated with LEA can include; impaired reproductive function (particularly low/reduced testosterone levels among males), low metabolic hormones, compromised bone health, and suppressed immune function [23]. Sport performance can be impacted by reduced glycogen stores and losses in FFM which may lead to reductions in muscular strength and aerobic performance [23]. A state of LEA can be intentionally driven due to eating disorders and/or disordered eating behaviour, or unintentionally due to poor education or awareness regarding appropriate fuelling strategies for the demands of the athletes sport [23]. It is suggested that male athletes can be in a state of reduced or moderate energy availability ((MEA) = 30-40 $kcal \cdot kg^{FFM} \cdot day^{-1}$) for short periods of time, but optimal or high energy availability ((HEA) = ≥40 $kcal \cdot kg^{FFM} \cdot day^{-1}$) is recommended [22].

In professional RU, players could be at risk of LEA for a variety of reasons, ranging from simply not fuelling enough to meet the demands of training and/or game-play, or due to body image related factors [47, 48, 67]. Furthermore, given the reported EI observed among professional RU players (see Table 3) and the substantial levels of FFM reported (see Table 1), these athletes would appear to be at potential risk of being in a state of LEA or MEA. Therefore, assessing EA among professional RU players would be valuable.

Table 3. Summary of previous research examining the energy and macronutrient profile of elite male professional rugby union players.

Study	Region	Phase	Method	Sample (*n*)	EI ($kcal \cdot day^{-1}$)	EE or EEE ($kcal \cdot day^{-1}$)	CHO	Protein	Fat
Lako et al. [68]	Fiji	n/s	2-Day Food Diary	All = 19	2350 ± 1469	n/a	272 ± 119 $g \cdot day^{-1}$ ~2.7 $g \cdot kg \cdot day^{-1}$	170 ± 107 $g \cdot day^{-1}$ ~1.7 $g \cdot kg \cdot day^{-1}$	115 ± 65 $g \cdot day^{-1}$ ~1.1 $g \cdot kg \cdot day^{-1}$
Bradley et al. [13]	United Kingdom	Pre-Season	2 x 24-hr Recalls	F = 10 B = 10	~3535 ± 454 ~3177 ± 430	n/a	~357 $g \cdot day^{-1}$ 3.3 ± 0.7 $g \cdot kg \cdot day^{-1}$ ~371 $g \cdot day^{-1}$ 4.1 ± 0.4 $g \cdot kg \cdot day^{-1}$	~272 $g \cdot day^{-1}$ 2.5 ± 0.3 $g \cdot kg \cdot day^{-1}$ ~232 $g \cdot day^{-1}$ 2.6 ± 0.6 $g \cdot kg \cdot day^{-1}$	~108 $g \cdot day^{-1}$ 1.0 ± 0.3 $g \cdot kg \cdot day^{-1}$ ~85 $g \cdot day^{-1}$ 1.0 ± 0.3 $g \cdot kg \cdot day^{-1}$
Bradley et al. [12]	United Kingdom	In-Season	6-Day Food Diary (no GD included)	F = 7 B = 7	~3965 ± 299 ~3392 ± 287	EE= 3798 ± 127 EE = 3344 ± 112	~385 $g \cdot day^{-1}$ 3.5 ± 0.8 $g \cdot kg \cdot day^{-1}$ ~318 $g \cdot day^{-1}$ 3.4 ± 0.7 $g \cdot kg \cdot day^{-1}$	~297 $g \cdot day^{-1}$ 2.7 ± 0.5 $g \cdot kg \cdot day^{-1}$ ~253 $g \cdot day^{-1}$ 2.7 ± 0.3 $g \cdot kg \cdot day^{-1}$	~154 $g \cdot day^{-1}$ 1.4 ± 0.2 $g \cdot kg \cdot day^{-1}$ ~131 $g \cdot day^{-1}$ 1.4 ± 0.3 $g \cdot kg \cdot day^{-1}$
Cunniffe et al. [7]	Australia	In-Season	HR-based EEE during game-play	F = 1 B = 1	n/a	EEE = ~1959 EEE = ~1648	n/a	n/a	n/a
Smith et al. [66]	United Kingdom	In-Season	14-Day DLW	All U24 = 8	n/a	EE = 4761 ± 1523	n/a	n/a	n/a

Mean ± standard deviation, EI = energy intake, EE = energy expenditure, EEE = exercise energy expenditure, CHO = carbohydrate, n/s = not specified, n/a = not applicable, F = forwards, B = backs, HR = heart rate, DLW = doubly labelled water, RU = rugby union, U24 = under-24 age level, GD = game-day. Absolute (g) and relative ($g \cdot kg \cdot day^{-1}$) macronutrient intakes are reported for CHO, protein, and fat.

Energy Intake

Whilst there is currently no gold-standard method for measuring EI, the most common dietary assessment methods utilised in professional RU are the written food diary and 24-hr recall (see Table 4). The written food diary, is where all food and fluids consumed are measured or estimated, then immediately recorded by the athlete for a specified number of days [64]. A limitation to traditional food diaries is the substantial burden it can place on the athlete to document everything consumed accurately and truthfully [64]. Compared to the general population, athletes have a greater amount of food entries to record due to the consumption of sports foods (e.g. carbohydrate/electrolyte drinks and gels), supplements, and typically more frequent eating occasions with meals that can be considerably large, adding complexity to the athletes recording process [64]. The use of a 24-hour dietary recall (interview recalling food intake over the last 24-hour period) is also very popular due to less burden and time for both the practitioner and athlete [63]. However, skilled interviewers who are trusted by the athlete are desired for this process due the honesty required by the athlete and the difficulty in remembering the often large and frequent food intakes and supplements consumed [63]. Interestingly, studies comparing self-reported energy intakes (e.g. food diaries and 24-hour recalls) were shown to under-estimate mean EI by up to 19% [64].

Although there is limited research assessing the dietary intakes of RU players [69-74] and very limited in professional RU players [12, 13, 68] (see Table 3), no studies have been conducted among professional RU players from NZ which has also been highlighted in a recent review [75]. The dietary assessment methods currently used among professional RU players are 24-hour recalls [13] and food diaries [12, 68]. Two studies conducted by the same authors assessed the dietary intakes of professional RU players using both 24-hour recalls [13] and food diaries [12]. The authors suspected that the 24-hour recalls significantly under-reported EI as the athletes still managed to maintain or gain BM following their pre-season training loads, which would suggest a higher EI was being consumed than reported [13]. Therefore, studies using traditional food diaries in professional RU players may also be subject to the under-reporting of EI [64]. Therefore, careful selection of validated dietary assessment methods, including emerging technical innovations are required due to the risk of under-estimated EI using traditional food diaries and 24-hour recalls [64].

In search of more valid and user-friendly methods to assess dietary intake, researchers have explored more technical innovations by using electronic devices and software applications to record dietary intake [76-86]. The electronic devices and software applications of interest are those which can capture and send photographs of foods and fluids consumed by a player, such as the Remote Food Photography Method (RFPM) [76-78, 81, 83-88]. With this method, individuals are required to take a photo before and after their meal to determine how much food was consumed, as well as a brief description of what they ate in terms of brand and amount [87]. These methods not only save individuals a lot of time, but it is likely to increase participant adherence when logging their meals [86]. Furthermore, these methods have demonstrated superior validity over traditional food diaries and 24-hour recalls in free-living individuals when compared to doubly labelled water (DLW) [64, 76, 84, 85] which is considered the gold-standard for measuring EI and EE [89-91].

This innovative method for assessing dietary intake through the capturing and sending of photographic food diaries has not been reported among professional RU players, however it has been used among elite adolescent RL players where this method is referred to as; the Snap-N-Send Method (see Table 4), which has demonstrated promising results [87, 88]. Limitations to photographic food diaries (Snap-N-Send Method) are; participant honesty and remembering to capture/send meals, and the ability of the practitioner to accurately interpret, estimate, and analyse how much food was in the photo. As with any estimation there is always a certain amount of error, however, it appears that as long as trained and experienced practitioners are interpreting the photographic food diaries provided with some form of calibration token to help determine portion sizes of food and fluid amounts consumed, then this can be a valid and reliable method for assessing dietary intake in athletes [87, 88]. Although this method of dietary assessment can be quite time-consuming and burdensome for practitioners, it potentially makes up for this by increasing validity, reliability, adherence, and ease of use for the player [64, 87]. Therefore, the Snap-N-Send Method is potentially the most accurate and user-friendly method for assessing EI in professional RU players due to its ease of use and low burden on the player [64, 81, 87].

Once the photographic food diaries have been collected, food amounts must then be estimated and entered into a dietary analysis software system to determine how much energy and nutrients have been consumed [87]. It is important to use a valid and reliable software system that has the full energy and nutrient profiles of the specific foods that the participants will be consuming [92]. A system that has been used extensively in nutrition research and is trusted in both Australia and New Zealand is the dietary analysis software FoodWorks (Xyris Software, Highgate Hill, Queensland, Australia). Notably, different countries will have their own systems with a food database specific to their country and/or region [92-94].

Table 4. Dietary assessment methods used among male professional rugby union players.

Method	Description	Pros	Cons
Retrospective			
24-hr Recall	A structured interview between practitioner and player. All food and fluids consumed over the last 24-hr period are recalled by the player.	• Low burden for player • Fast to complete for player and practitioner • Useful snapshot of dietary intake and habits • Works well in conjunction with Snap-N-Send Method to follow up recorded intakes	• Requires a trained interviewer • Relies on player honesty and memory • Moderate burden when using with an entire squad • Needs to be repeated on a range of days to achieve variation between days • Resources required to assist portion size estimates
Prospective			
Written Food Diary	Self-reported diary recording all foods and fluids consumed and when. Player measures and/or estimates food amounts and records everything they consume at the time of consumption. Usually collected over 1-7 days	• Detailed dietary intake can be collected • Does not require memory other than remembering to record meals at the time of consumption • Can provide food amount, frequency, time of meals, dietary preferences	• High player burden; remembering to record meals, measuring and/or estimating food and fluids • High practitioner burden during analysis • Players may change their eating habits due to being recorded • Requires player honesty, player may choose not to record certain foods
***** Snap-N-Send Method / RFPM	Player takes a photo of everything consumed. A follow up photo is sent if any food is not eaten. The player provides a brief description of any foods that cannot be seen, identified, or added by the player. The practitioner sends messages to; 'nudge' players to log food, provide encouragement and feedback on images sent and clarify any further detail required.	• Lower burden for player • Most players have a phone or camera capturing device near to conveniently Snap-N-Send photos easily • If photos are taken and sent live, meal timing and meal frequency can be collected • More detail can be asked for immediately by practitioner • Better player engagement and opportunity for immediate feedback	• High burden for practitioner • Relies on players ability to remember and capture accurate photos • Practitioner may have to remind player to take photos or send 'nudge' reminders • Relies on player honesty to capture everything they consume • Player may change their eating habits due to being recorded

RFPM = remote food photography method, ***** = administered in rugby league. Literature cited [87, 95]

Energy Expenditure

Once a valid, reliable, and user-friendly method for assessing EI has been established, the same must be achieved for measuring EE to determine energy balance and/or EA [63]. There are a range of complex factors that make up EE such as; RMR, non-exercise activity thermogenesis, thermic effect of food, and EEE, whereby determining how to best assess EE in a valid, reliable, and user-friendly way becomes challenging [63]. The most common methods for assessing EE in athletic populations include using wearable devices such as; heart rate (HR) monitors, accelerometers, combined heart rate and activity monitors, wearable micro-technology, and laboratory-based predictions [96, 97].

The use of these devices in professional RU are limited due to the contact nature of the sport, which could lead to potential damage to the device and/or harm to the athlete. A recent study, which is the currently the only one to assess EE in senior professional RU players to date [12], used SenseWear armbands (SWA; Bodymedia, USA) to determine EE (see Table 3). However, participants removed the SWA during collision-based training and during pool recovery sessions, which the authors suggest may have led to some underestimation of EE. Additionally, the SWA has been shown to underestimate EE in athletes during high-intensity exercise, resistance training, and mixed exercise forms, whereby EE was further underestimated to a greater degree in better trained athletes [98]. Recent research in young professional RL players has demonstrated that a single collision-based training session can considerably increase EE [99], and it appears that the demands of rugby significantly increase RMR following game-play [100]. These factors are potentially too sensitive for devices like the SWA to detect, requiring the use of more valid and reliable methods in professional RU players [12].

The most precise method for measuring EE is through direct calorimetry which provides the most precision. However, due to the difficulty in applying this method outside of a laboratory setting, this is rarely used in high-performance environments [97]. However, a method that is suitable for use outside of the laboratory setting and is the gold-standard for measuring EE in free-living individuals is the use of DLW [89, 91, 97]. This method is not widely used due to the high-cost and the need for trained and experienced laboratory technicians to analyse the samples [91, 97]. The use of DLW for assessing EE has been used in animal studies since 1964 [101], in human studies since 1982 [89-91, 102], in elite athletes since around 1986 [103] and recently in professional RL [65] and young developing RL and RU players [66, 88, 99, 100]. The DLW method is considered very safe as it uses deuterium (H^2) and oxygen (O^{18}) which are non-radioactive elements found naturally within the human body [97], and participants are given an appropriate dose of the two isotopes based on their BM and total body water [91, 97]. Due to the DLW method determining EE using physiological bio-markers, it is more sensitive to metabolic changes from exercise; such as increased RMR following high-intensity and/or collision based activities [100]. This is why the DLW method is the gold-standard in determining EE in free-living individuals and is used to validate other methods for both EI and EE [64, 96].

Other than being the gold-standard measure for EE, further advantages of using DLW is the fact that it is relatively non-invasive. Once participants have consumed the DLW solution, they can go about their daily activities without having to worry about wearable devices and are therefore, not constantly reminded about being monitored [96]. Although DLW provides very accurate measures for EE, on its own this is all that is reported. Additional methods are required to determine EEE from training sessions and game-play [65, 66, 91], which is important in professional RU players to better understand energy demands and the players state of EA.

A convenient method for assessing EEE during physical activity [104-107] and professional rugby [7, 108, 109] is with the use of HR monitoring devices. One particular study assessed the EEE of professional RU players during game-play using HR monitors [7] (see Table 3). It has been suggested that HR-based methods over-estimate EEE and that metabolic power calculations may provide better estimates [110]. However, other research suggests that metabolic power calculations may under-estimate EEE [111]. Therefore, more studies assessing EEE and when possible, comparing these with a gold-standard measures are required. Previous limitations for HR device use in collision-based sports such as rugby, were that the HR units were attached just below and at the centre of the players chest, which may lead to a loss of data points due to the chest strap not staying securely in place. Furthermore, this device location exposes the HR unit to contact/collisions where the unit and or player could be harmed. However, as wearable technology has improved, specialty HR conductive vests which situate the HR unit on the players upper back and between the shoulder blades alongside their global positioning system (GPS) unit, now provide secure and safe collection of HR data during full-contact training and game-play.

Once EEE demands are established or monitored from specific training sessions and game-play, determining the remaining EE factors are required, such as RMR. Indirect calorimetry (IC) is a very precise method for assessing RMR and is considered the gold-standard for this measure. However, limitations for this method are that it can be costly, and requires strict standardisation protocols and specialised equipment and technicians [97, 112, 113]. This method of assessment has been effectively used among professional RL [65] and adolescent RL and RU players from the northern hemisphere [66, 88, 99, 100]. However, no studies have examined the RMR of professional RU players from NZ and how these measures compare to common prediction equations. For the assessment of RMR, participants can either wear a mask or have a ventilation hood placed over their head, which is then connected to a gas analyser (calorimeter) to collect and quantify the volume and concentration of oxygen inspired and carbon dioxide expired. The protocol usually takes 30-mins following an overnight fasted and rested state, in which participants lie down and relax for ~15-20-mins followed by a 15-20-min analysis (lying down) with the gas analyser connected [99, 112, 113].

When RMR is not able to be assessed using IC, previously established prediction equations are often used to estimate RMR [114, 115], of which some equations have been validated in athletic populations [116] and are often dependent on the ability to determine accurate FFM or lean body mass (LBM) measures. Which raises another concern, the term LM, FFM, and LBM need to be clearly defined as it is often unclear whether LBM is the same as FFM (all mass except FM), or is the same as LM (all mass except FM and BMC). Provided that the LBM of participants in the early RMR studies were around 46-63 kg [117], the appropriateness of these prediction equations for larger athletes such as professional RU players are questionable, given that LM values have been reported between 75-95 kg in professional RU players (see Table 1). Recent research has suggested that population specific prediction equations should be developed, particularly in larger athletes to improve accuracy when calculating energy requirements [24].

Macronutrient Profile of Professional Male Rugby Union Players

Inclusive of optimising energy requirements, consuming an adequate amount of macronutrients in the form of carbohydrates, proteins, and fats in the right distribution depending on the day or goal, is also important for athletes to optimise their training and performance [60, 118, 119]. When preparing for training and game-play, it is important for the athlete to ingest a range of macronutrients prior, to help increase performance outcomes [120]. Upon completion of training sessions and game-play, refuelling to replenishing fuel stores and repair muscle is vital to promote recovery and prepare for the next training session and/or game over the course of the season [121].

Carbohydrates

Carbohydrates are important for the restoration of muscle and liver glycogen which is a fundamental goal of recovery between training sessions and game-play, especially when multiple training sessions or games are undertaken within a short time frame [122]. Carbohydrate ingestion may also attenuate central fatigue, reduce the perception of effort, and optimise decision making and skill execution due to elevated blood glucose levels [123]. Adequate carbohydrate availability may also promote positive adaptations to bone remodelling around training independent of EA [62]. Analysis of RU during training and game-play have shown that both anaerobic and aerobic energy pathways contribute to rugby performance and therefore rely on adequate carbohydrate intake [1]. When determining carbohydrate needs, it has been suggested that athletes involved in moderate amounts of intense training (2-3 hours per day performed 5-6 times per week) need 5-8 $g \cdot kg \cdot day^{-1}$ to maintain liver and muscle glycogen stores [122, 124]. However, it is also recommended that athletes involved in high-volume intense training (3-6 hours per day in 1-2 daily workouts for 5-6 days per week) may need to consume 8-10 $g \cdot kg \cdot day^{-1}$ of carbohydrate to maintain muscle glycogen levels [122]. Following these guidelines, professional RU players weighing between 80 and 140 kg of BM would have to consume somewhere between 640 and 1400 g of carbohydrates per day. Studies have reported that the higher end of these recommendations are mostly unachieved in team-sport athletes [125, 126], let alone relatively heavy/large RU players. Furthermore, carbohydrate intakes this high may not allow for adequate protein and fat intakes to be included [125].

Considering this, recent studies within professional RU players (Table 3) have demonstrated much lower carbohydrate intakes than recommendations, ranging between 3.3 and 4.8 $g \cdot kg \cdot day^{-1}$, equalling an average of ~300 – 400 g of carbohydrate per day which was roughly 32 – 46% of total EI [12, 13, 75]. These carbohydrate intakes are well below current recommendations [122, 124, 127, 128] and are below those specifically recommended for team-sport athletes [121, 125, 126]. However, these moderate carbohydrate intakes appear to still induce positive training adaptations in professional RU players [12, 13]. Furthermore, these moderate intakes may also be enough to allow professional rugby players to perform at a high-level during game-play [129, 130]. Recent studies within professional RL have demonstrated that players can utlise roughly 40% of their muscle glycogen during a game [129, 130], and that a carbohydrate diet consisting of 3 g·kg·day^{-1} compared to 6 g·kg·day^{-1} did not result in any significant differences in pre-game glycogen concentrations or movement patterns during game-play [129]. Although these studies were carried out in RL, which involve different training and game-play demands to RU [131], the results are insightful and help highlight the need for further investigations regarding optimal carbohydrate intakes for RU players.

Protein

Aside from managing an appropriate carbohydrate intake, athletes must consume an adequate amount of protein for optimal recovery and performance by facilitating muscle repair, muscle remodelling, and immune function [121, 132-134]. If adequate protein requirements are not met, athletes may develop and maintain a negative nitrogen balance, indicating protein catabolism and slower recovery. Over time, this may lead to stalls in muscle development, injuries, illness, and/or training intolerance [60, 61]. The sport of RU is a high-intensity intermittent sport which includes multi-directional movements with rapid accelerations, decelerations and high-impact collisions [75, 121]. These multi-directional movement demands require repeated eccentric muscle contractions which can lead to notable exercise-induced muscle damage (EIMD), which alongside collisions that promote impact-induced muscle damage (IIMD), can result in soreness, degradation, and impaired muscle function following training and game-play [11, 121, 135-137]. Therefore, adequate protein ingestion is critical for growth and adaptation by repairing anatomical and physiological structures due to the metabolic, muscular, and collision-based demands of professional RU players [11, 60, 61, 99, 121, 135, 137].

The recommended intakes for protein among team-sport athletes are 1.2-2.0 g·kg·day^{-1} which is between 80-140g and 180-300 g·day^{-1} for a BM range of 70-150 kg, respectively [60, 61]. Unlike carbohydrate, which were below the recommended guidelines, protein intakes within professional RU players exceeded recommendations (Table 3) with average intakes above 2.0 g·kg·day^{-1} [12, 13] apart from one study [68]. Professional RU players from the northern hemisphere reported protein intakes between 2.5 and 2.7 g·kg·day^{-1} for both forwards and backs [12, 13]. Although these observed protein intakes are higher than recommendations, it has been suggested that protein intakes of 2.5-3.0 g·kg·day^{-1} may be appropriate to support muscle hypertrophy and preserve lean tissue during periods of intense training and where energy requirements may not be met [133, 134, 138, 139], which has been shown to occur in professional rugby union players [12]. Furthermore, the current high protein intakes reported may be beneficial for RU players due to the importance of preserving FFM and promoting repair and recovery following EIMD and IIMD from training and game-play throughout the season.

Dietary Fat

Dietary fat is also an important macronutrient that may not receive enough attention among high-intensity intermittent-sport realms, due to carbohydrate being the pre-dominant fuel source for high-intensity exercise, and protein for muscle repair [140]. However, dietary fat plays an important role in cell membrane synthesis, facilitating the absorption of fat-soluble vitamins, and vascular health [60, 61, 75]. It has been suggested that higher-fat diets may maintain circulating testosterone concentrations more so than low-fat diets [60, 140], which may benefit professional RU players due to the numerous collisions, muscle damage, gym/resistance training, and potential energy deficits they may be exposed to [121, 141]. Dietary fat also appears to play an important role in maintaining a healthy immune and endocrine system, reducing inflammation (predominantly through essential polyunsaturated fatty acids) [141], and being the most energy-dense (9 kcal per 1 gram of fat) of the macronutrients, which may assist in meeting EB requirements [142, 143]. Therefore, achieving an adequate dietary fat intake may help keep the professional RU player robust and induce positive adaptations to training and game-play.

The recommended dietary fat intakes among team-sport athletes are the same as recommended for general populations which is around 20-35% of total EI, which is roughly 0.8-1 $g \cdot kg \cdot day^{-1}$ [60, 61, 128]. However, some suggest that proportions up to 50% of total EI from dietary fat can be safely ingested by athletes during regular high-volume training [60, 143]. Although some variability exists in the percent of total energy from fat, all studies in professional RU players (see Table 3) reported an average total fat intake between 24% and 34% which is within the recommended range [12, 13, 72, 74]. Although the percent of total energy from fat is within the recommended range, when relative to BM, dietary fat intakes were approximately 1.4 $g \cdot kg \cdot day^{-1}$, which is slightly higher than the current recommendation [60, 61]. However, the authors suggest that given the importance of healthy fats for performance, it would be unwise to suggest a reduction in dietary fat intake [12].

Summary and Future Recommendations

The current review highlights that professional RU players possess specific body composition and fitness requirements to meet the demands of game-play, training, and the competitive season. Forwards are clearly larger than backs in all aspects, which suits their positional requirements. Likewise, backs are smaller and leaner than forwards to suit the requirements of their position. However, each specific playing position possesses its own requirements which also need to be understood. Clearly, all positions must be able to tolerate frequent high-impact collisions and wrestling/tackling type movements which may benefit from a greater FFM. This may also enhance strength and power characteristics which can positively contribute to the contact aspect of the game. However, all positions may need to ensure BF% and FM levels are optimal to reduce any excess mass that does not contribute to force production, due to the running demands and intensity of game-play. Therefore, practitioners working with professional RU players need to promote optimal body composition and nutrition strategies based on the individual's goals and position.

There is limited research regarding the body composition requirements of specific playing positions and playing levels using DXA and Sum8SF. Implementing studies in this area would provide a greater understanding of the position specific physical demands. Furthermore, when the assessment of body composition has been carried out using DXA to examine FFM, BF%, and FM among professional RU players, this has predominantly been implemented among northern hemisphere and Australian players. These regions may possess different physical profiles and game-play demands to professional NZ players. Therefore, future studies should be administered in this area, which would enhance our understanding for this population group. No data exists among elite female RU players for the assessment of body composition using DXA. Assessing the body composition of elite female RU players using DXA would allow for a better understanding of the positional requirements among this group and would also allow for the examination of BMC and BMD which are important markers to monitor EA particularly among female athletes. Provided that DXA can be difficult to obtain, Sum8SF prediction equations should be explored to provide practical field-based estimates of BF% and an estimate of FFM as a result, if DXA cannot be accessed.

Likewise, limited research exists regarding the energy and nutrition requirements of professional RU players, and there are no studies that have examined these requirements among professional RU players from NZ. Given the energy intakes reported in the current literature and the substantial BM and FFM profiles of professional RU players, some individuals may be at risk of unintentional or intentional MEA or LEA. Interestingly, players also do not meet the carbohydrate requirements for team-sport athletes which may possess its own set of negative associations independent of EA. Notably, no data on GD exists in professional RU players, therefore studies performed during a competition week inclusive of GD and among players who will be playing to provide an accurate profile of fuelling requirements leading into GD.

For valid, reliable, and user-friendly measures of energy requirements and dietary intake among professional RU players from NZ, future research should assess EI using photographic food diaries (Snap-N-Send Method) and EE using the DLW technique and IC for RMR. Given the substantially larger profiles of professional RU players compared to the participants used to develop commonly used RMR prediction equations, exploring the development of a population specific prediction equation for professional RU players should be considered. Lastly, to determine the amount of EEE from specific training sessions and game-play, the use of HR monitors may be implemented to determine the energy demands of specific training sessions and days of the week. Better understanding of these energy demands will enhance nutrition, body composition, and training prescription.

CHAPTER THREE

Physical and Fitness Characteristics of Elite Professional Rugby Union Players

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Prelude

The literature review in Chapter Two demonstrated the substantial differences in body composition between forwards and backs, and between different regions around the world. Although it has been suggested that body composition can influence various fitness characteristics, no studies have examined the relationship between these physical and fitness characteristics among elite male professional rugby union players. Therefore, this study was the first to examine the relationships between physical and fitness characteristics by position and the first to examine the body composition of New Zealand elite professional rugby union players using Dual-energy X-ray Absorptiometry.

Abstract

This study explored the physical and fitness characteristics of elite professional rugby union players and examined the relationships between these characteristics within forwards and backs. Thirty-nine elite professional rugby union players from the New Zealand Super Rugby Championship participated in this study. Body composition was measured using dual-energy Xray absorptiometry alongside anthropometrics. Fitness characteristics included various strength, power, speed, and aerobic fitness measures. Forwards were significantly ($p = < 0.01$) taller and heavier than backs, and possessed greater lean mass, fat mass, fat percentage, bone mass, and skinfolds. Forwards demonstrated greater strength and absolute power measures than backs ($p = 0.02$), but were slower and possessed less aerobic fitness ($p = < 0.01$). Skinfolds demonstrated very *large* correlations with relative power ($r = −0.84$) and speed ($r = 0.75$) measures within forwards, while backs demonstrated *large* correlations between skinfolds and aerobic fitness ($r = −0.54$). Fat mass and fat percentage demonstrated *very large* correlations with speed ($r = 0.71$) and aerobic fitness ($r = −0.70$) measures within forwards. Skinfolds, fat mass, and fat percentage relate strongly to key fitness characteristics required for elite professional rugby union performance. Individual and positional monitoring is important due to the clear differences between positions.

Keywords: anthropometrics; body composition; strength; speed; power; aerobic fitness.

Introduction

Rugby union (RU) is a high contact field-based team sport which consists of an 80-min game consisting of two 40-min halves separated by a break no longer than 15 min. Each team has 15 players on the field at a time, comprising eight forwards (numbers 1–8) and seven backs (numbers 9–15). The team also has eight reserves on the side line (bench) who can be substituted only once during the game [1]. The game itself is composed of collisions and intermittent exercise, where short periods of maximal or high intensity activity (e.g., sprinting, tackling, rucking, scrummaging, mauling) last between 5 and 15 s, interspersed with activity of lower intensities (e.g., standing, walking, jogging) of up to 40 s [4]. During a game, players will generally cover approximately 6500 to 7500 m, with an average heart rate around 172 bpm [6, 7].

The sport of RU requires a range of fitness characteristics, such as strength, power, speed, and aerobic fitness, in order to perform well and meet the demands of the sport [9, 58]. Players all possess varying levels of physical characteristics, such as anthropometric (height, body mass, skinfold) and body composition (lean mass, fat mass, bone mass) in order to achieve adequate levels of the desired aforementioned fitness qualities and to meet specific positional demands of the sport [13, 144, 145]. Numerous studies have shown that these fitness [13, 20, 58] and physical characteristics [3, 30, 31, 33-35] vary greatly depending on the player's position within the team. In general, forwards have a greater body mass and strength emphasis in order to scrummage with more force, tolerate more collisions and gain and retain possession of the ball [3]. Meanwhile, backs generally have less body mass, a more efficient lean to fat mass ratio, and more emphasis on speed and manoeuvrability in order to utilise possession of the ball and create scoring opportunities from more open spaces [1].

The importance of anthropometrics on team success in professional RU has been investigated [17, 18]. The consensus from these studies suggests that having larger players, particularly heavier forwards and taller backs, generally leads to greater team success in international World Cup competitions. Fitness and physical characteristics have also been explored in relation to game statistics deemed important for success [9] in which body composition, speed, repeated sprint ability, and strength are important factors in the performance of key game behaviours during competition. In particular, Smart et al. [9] suggested that decreasing percent body fat may improve work rate and the ability to repeatedly perform tasks in competition, especially the important aforementioned fitness qualities listed within our study. Therefore, it is no surprise that as playing level increases from semi-professional to professional, players are heavier, have greater lean mass, and lower skinfold and percent body fat scores, while demonstrating greater strength, power and speed [20].

Although a range of studies have reported the physical [3, 30, 31, 33-35] and fitness [13, 20, 58] characteristics of professional RU players and have suggested that body composition with optimal amounts of lean mass and fat mass are important for specific fitness qualities, there is limited literature directly examining the relationships between physical and fitness characteristics within professional RU forwards and backs. Furthermore, physical characteristics in the form of body composition have traditionally been collected using skinfold measurements, which are a practical measure due to their reliability, ease of use, low cost, and portability [32, 34]. However, a method that has gained popularity for body composition analysis within professional athletes [44, 46] and specifically within professional rugby players [3, 30-35, 57, 146] is the use of dual-energy X-ray absorptiometry (DXA).

Gaining a greater understanding of the relationships between physical and fitness characteristics is important to better comprehend the athletic profile of these elite professional RU players. This may allow for more detailed nutritional and physical training programmes not only for current professional players, but for future RU players progressing through academies and development programmes in order to optimise important physical and fitness characteristics. Therefore, the aim of this study was to; (a) explore the physical and fitness characteristics of elite professional RU players and (b) investigate the relationship between physical and fitness characteristics within forwards and backs.

Methodology

Participants and Study Design

Thirty-nine elite male professional RU players (26.6 ± 3.3 y, 187.6 ± 7.6 cm, 108.0 ± 14.1 kg) playing in the NZ Super Rugby Championship were recruited for this study. Professional experience for players was 7.3 ± 2.9 y, which was quantified by determining when players were first selected for a professional rugby team (e.g., Province/Franchise). Players were categorised into forwards and backs for analysis and comparison. Forwards were comprised of; hookers (*n* = 4), props (*n* = 6), locks (*n* = 5), and loose forwards (*n* = 8). Backs were comprised of; half-backs (*n* = 3), first-fives (*n* = 3), midfield (*n* = 5), and outside backs (*n* = 5).

Data were collected using a cross-sectional study design, in which all testing took place at the end of the Super Rugby Championship pre-season. All anthropometric, body composition and fitness testing took place in the same week, with DXA and surface anthropometry measures being collected on the same day. All participants provided informed consent and the research was approved by the University of Waikato Human Research Ethics Committee (2019#02).

Anthropometrics

Upon waking and following a voided bladder, participants were then asked to change into only their underwear or tight-fitting sport shorts. Body mass measurement was obtained using a set of portable electronic scales (SECA, Birmingham, UK) to 0.1 kg accuracy. Thereafter, height was assessed using a portable stadiometer (SECA, Birmingham, UK) to 0.5 cm accuracy. The sum of eight site skinfold measurements were then carried out by the same Level 1 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist, using Harpenden callipers (British Indicators, Hertfordshire, UK) to 0.1 mm accuracy. Skinfold measurements were made on the right side of the body using ISAK techniques previously described [41], with a sum of eight skinfolds calculated from the measures of the; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, anterior mid-thigh, and medial mid-calf skinfold sites. Duplicate measures were carried out for all sites to determine re-test reliability, in which a third measure was recorded if the difference between duplicate measures was greater than 4% for a single skinfold [3]. Anthropometrical technical errors of measurement were below the recommended limits [147], and all anthropometric equipment was calibrated as per the manufacturers' guidelines.

Body Composition

Total body composition (lean mass, fat mass, body fat percentage, bone mass and bone mineral density) was measured using a fan-beam DXA scanner (Hologic Discovery A, Hologic, Bedford, MA, USA), with analysis performed using Apex 4.6.0.3 software (Hologic, Bedford, MA, USA). All scanning procedures were standardised for all participants following the guidelines of the DXA manufacturer and the standards outlined by the International Society for Clinical Densitometry. The same qualified technician performed all measurements for positioning consistency. The scanner was tested for consistent calibration daily as per the manufacturer's guidelines for quality control purposes. All scans were undertaken using the array mode and all participants were scanned on the same day within a five-hour window (0830–1330 h), with all participants consuming breakfast and fluids at the same time (0700 h).

All protocols followed previously described techniques to maximise technical reliability and minimise error [44, 52], however, participants were unable to be scanned in a fasted state. Participants were required to remove all metal items from their body and were scanned wearing tight-fitting sport shorts or underwear, free from zips, studs and/or metal objects. Participants were then instructed to lay supine on the scanning bed as still as possible for the duration of the scan. The same technician that performed the scan manually segmented the whole-body scan into regions during the analysis process. The head was included in the analysis for all total body measures. Two participants that were too tall for the scanning bed had their feet removed from the scan as advised by Hologic. This allowed the head to be included in the scan, which is recommended to offset the remaining tissue percentages [148].

Fitness Testing

All fitness testing took place on the same day using methods previously described [58, 149, 150]. Speed and aerobic fitness tests were carried out in the morning, while strength and power tests were performed in the afternoon five hours later. Before performing the sprints followed by aerobic fitness tests in the morning, participants completed a 15-min warm-up following the same procedure as Ross et al. [149]. Prior to performing the power followed by strength tests in the afternoon, participants completed a 20-min warm up which consisted of foam rolling and dynamic functional movements.

Strength

Strength was quantified via one repetition maximum (1RM) assessments in the squat, bench press and weighted chin-up. For the squat, participants selected either a barbell front or back squat and self-selected their stance width and were required to reach "parallel" for the lift to be counted (hip crease level with knee cap). For the bench press, participants used a pronated self-selected grip width on a barbell and were required to lower the bar to chest level with feet and glutes remaining in contact with the floor and bench at all times. Participants commenced the chin up with arms extended in a supinated grip and were required to raise themselves to where their chin was over the bar in order for the lift to be deemed successful. Squat and bench press 1RMs were calculated based on the amount of external resistance lifted only. Meanwhile, chin up 1RM was calculated as bodyweight plus added external weight (Chin Up BW+AW), in which a dip-belt was used to load external resistance. All participants were instructed to warm up with three sets of sub-maximal loads (3–5 repetitions at 50%, 60%, 70% of perceived maximum strength), and thereafter, progressively increase resistance on each exercise until they reached their 1RM, with approximately three minutes rest between attempts [58, 150].

Power

Vertical power was collected by having participants perform maximal countermovement jumps (CMJ). The bodyweight condition (CMJPP) was performed while holding a 1-kg pole, while the loaded condition (CMJ40PP) was performed using a 40-kg barbell. A linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) was attached to the pole or bar in order to assess peak power (PP). Participants lowered to a self-selected squat depth and explosively jumped as high as possible while maintaining hold of the pole or barbell. Three practice jumps were performed by the participants, followed by three maximal jumps for CMJ and CMJ40 with three minutes rest between trials. For analysis, the highest value recorded by each participant was included. Relative power (W/kg) was also calculated for the bodyweight condition (CMJRP) and loaded condition (CMJ40RP) by dividing each participant's PP by their body mass. Horizontal power was indirectly measured using a broad jump with participants following the same protocol as used for vertical power. The broad jump was performed with full arm swing, feet hip width, and toes on a marked line. A tape measure was used to determine jump distance from toe-off to the back of the most rear foot, to the nearest centimetre. In order for the jump to be included in the analysis, in which the furthest jump attempt was used, participants were required to land on two feet without falling.

Speed

Speed was measured outdoors on an artificial (turf) running surface, in which participants performed a 20 m maximal-effort sprint. Dual-beam electronic timing lights (Speedlight TT, Swift Performance Equipment, Lismore, Australia) were set up at 0, 10, and 20 m distances. From a crouched, split-stance position with no countermovement or "rocking' motion, participants began the sprint 30 cm behind the starting gate. At each split, speed was recorded to the nearest 0.01 s. Two sprints were performed, with five minutes rest between efforts, with the fastest sprint by each participant being used for analysis.

Aerobic Fitness

The 20 m Yo-Yo intermittent recovery 1 (IR1) test was carried out on an artificial (turf) running surface to assess the participants' aerobic fitness. The IR1 was completed according to previously described methods [151]. Participants were asked to complete two 20 m shuttles before a beep was emitted from a stereo at each end, followed by 10 s of active recovery between shuttles. Over the course of the test, the required speed for each shuttle gradually increased, in which participants were required to run until they were no longer able to complete the shuttles in time with the beeps. When a participant failed twice to reach the designated lines before the beeps, the end of the test was considered. For analysis, the final level and shuttle reached was converted to total distance covered (m) for each participant.

Statistical Methods

All athlete characteristics are expressed as means and standard deviations (mean ± SD). All data were checked for normality using the Shapiro–Wilk test ($p > 0.05$). Differences between forwards and backs were compared using an independent *t*-test. Significance was set as $p < 0.05$. Positional differences with 95% confidence limits (95% CL) were calculated for all measures. Effect sizes (ES) were calculated with the following quantitative thresholds: *trivial* < 0.20, *small* 0.21–0.60, *moderate* 0.61–1.20, *large* 1.21–1.99 and *very large* > 2.0 [152]. Correlation coefficient were calculated to determine relationships between physical and fitness characteristics. The magnitude of the correlations were rated as *trivial* (< 0.09), *small* (0.10–0.29), *moderate* (0.30–0.49), *large* (0.50–0.69), *very large* (0.70–0.89), or *nearly perfect* (0.90–0.99) [153]. All statistical analyses were conducted using SPSS v24 for Windows (IBM, New York, NY, USA).

Results

Physical Characteristic Comparison

The demographics and physical characteristics between forwards and backs can be observed in Table 5. Forwards were significantly ($p = < 0.01$) taller (ES = 1.20) and heavier (ES = 2.10) than backs. Forwards possessed significantly ($p = < 0.01$) greater lean mass (ES = 2.06), fat mass (ES = 1.87), body fat percentage (ES = 1.51), bone mass (ES = 1.45), and skinfolds (ES = 1.51) than backs. Forwards were older, more experienced and possessed greater bone mineral density than backs; however, no significant differences were present.

Table 5. Physical characteristics of elite professional rugby union players.

	All Players (n = 39)	Position: Forwards (n = 23)	Position: Backs (n = 16)	% Difference (±95% CL)	Effect Size (±95% CL)	Qualitative Inference
Demographics						
Age (y)	26.6 ± 3.3	27.2 ± 2.8	25.7 ± 3.8	6.0 ± 9.2	0.47 ± 0.33	*Small* +
Experience (y)	7.3 ± 2.9	7.7 ± 2.8	6.7 ± 3.1	15.7 ± 35.4	0.36 ± 0.33	*Small* +
Anthropometrics						
Height (cm)	187.6 ± 7.6	190.9 ± 5.9 *	183.0 ± 7.5	4.3 ± 2.5	1.20 ± 0.35	*Moderate* +
Body Mass (kg)	108.0 ± 14.1	116.5 ± 10.1 *	95.9 ± 9.4	21.5 ± 7.4	2.10 ± 0.40	*Very Large* +
Sum8SF (mm)	68.3 ± 16.9	76.7 ± 16.4 *	56.2 ± 8.0	36.5 ± 15.7	1.51 ± 0.37	*Large* +
Body Composition						
Lean Mass (kg)	86.6 ± 9.5	92.3 ± 5.7*	78.5 ± 7.9	17.6 ± 6.7	2.06 ± 0.40	*Very Large* +
Fat Mass (kg)	18.3 ± 5.0	21.1 ± 4.5*	14.3 ± 1.8	48.2 ± 16.0	1.87 ± 0.39	*Large* +
BF% (%)	16.6 ± 2.5	17.8 ± 2.4*	14.8 ± 1.2	20.4 ± 8.2	1.51 ± 0.37	*Large* +
Bone Mass (kg)	3.9 ± 0.4	4.1 ± 0.4 *	3.6 ± 0.3	13.4 ± 6.0	1.45 ± 0.36	*Large* +
BMD (g/cm^2)	1.37 ± 0.08	1.39 ± 0.09	1.34 ± 0.06	3.8 ± 3.4	0.67 ± 0.33	*Moderate* +

Mean ± SD reported for all players, forwards and backs. 95% CL = 95% confidence limit, Sum8SF = sum of eight-site skinfolds, BF% = body fat percentage, BMD = bone mineral density. * Significant difference (p = < 0.05) compared to backs. Note: + or – indicates that forwards demonstrated a higher or lower value than backs.

Fitness Characteristic Comparison

Fitness characteristics between forwards and backs can be observed in Table 6. Forwards demonstrated significantly greater 1RM strength in the squat (p = 0.02; ES = 0.81), bench press (p = 0.02; ES = 0.81), and chin up (p = 0.01; ES = 0.90) compared to backs. Forwards also demonstrated significantly greater CMJPP (p = < 0.01; ES = 1.15) and CMJ40PP (p = < 0.01; ES = 0.99) compared to backs. Conversely, forwards possessed lower CMJRP (p = 0.25; ES = −0.38) and CMJ40RP (p = 0.06; ES = −0.64) compared to backs, although differences were not significant. Forwards demonstrated significantly less broad jump distance (p = 0.02; ES = −0.79), slower 10 m sprint (p = < 0.01; ES = 1.99), and 20 m sprint times (p = < 0.01; ES = 1.90) and covered less distance in the Yo-Yo test (p = < 0.01; ES = −2.56) compared to backs.

Table 6. Fitness characteristics of elite professional rugby union players.

	All Players (n = 39)	Position: Forwards (n = 23)	Position: Backs (n = 16)	% Diff (±95% CL)	Effect Size (±95% CL)	Qualitative Inference
Strength						
Squat 1RM (kg)	189.3 ± 25.1	197.2 ± 26.5 *	178.1 ± 18.3	10.7 ± 8.4	0.81 ± 0.34	*Moderate +*
Bench Press 1RM (kg)	141.5 ± 14.6	146.1 ± 14.2 *	135.0 ± 12.8	8.2 ± 6.7	0.81 ± 0.34	*Moderate +*
Chin Up BW + AW (kg)	150.4 ± 13.1	155.0 ± 12.1 *	143.8 ± 12.0	7.8 ± 5.7	0.93 ± 0.34	*Moderate +*
Power						
CMJPP (W)	4889.3 ± 636.5	5151.8 ± 620.5 *	4512.1 ± 451.9	14.2 ± 8.1	1.15 ± 0.35	*Moderate +*
CMJRP (W/kg)	45.8 ± 7.2	44.7 ± 7.8	47.4 ± 6.3	−5.7 ± 9.3	−0.38 ± 0.33	*Small −*
CMJ40PP (W)	4568.7 ± 509.1	4756.5 ± 549.7 *	4298.7 ± 285.4	10.7 ± 6.4	0.99 ± 0.34	*Moderate +*
CMJ40RP (W/kg)	42.9 ± 6.5	41.3 ± 6.8	45.2 ± 5.3	−8.8 ± 8.2	−0.64 ± 0.33	*Moderate −*
Broad Jump (cm)	261.3 ± 18.6	252.3 ± 25.3 *	269.0 ± 13.0	−6.2 ± 4.5	−0.79 ± 0.34	*Moderate −*
Speed						
Sprint 10 m (s)	1.73 ± 0.09	1.78 ± 0.08 *	1.66 ± 0.04	7.5 ± 2.2	1.99 ± 0.40	*Large +*
Sprint 20 m (s)	3.02 ± 0.17	3.11 ± 0.15 *	2.88 ± 0.07	8.0 ± 2.5	1.90 ± 0.39	*Large +*
Aerobic Fitness						
Yo-Yo Distance (m)	1812.3 ± 454.3	1516.5 ± 291.9 *	2237.5 ± 266.3	−32.2 ± 6.8	−2.56 ± 0.44	*Very Large −*

Mean ± SD reported for all players, forwards and backs. 95% CL = 95% Confidence Limit, % Diff = % difference, 1RM = one-repetition maximum, BW+AW = bodyweight plus added weight, CMJPP = bodyweight countermovement jump peak power, CMJRP = bodyweight countermovement jump relative power, CMJ40PP = countermovement jump with 40kg peak power, CMJ40RP = countermovement jump with 40kg relative power. * Significant difference (p = < 0.05) compared to backs. Note: + or – indicates that forwards demonstrated a higher or lower value than backs.

Characteristic Relationships

The relationships between physical and fitness characteristics can be observed in Table 7. *Trivial* to *very large* correlations existed between physical and fitness characteristics within forwards and backs. Of the 1RM strength measures, the squat demonstrated *small* to *large* correlations with anthropometric (r = −0.22–0.59) and body composition (r = 0.14–0.69) measurements for forwards. Within backs, 1RM strength measures demonstrated *trivial* to *large* correlations with anthropometrics (r = 0.03–0.88) and body composition (r = 0.08–0.89) measures, in which chin up demonstrated the strongest relationships with body mass (r = 0.88) and lean mass (r = 0.89).

In relation to power measures, the strongest correlations observed within forwards and backs were CMJRP (r = −0.82) and CMJ40RP (r = −0.85). The strongest correlations for forwards were between CMJRP, CMJ40RP and Sum8SF (r = −0.82–−0.84, respectively), while backs demonstrated strongest relationships between CMJRP, CMJ40RP and body mass (r = −0.70–−0.85, respectively). Regarding speed measures, both 10 and 20 m sprint times shared their largest correlations with Sum8SF (r = 0.75) and fat mass (r = 0.69–0.71, respectively) within forwards. The largest correlations for backs in relation to 10 and 20 m sprint was body fat percentage (r = 0.40) and age (r = 0.51), respectively. In relation to aerobic fitness, forwards'

Yo-Yo distance correlated most strongly with fat mass ($r = -0.66$) and body fat percentage ($r = -0.70$), while backs' Yo-Yo distance correlated most strongly with Sum8SF ($r = -0.54$).

Table 7. Relationships between physical and fitness characteristics within forwards (n = 23) and backs (n = 16).

	Squat 1RM	Bench Press 1RM	Chin Up 1RM	CMJ PP	CMJ RP	CMJ40 PP	CMJ40 RP	Broad Jump	10 m Sprint	20 m Sprint	Yo-Yo Distance
Forwards											
Demographics											
Age	0.04	0.08	0.20 *	−0.33 §	−0.21 *	−0.33 §	−0.21 *	−0.48 §	0.46 §	0.46 §	−0.23 *
Experience	−0.09	0.05	0.16 *	−0.48 §	−0.30 §	−0.49 §	−0.31 §	−0.51 ‡	0.47 §	0.47 §	−0.07
Anthropometrics											
Height	−0.22 *	−0.07	0.23 *	0.14 *	0.02	0.16 *	0.00	0.39 §	−0.03	−0.10 *	0.47 §
Body Mass	0.59 ‡	0.27 *	−0.05	−0.43 §	−0.78 †	−0.36 §	−0.76†	−0.28 *	0.69 ‡	0.69 ‡	−0.42 §
Sum8SF	0.49 §	0.16 *	−0.16 *	−0.69 ‡	−0.82 †	−0.67 ‡	−0.84†	−0.62 ‡	0.75 †	0.75 †	−0.50 ‡
Body Composition											
Lean Mass	0.52 ‡	0.28 *	0.07	−0.39 §	−0.74 †	−0.27 *	−0.68 ‡	−0.24 *	0.62 ‡	0.63 ‡	−0.30 §
Fat Mass	0.69 ‡	0.23 *	−0.19 *	−0.46 §	−0.73 †	−0.45 §	−0.75 †	−0.44 §	0.69 ‡	0.71 †	−0.66 ‡
BF%	0.68 ‡	0.20 *	−0.24 *	−0.45 §	−0.66 ‡	−0.49 §	−0.71 †	−0.47 §	0.65 ‡	0.67 ‡	−0.70 †
Bone Mass	0.14 *	0.19 *	0.15 *	−0.18 *	−0.33 §	−0.08	−0.27 *	−0.00	0.13 *	0.13 *	−0.13 *
BMD	0.17 *	0.17 *	0.18 *	−0.16 *	−0.27 *	−0.09	−0.22 *	−0.13 *	0.12 *	0.15 *	−0.20 *
Backs											
Demographics											
Age	0.19 *	−0.27 *	0.11 *	−0.47 §	−0.40 §	−0.44 §	−0.30 §	−0.19 *	0.33 §	0.51 ‡	−0.09
Experience	−0.07	−0.41 §	0.03	−0.46 §	−0.30 §	−0.39 §	−0.16 *	−0.17 *	0.24 *	0.40 §	0.05
Anthropometrics											
Height	0.18 *	0.02	0.64 ‡	−0.00	−0.56 ‡	0.15 *	−0.56 ‡	0.41 §	−0.10 *	−0.21 *	0.23 *
Body Mass	0.56 ‡	0.42 §	0.88 †	0.07	−0.70 †	0.03	−0.85 †	0.00	0.03	−0.08	−0.06
Sum8SF	0.03	0.25 *	−0.09	0.16 *	0.17 *	0.02	0.07	−0.45 §	0.03	0.00	−0.54 ‡
Body Composition											
Lean Mass	0.60 ‡	0.47 §	0.89 †	0.13 *	−0.65 ‡	0.07	−0.82 †	0.05	−0.00	−0.12 *	−0.05
Fat Mass	0.21 *	0.28 *	0.58 ‡	−0.05	−0.61 ‡	−0.02	−0.68 ‡	−0.32 §	0.29 *	0.14 *	−0.13 *
BF%	−0.32 §	−0.12 *	−0.17 *	−0.19 *	−0.13 *	−0.12 *	−0.06	−0.48 §	0.40 §	0.30 §	−0.20 *
Bone Mass	0.34 §	0.32 §	0.63 ‡	0.21 *	−0.33 §	0.26 *	−0.42 §	0.19 *	0.01	−0.02	0.29 *
BMD	0.08	0.29 *	0.23 *	0.49 §	0.26 *	0.50 ‡	0.16 *	0.18 *	−0.15 *	−0.13 *	0.34 §

1RM = one repetition maximum, CMJPP = bodyweight countermovement jump peak power, CMJRP = bodyweight countermovement jump relative power, CMJ40PP = countermovement jump with 40kg peak power, CMJ40RP = countermovement jump with 40kg relative power, Sum8SF = sum of eight-site skinfolds, BF% = body fat percentage, BMD = bone mineral density. Magnitudes of correlations: † *very large* (0.70–0.89), ‡ *large* (0.50–0.69), § *moderate* (0.30–0.49), * *small* (0.10–0.29), all other results are *trivial* (< 0.09).

Discussion

This study explored the physical and fitness characteristics of elite professional RU players in NZ. To the authors' knowledge, this is the first study to examine the relationships between these characteristics within elite professional RU players. Within this study, forwards were substantially bigger and stronger in all areas and possessed greater absolute power compared to backs. In contrast, backs were leaner, faster, aerobically fitter, and possessed greater relative power and broad jump distance. When examining the relationships between physical and fitness characteristics, skinfold measures were most consistently correlated with power and speed measures for forwards, showing *large* to *very large* correlations. Skinfolds, fat mass and body fat percentage within forwards were most consistently correlated with relative power, speed and Yo-Yo distance, showing *large* to *very large* correlations. Moreover, backs demonstrated *large* to *very large* correlations for body mass, lean mass and fat mass in relation to strength and relative power measures. In addition, *large* correlations were observed between age and 20 m sprint, and between skinfolds and Yo-Yo distance within backs.

These findings support previous studies which demonstrated forwards as having different body composition [3, 30, 31, 33, 34] and anthropometric characteristics than backs, including greater strength and absolute power measures, but slower sprint performance and less aerobic fitness [9, 12, 13, 20]. The characteristic differences between forwards and backs can be attributed to specific positional demands, in which being larger and stronger can assist forwards with winning line outs, scrumming with more force [154], gaining and retaining possession of the ball at break downs [9], and absorbing more collisions through tackles and ball carries [7]. Conversely, backs need to be leaner, faster, and aerobically fitter in order to defend or out manoeuvre their opponent in more open spaces, cover more distance, perform more sprints, and ultimately finish phases with trying scoring opportunities [7, 9]. However, as the game has evolved, the versatility of backs has increased by performing more additional tasks typically carried out by forwards (e.g., turnovers, clearing rucks) [3]. It has been suggested that teams with larger players (in particular larger forwards and taller backs) have greater success in test matches and World Cup competitions [17, 18].

Studies within southern [3, 9, 33, 34] and northern hemisphere [13, 31] professional RU players demonstrated similar anthropometric, body composition, and fitness characteristic differences between forwards and backs, as seen in the current study. Interestingly, both forwards and backs within our study demonstrated greater height, body mass, lean mass, and fat mass, but possessed less bone mass and body fat percentage compared to professional RU players observed in the northern hemisphere (United Kingdom) [31]. Meanwhile, similar strength and speed measures were observed between the current study and northern hemisphere players [13]. Within the southern hemisphere, similar strength and speed measures were observed in a previous study conducted in NZ [9], while similar heights, lean mass and bone mass were observed between professional NZ and Australian players. However, less fat mass and body fat percentage were observed in Australian players [3, 33, 34]. These findings suggest that anthropometric, body composition, and fitness characteristic differences between forwards and backs are very similar within northern and southern hemisphere teams, though variances may be due to differences in environmental conditions, game-play [155, 156], strength and conditioning practices [157], and ethnic/cultural make-up [3, 32-34].

Increasing body mass, in particular lean mass, while reducing fat mass is a common goal within professional RU players. Excess fat mass may attenuate force production and increase energy expenditure, leading to decreased strength, power, and speed while potentially increasing fatigue [33]. This is supported by the literature examining the relationships between physical fitness and game behaviours, in which work rate and the ability to repeatedly perform tasks may be improved by reducing body fat percentage [9]. The results of our study demonstrate that higher skinfold, fat mass, and body fat percentage correlated strongly with decreased power, speed, and aerobic fitness measures within forwards. These results suggest that leaner forwards may possess more favourable fitness characteristics; however, too much body mass, regardless of composition, may lead to decreased power, slower sprint times, and less distance covered in the Yo-Yo. Nevertheless, certain positions (e.g., props, locks, loose forwards) may require additional fat mass to withstand the forces associated with scrummaging and high frequency collisions [57], though more research is required within this area. Meanwhile, greater body mass and lean mass within backs correlated with greater strength, but lower relative power, which could partly be due to increased overall body mass and fat mass [31, 33]. Furthermore, fat mass and body fat percentage within backs demonstrated only *small* to *moderate* correlations with speed and aerobic fitness measures compared to *large* and *very large* correlations observed within forwards. Additionally, *large* correlations between skinfolds and aerobic fitness were observed within forwards and backs, suggesting greater skinfolds relate to less Yo-Yo distance.

Interestingly, Smart et al. [9] suggested that greater emphasis may need to be applied to speed and acceleration, especially over 10 m, due to the relationships observed with the number of line breaks, tackle breaks and tries scored, which are important game behaviours for successful phase and team outcomes. Our study observed that forwards with more skinfolds, fat mass, and body fat percentage may possess slower sprint times; therefore, both fat and skinfold measures appear important individual tracking tools, especially for forwards to improve speed measures. Additionally, lower skinfolds, fat mass and body fat percentage may also improve aerobic fitness (Yo-Yo distance), which was also a key variable influencing game-play [9]. It is important to note that there is no specific target for anthropometrics, body composition, and fitness characteristics for professional RU players. The physical and fitness aspect of a player is only one component of performance. The ability to read game-play, make the right decisions quickly, and connect with other players are also very important aspects relating to performance [1, 9].

Optimising physical and fitness characteristics for the individual may allow players to execute skill and tactical attributes with even greater success [9]. Numerous studies have shown large physical and fitness changes following a pre-season training block [13, 33, 150], demonstrating increases in lean mass while decreasing fat mass. Although it appears that professional RU players generally maintain body mass throughout the in-season period, in numerous players, lean mass is lost and substituted by an increase in fat mass [31]. Therefore, decreases in fitness characteristics may also occur due to the relationships observed with lean mass, fat mass and skinfolds. However, more research is needed to determine changes in physical and fitness characteristics throughout a season.

Future studies could monitor both physical and fitness characteristics throughout the in-season period to determine what effect changes in body composition may have on fitness characteristics. This would help profile individual players and assist in optimising strength and conditioning and nutrition programmes. Future studies could also explore different methods for maintaining lean mass while reducing increases in fat mass during in-season periods. It is well documented that professional RU players demonstrate great increases in lean mass and decreases in fat mass during pre-season periods [13, 33, 150] and appear to increase body mass, lean mass index, and strength measures over consecutive seasons [158]. However, players may be able to improve further by reducing losses in lean mass and increases in fat mass during the in-season.

A limitation within the current study was that players were not able to be in an overnight fasted state for DXA scans, which is suggested for best practice [44, 52]. Though not ideal, food and fluid intakes remained below 500 g for each player, which has been shown to minimise biological measurement error when using DXA [53]. Nevertheless, we acknowledge some error may be present across the whole group, though all players were under the same conditions. Furthermore, scanning the head and body separately followed by adding the partial scans together is potentially a more accurate method for taller individuals than excluding the feet from the scan, as carried out in two of our players. Although minimal, it is important to note that adding partial scans can increase scan time and exposure to radiation [55]. Lastly, our study was limited in that we could only use a small sample size of elite players and could only group players according to their primary positional group (forwards and backs). A larger sample would have allowed further exploration of forwards (front row, second row, back row) and backs (inside backs, midfield, outside backs) or separate positions within these classifications. This would be useful given the unique differences in roles between each position within a RU team [20].

Conclusion

In conclusion, we report that there are significant differences in the physical and fitness characteristics between NZ elite professional RU forwards and backs. The present study also reported that strength, power, speed, and aerobic fitness measures were most strongly correlated with skinfolds, fat mass, and body fat percentage within both forwards and backs. This information may be useful for practitioners developing future professional RU players, and to help monitor and optimise training and nutritional programmes in current professional RU players.

CHAPTER FOUR

The Physical Characteristics of Elite Female Rugby Union Players

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Prelude

Chapter Three was the first study to examine the physical characteristics of elite male professional rugby union players from New Zealand which demonstrated valuable insight regarding the body composition of these players between positions and regions of the world when compared to previous studies. Given the considerable differences among regions, and that no body composition assessment using Dual-energy X-ray Absorptiometry have been carried in the elite women's game world-wide let alone in New Zealand players, this study aimed to examine the physical characteristics of elite female rugby union players from New Zealand. This study was also the first to assess the bone health of players within this population group, which is an important screening measure for elite female athletes in relation to relative energy deficiency.

Abstract

This study explored the anthropometric and body composition characteristics of elite female rugby union players, comparing between and within different playing positions. Thirty elite female rugby union players (25.6 ± 4.3 y, 171.3 ± 7.7 cm, 83.5 ± 13.9 kg) from New Zealand participated in this study. Physical characteristics were assessed using anthropometric (height, body mass, skinfolds) and body composition (dual-energy X-ray absorptiometry) measures. Forwards were significantly taller ($p < 0.01$; $d = 1.34$), heavier ($p < 0.01$; $d = 2.19$), and possessed greater skinfolds ($p < 0.01$; $d = 1.02$) than backs. Forwards also possessed significantly greater total ($p < 0.01$; $d = 1.83$–2.25) and regional ($p < 0.01$; $d = 1.50$–2.50) body composition measures compared to backs. Healthy bone mineral density values were observed in both forwards and backs, with significantly greater values observed at the arm ($p < 0.01$; $d = 0.92$) and femoral neck ($p = 0.04$; $d = 0.77$) sites for forwards. Tight-five players were significantly heavier ($p = 0.02$; $d = 1.41$) and possessed significantly greater skinfolds ($p < 0.01$; $d = 0.97$) than loose-forwards. Tight-five also possessed significantly greater total body composition measures ($p < 0.05$; $d = 0.97$–1.77) and significantly greater trunk lean mass ($p = 0.04$; $d = 1.14$), trunk fat mass ($p < 0.01$; $d = 1.84$), and arm fat mass ($p = 0.02$; $d = 1.35$) compared to loose-forwards. Specific programming and monitoring for forwards and backs, particularly within forward positional groups, appear important due to such physical characteristic differences.

Keywords: bone mineral density; lean mass; fat mass; fat percentage; skinfolds.

Introduction

Rugby union (RU) is a high contact field-based team sport which is played all over the world at junior, senior, sub-elite, and elite levels by both males and females. In recent years, RU has become increasingly popular with more elite competitions and matches being contested by female RU players each year [1]. The same rules apply for both sexes, in which a game is contested over two 40 min halves by two teams consisting of 15 players aside comprised of eight forwards (numbers 1–8) and seven backs (numbers 9–15), with eight reserves on the bench (side-line). The game is intermittent in nature which is characterized by repeated bouts of high-intensity exercise (running, sprinting, tackling, scrummaging, rucking, and mauling) interspersed with periods of lower intensity exercise (standing, walking, and jogging). Both provincial [2] and elite [3] female RU players have been shown to cover approximately 5500 to 6400 m during a game, with elite female players demonstrating an average heart rate ~161 bpm and ~700 impacts during a game [3].

Specific anthropometric (height, body mass, skinfold) and body composition (lean mass, fat mass, bone mass) characteristics are required for specific positions in order to meet the physical demands of the sport [4]. Specifically, adequate amounts of body mass in the form of lean mass, fat mass, and bone mass appear to be crucial in order to withstand the frequency and intensity of collisions during offensive and defensive match-play [5]. Meanwhile, an optimal body composition that promotes lean mass and reduces fat mass are also desired to support the development of power, speed, and aerobic fitness, which are important factors to repeatedly perform and complete tasks at a high level [6].

Despite the known positional differences regarding anthropometrics and body composition within elite male RU players [5,7–12], body composition research within elite female RU players is limited. Elite female RU forwards have been shown to be significantly taller, heavier, and possess greater skinfolds and predicted fat percentage compared to backs [13–15]. However, a more recent study [16] demonstrated that forwards were larger and possessed more lean and fat mass than backs, but no significant differences were reported. Further research is required to understand the positional differences within these athletes, as it is well understood that specific roles between and within forwards and backs vary greatly due to the demands of the sport [4,17].

Body composition within elite female RU players has been predominantly determined using skinfolds and predictive equations to provide an estimated body fat percentage [13–15]. More advanced methods have also been implemented to assess body composition within these athletes, such as air displacement plethysmography (ADP) [16]. However, a method that has gained popularity for body composition analysis within elite male RU players is the use of dual-energy X-ray absorptiometry (DXA) [5,7–12,18]. Implementing DXA to assess body composition allows the measurement of lean, fat, and bone mass for both total and regional body compartments [19]. Moreover, DXA is the gold standard for measuring bone mineral content (BMC) and bone mineral density (BMD), which provide valuable information regarding the bone health of an athlete [20], which is particularly important among elite female athletes due to associations with female athlete triad [21].

Although a recent study has investigated the body composition of elite female rugby league (RL) players using DXA [22], no study has investigated the body composition and BMD of elite female RU players using DXA. Due to the differences in match-play demands observed between RU and RL [23,24], and between female and male RU [3,25], specific body composition information is required for elite female RU players. This information would be beneficial for talent identification purposes, and for practitioners developing female RU players by providing body composition benchmarks to inform training and nutrition programs. Therefore, the purpose of this study was to investigate the anthropometric and body composition characteristics of New Zealand (NZ) elite female RU players. Comparisons between forwards and backs, including differences within both forward and back positional groups, were explored. It was hypothesized that forwards would possess significantly greater anthropometric, total, and regional body composition measures compared to backs, and significant differences would be observed among forward and back positional groups.

Methodology

Participants and Study Design

Thirty elite female RU players (25.6 ± 4.3 y, 171.3 ± 7.7 cm, 83.5 ± 13.9 kg) from NZ were recruited for this study. Players were first categorized into forwards (*n* = 15) and backs (*n* = 15) for analysis and comparison, followed by positional groups within forwards (tight-five (TF) and loose-forwards (LF)) and backs (inside-backs (IB) and outside-backs (OB)). The TF (*n* = 9) were comprised of hookers (*n* = 3), props (*n* = 4), and locks (*n* = 2), while LF (*n* = 6) were comprised of flankers and no. 8′s. The IB (*n* = 8) were comprised of half-backs (*n* = 2), first-fives (*n* = 3), and second-fives (*n* = 3), while OB (*n* = 7) were comprised of centers (*n* = 2), wingers, and full backs (n = 5). All testing took place during the middle of the in-season period and all participants provided informed consent. The research was approved by the University of Waikato Human Research Ethics Committee (HREC 2019#02).

Anthropometrics

All anthropometric measures were collected using methods previously described [12]. Body mass was assessed using electronic scales (SECA, Birmingham, UK) to 0.1 kg accuracy upon waking with bladder voided. Height was then immediately assessed using a stadiometer (SECA, Birmingham, UK) to 0.5 cm accuracy. A Level 3 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist with a technical error of measurement of 1.8% carried out sum of eight site skinfold measurements on all players. Skinfolds were taken using Harpenden callipers (British Indicators, Hertfordshire, UK) to 0.1 mm accuracy. Sum of eight-site skinfold measurements from the following sites; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, anterior mid-thigh, and medial mid-calf were made on the right side of the body using ISAK techniques previously described by Norton and Colleagues [26]. All anthropometric equipment was calibrated as recommended by the manufacturer's guidelines.

Body Composition

Using previously described methods [12], total and regional body composition (lean mass, fat mass, body fat percentage, BMC, and BMD), were measured with a fan-beam DXA scanner (Hologic Discovery A, Hologic, Bedford, MA), with analyses performed using Apex 4.5.2 software (Hologic, Bedford, MA) using a whole-body scan protocol. The following clinical site measures for BMD; anterior-posterior lumbar spine (L2–L4) and left hip (femoral neck, trochanter, intertrochanter, and total hip) were included. All scanning procedures were standardized for all participants following the guidelines of the DXA manufacturer and the standards outlined by the International Society for Clinical Densitometry (ISCD). The scanner was tested for consistent calibration daily as per manufacturer guidelines for quality control purposes.

The quality control, acquisition, analysis, and interpretation of all scans were performed by the same experienced and Certified Clinical Densitometrist (CCD), therefore maintaining consistency and reliability of the scan results [27]. The head was included in the analysis for all total body measures and all scans were undertaken using the array mode. Scanned data was separated into axial, appendicular, and whole-body bone values. In the Bone Density Research

Laboratory site, coefficients of variation (CV) for precision and accuracy for the spine phantom were 0.3% and 0.4%, respectively. The in vivo precision CV for the CCD technician are 0.9% for total body, 0.6% for lumbar spine (L2–L4), and 0.2% for left total hip BMD sites. The prevalence of osteoporosis and osteopenia were estimated based on the World Health Organization (WHO) classifications (t-score > -1.0 = normal; t-score -1.1 to -2.4 = osteopenia; t-score < -2.5 = osteoporosis) using the young adult reference database.

All participants were scanned on the same day within a five-hour window (1000–1500 h), with all participants consuming breakfast and fluids (~500g) at the same time (0830 h). Participants were required to remove all metal items from their body and were scanned wearing tight-fitting sport shorts and top that were free from zips, studs, and/or metal objects. Participants were then instructed to lay supine on the scanning bed as still as possible for the duration of the scan. All protocols followed previously described techniques to maximize technical reliability and minimize error [19,28], however, players were unable to be scanned in a fasted state.

Statistical Methods

All data expressed as means and standard deviation (SD). A 95% confidence interval (95% CI) was presented alongside mean difference and standard error (SE) for all variables. Tests of normality (Shapiro–Wilk) were carried out, which revealed normally distributed data. Differences between forwards and backs and within positional groups (TF vs LF and IB vs OB) were compared using an independent *t*-test. Statistical significance was set as $p < 0.05$ for analyses. Henceforth, when the term ‘significant’ and ‘significantly’ is stated, it denotes a statistically significant difference. Effect sizes were calculated using the Cohen’s *d* method with the following thresholds: *d* = *small* 0.20–0.49, *medium* 0.50–0.79, and *large* >0.80 [29]. All statistical analyses were conducted using SPSS v24 for Windows (IBM, New York, NY, USA).

Results

Analysis Between Forwards and Backs

The demographics, anthropometrics, and total body composition for all players and by position can be observed in Table 8. Forwards were significantly taller ($p < 0.01$; $d = 1.34$), heavier ($p < 0.01$; $d = 2.19$), and had significantly greater skinfold totals ($p < 0.01$; $d = 1.02$) than backs. Forwards possessed significantly greater total lean mass ($p < 0.01$; $d = 1.83$), fat mass ($p <$

0.01; $d = 2.25$), body fat percentage ($p < 0.01$; $d = 1.87$), and BMC ($p < 0.01$; $d = 1.40$) than backs.

Table 8. Demographics, anthropometrics, and total body composition characteristics of elite female rugby union players.

	All Players	Position		Mean Diff	95% CI	% Diff; ES
		Forwards	Backs			
	(*n* = 30)	(*n* = 15)	(*n* = 15)	(± SE)		
Age (y)	25.6 ± 4.3	25.3 ± 3.6	25.8 ± 5.0	−0.5 ± 1.6	-3.7, 2.8	−1.8; −0.11
Height (cm)	171.3 ± 7.7	175.6 ± 6.3 *	167.0 ± 6.6	8.6 ± 2.4	3.8, 13.5	5.2; 1.34
Body Mass (kg)	83.5 ± 13.9	93.7 ± 10.9 *	73.3 ± 7.5	20.5 ± 3.4	13.5, 27.5	27.9; 2.19
Sum8SF (mm)	111.3 ± 36.7	128.2 ± 36.6 *	94.4 ± 29.0	33.8 ± 12.1	9.1, 58.5	35.8; 1.02
Lean Mass (kg)	60.9 ± 7.8	66.2 ± 6.3 *	55.6 ± 5.3	10.6 ± 2.1	6.3, 14.9	19.0; 1.83
Fat Mass (kg)	20.3 ± 6.6	25.3 ± 5.4 *	15.4 ± 3.1	9.9 ± 1.6	6.6, 13.2	64.5; 2.25
BF% (%)	23.6 ± 4.2	26.5 ± 3.1 *	20.8 ± 3.0	5.8 ± 1.1	3.5, 8.1	27.7; 1.87
BMC (kg)	2.9 ± 0.3	3.1 ± 0.3 *	2.7 ± 0.2	0.4 ± 0.1	0.2, 0.5	13.1; 1.40
BMD (g/cm^2)	1.24 ± 0.08	1.26 ± 0.08	1.23 ± 0.07	0.03 ± 0.03	-0.03, 0.08	2.1; 0.33

Mean ± standard deviation (SD) reported for all players, forwards and backs. Mean Diff (± SE) = mean difference ± standard error of mean difference, 95% CI = 95% confidence interval (lower limit, upper limit), % Diff = percentage difference, ES = effect size, BF% = body fat percentage, BMC = bone mineral content, BMD = bone mineral density, Sum8SF = sum of eight-site skinfolds. * Statistically significant difference ($p < 0.05$) compared to backs.

Regional body composition for all players and by position can be observed in Table 9. Forwards possessed significantly greater measures across the trunk, arms, and legs for lean mass ($p < 0.01$; $d = 1.77$, 1.53, 1.50, respectively), fat mass ($p < 0.01$; $d = 1.75$, 1.87, 2.50, respectively), and BMC ($p < 0.01$; $d = 0.88$, 1.51, 1.48, respectively) compared to backs. No clear differences were observed for age between forwards and backs.

Table 9. Regional body composition characteristics of elite female rugby union players.

		All Players	Position		Mean Diff	95% CI	% Diff; ES
			Forwards	Backs			
		(*n* = 30)	(*n* = 15)	(*n* = 15)	(± SE)		
Trunk	Lean Mass (kg)	29.4 ± 4.2	32.2 ± 3.7 *	26.6 ± 2.5	5.6 ± 1.2	3.3, 7.9	21.0; 1.77
	Fat Mass (kg)	8.5 ± 3.5	10.8 ± 3.4 *	6.2 ± 1.6	4.6 ± 1.0	2.6, 6.6	75.3; 1.75
	BMC (kg)	0.90 ± 0.12	0.94 ± 0.12 *	0.85 ± 0.10	0.10 ± 0.04	0.01, 0.18	11.2; 0.88
Arms	Lean Mass (kg)	6.9 ± 0.9	7.5 ± 0.8 *	6.3 ± 0.7	1.1 ± 0.3	0.6, 1.7	17.9; 1.53
	Fat Mass (kg)	2.3 ± 0.9	2.9 ± 0.8 *	1.7 ± 0.4	1.2 ± 0.2	0.7, 1.7	71.7; 1.87
	BMC (kg)	0.40 ± 0.06	0.44 ± 0.05 *	0.37 ± 0.04	0.07 ± 0.02	0.04, 0.11	19.5; 1.51
Legs	Lean Mass (kg)	21.5 ± 3.0	23.3 ± 2.4 *	19.6 ± 2.5	3.7 ± 0.9	1.8, 5.5	18.6; 1.50
	Fat Mass (kg)	8.5 ± 2.6	10.5 ± 1.8 *	6.5 ± 1.4	4.0 ± 0.6	2.8, 5.2	62.2; 2.50
	BMC (kg)	1.08 ± 0.14	1.17 ± 0.13 *	1.00 ± 0.10	0.17 ± 0.04	0.08, 0.26	17.0; 1.48

Mean ± SD reported for all players, forwards and backs. Mean Diff (± SE) = mean difference ± standard error of mean difference, 95% CI = 95% confidence interval (lower limit, upper limit), % Diff = percentage difference, ES = effect size, BMC = bone mineral content. * Statistically significant difference ($p < 0.05$) compared to backs.

BMD Between Forwards and Backs

The BMD for all players and by position can be observed in Table 10. No significant differences were observed between forwards and backs for total body (p = 0.63, d = 0.33) and total hip (p = 0.73, d = 0.50) BMD. However, forwards demonstrated significantly greater BMD in the arms (p < 0.01, d = 0.92) and femoral neck (p = 0.04; d = 0.77) compared to backs. There were no significant differences between forwards and backs for total body and clinical site BMD t-scores.

Table 10. Total and clinical site bone mineral density (g/cm^2) of elite female rugby union players.

	All Players	Position		Mean Diff	95% CI	% Diff; ES
		Forwards	Backs			
	(n = 30)	(n = 15)	(n = 15)	(SE)		
Arms	0.84 ± 0.06	0.87 ± 0.07 *	0.82 ± 0.05	0.05 ± 0.02	0.01, 0.10	6.5; 0.92
Legs	1.29 ± 0.09	1.31 ± 0.10	1.27 ± 0.07	0.05 ± 0.03	−0.02, 0.11	3.7; 0.54
Ribs	0.77 ± 0.07	0.78 ± 0.07	0.76 ± 0.06	0.02 ± 0.02	−0.03, 0.07	3.1; 0.36
Spine	1.17 ± 0.13	1.19 ± 0.14	1.15 ± 0.12	0.04 ± 0.05	−0.05, 0.14	3.7; 0.34
Pelvis	1.55 ± 0.18	1.56 ± 0.17	1.55 ± 0.19	0.01 ± 0.07	−0.12, 0.15	0.7; 0.06
Head	2.19 ± 0.24	2.20 ± 0.27	2.18 ± 0.21	0.03 ± 0.09	−0.16, 0.21	1.2; 0.11
Total	1.24 ± 0.08	1.26 ± 0.08	1.23 ± 0.07	0.03 ± 0.03	−0.03, 0.08	2.1; 0.33
Total t-score	1.58 ± 0.97	1.80 ± 1.03	1.31 ± 0.86	0.49 ± 0.39	−0.32, 1.30	37.5; 0.51
Clinical Sites						
Lumbar (L2–L4)	1.31 ± 0.15	1.36 ± 0.14	1.25 ± 0.13	0.10 ± 0.05	0.00, 0.21	8.1; 0.73
Femoral Neck	1.12 ± 0.11	1.16 ± 0.10 *	1.07 ± 0.12	0.08 ± 0.04	0.00, 0.16	7.8; 0.77
Trochanter	0.94 ± 0.10	0.95 ± 0.10	0.94 ± 0.11	0.01 ± 0.04	−0.07, 0.09	0.8; 0.07
Intertrochanter	1.39 ± 0.14	1.42 ± 0.13	1.35 ± 0.14	0.07 ± 0.05	−0.03, 0.17	5.3; 0.53
Total hip	1.21 ± 0.11	1.24 ± 0.10	1.18 ± 0.12	0.06 ± 0.04	−0.03, 0.14	4.7; 0.50
Clinical site t-score	1.99 ± 1.46	2.46 ± 1.41	1.44 ± 1.37	1.03 ± 0.57	−0.16, 2.21	71.4; 0.74

Mean ± SD reported for all players, forwards and backs. Mean Diff (± SE) = mean difference ± standard error of mean difference, 95% CI = 95% confidence interval (lower limit, upper limit), % Diff = percentage difference, ES = effect size. * Statistically significant difference (p < 0.05) compared to backs.

Analysis Within Forward and Back Positional Groups

Within position differences for forwards and backs can be observed in Table 11. The TF possessed significantly greater body mass (p = 0.02; d = 1.41) and skinfolds (p < 0.01; d = 2.01) compared to LF. The TF demonstrated significantly greater total lean mass (p = 0.04; d = 0.97), fat mass (p < 0.01; d = 1.75), and body fat percentage (p < 0.01; d = 1.77) than LF. Regarding regional body composition, TF presented significantly greater trunk lean mass (p = 0.04; d = 1.14), trunk fat mass (p < 0.01; d = 1.84), and arm fat mass (p = 0.02; d = 1.35) compared to LF. No significant differences were observed between IB and OB for all measures.

Table 11. Demographics, anthropometrics, total and regional body composition within forward and back positional groups.

	Forward Positional Groups (*n* = 15)					Back Positional Groups (*n* = 15)				
	TF (*n* = 9)	**LF (*n* = 6)**	**Mean Diff (± SE)**	**95% CI**	**% Diff; ES**	**IB (*n* = 8)**	**OB (*n* = 7)**	**Mean Diff (± SE)**	**95% CI**	**% Diff; ES**
Age (y)	25.2 ± 3.0	25.5 ± 4.8	−0.3 ± 2.0	−4.6, 4.0	−1.1; −0.07	26.8 ± 4.9	24.7 ± 5.3	2.0 ± 2.6	−3.6, 7.7	8.2; 0.40
Anthropometrics										
Height (cm)	174.8 ± 7.6	176.8 ± 3.9	−2.1 ± 3.4	−9.4, 5.3	−1.2; −0.32	168.8 ± 8.0	164.9 ± 4.3	3.8 ± 3.4	−3.5, 11.2	2.3; 0.58
Weight (kg)	98.8 ± 10.9 *	86.0 ± 4.9	12.8 ± 4.8	2.5, 23.1	14.9; 1.41	73.6 ± 5.8	72.9 ± 9.6	0.7 ± 4.0	−8.0, 9.4	0.9; 0.09
Sum8SF (mm)	149.2 ± 28.8 *	96.8 ± 20.9	52.4 ± 13.7	22.8, 82.1	54.2; 2.01	95.5 ± 31.2	93.2 ± 28.9	2.3 ± 15.6	−31.4, 36.0	2.5; 0.08
Body Composition										
Total Lean Mass (kg)	68.5 ± 7.1 *	62.9 ± 2.3	5.6 ± 3.1	−1.0, 12.2	8.9; 0.97	55.5 ± 4.9	55.8 ± 6.0	−0.3 ± 2.8	−6.4, 5.8	−0.5; −0.05
Total Fat Mass (kg)	28.2 ± 4.7 *	21.0 ± 3.2	7.3 ± 2.2	2.5, 12.0	34.6; 1.75	15.8 ± 2.1	14.9 ± 4.0	0.9 ± 1.6	−2.5, 4.5	6.6; 0.31
Total Fat % (%)	28.2 ± 2.4 *	24.0 ± 2.3	4.2 ± 1.3	1.5, 6.9	17.5; 1.77	21.4 ± 2.4	20.1 ± 3.7	1.3 ± 1.6	−2.1, 4.8	6.6; 0.43
Trunk Lean Mass (kg)	33.7 ± 3.7 *	29.9 ± 2.6	3.8 ± 1.8	0.2, 7.6	12.7; 1.14	27.2 ± 2.2	25.9 ± 2.7	1.3 ± 1.3	−1.4, 4.1	5.1; 0.54
Trunk Fat Mass (kg)	12.7 ± 2.9 *	8.0 ± 1.9	4.7 ± 1.3	1.8, 7.6	58.6; 1.84	6.2 ± 1.3	6.1 ± 2.0	0.1 ± 0.9	−1.8, 1.9	0.4; 0.02
Arm Lean Mass (kg)	7.7 ± 0.8	7.2 ± 0.6	0.5 ± 0.4	−0.4, 1.3	6.7; 0.65	6.2 ± 0.6	6.5 ± 0.9	−0.3 ± 0.4	−1.1, 0.6	−3.8; −0.33
Arm Fat Mass (kg)	3.2 ± 0.8 *	2.3 ± 0.6	0.9 ± 0.4	0.2, 1.8	41.5; 1.35	1.8 ± 0.2	1.5 ± 0.4	0.3 ± 0.2	−0.1, 0.7	19.0; 0.86
Leg Lean Mass (kg)	23.8 ± 2.8	22.6 ± 1.5	1.2 ± 1.3	−1.5, 3.9	5.2; 0.50	19.1 ± 2.3	20.3 ± 2.8	−1.2 ± 1.3	−4.0, 1.7	−5.7; −0.46
Leg Fat Mass (kg)	11.1 ± 1.5	9.5 ± 1.9	1.6 ± 0.9	−0.3, 3.5	16.6; 0.96	6.8 ± 1.0	6.1 ± 1.8	0.7 ± 0.7	−0.9, 2.3	11.6; 0.50

Mean ± SD reported for all positions. TF = tight-five, LF = loose-forwards, IB = inside-backs, OB = outside-backs, Mean Diff (± SE) = mean difference ± standard error of mean difference, 95% CI = 95% confidence interval (lower limit, upper limit), % Diff = percentage difference, ES = effect size, Sum8SF = sum of eight-site skinfolds.
* Statistically significant difference ($p < 0.05$) compared to LF.

Discussion

The purpose of this study was to investigate the anthropometric and body composition characteristics of NZ elite female RU players. Comparisons were made between forward and back positions, including analysis of within position differences. As hypothesized, forwards demonstrated significantly greater values across all anthropometric, total, and regional body composition measures than backs. Additionally, forwards presented greater BMD across all sites with significant differences present at the arms and femoral-neck compared to backs. Interestingly, only forward positional groups demonstrated significant differences, in which TF possessed significantly greater anthropometric, total, and regional body composition measures compared to LF. This study is the first to assess the body composition characteristics of elite female RU players using DXA, and the first to explore differences between forward and back positional groups.

The anthropometric and body composition differences between forwards and backs are consistent with previous research within both elite female [13–16] and elite male RU players [5,7–12]. Irrespective of sex, forwards require these specific physical characteristics to meet match demands where being taller is desirable in order to gain and retain possession of the ball during line outs, while greater body mass may assist in gaining and retaining ball possession during scrums, rucks, and mauls [4]. Meanwhile, backs are generally shorter, lighter, and leaner in order to achieve higher speeds in more open spaces in an attempt to outmaneuver opponents to create scoring opportunities [4]. Studies within male RU players have also demonstrated that as playing level increases, players are generally heavier with greater lean mass, whilst possessing lower skinfold and body fat percentage [17]. Researchers have also suggested that being taller and heavier appear to be important key performance indicators for World Cup success in elite male RU players [30,31]. More research is required to determine whether such trends exist within elite female RU players.

Within the current study, both forwards and backs were taller and heavier than elite female RU players reported in previous studies [13–16]. Although forwards and backs within the current study were substantially heavier compared to other elite female RU players [13–16], the current players possessed noticeably lower skinfolds, even when comparing sum of eight-site skinfolds within this study, with sum of seven-site skinfolds within previous studies [14,15]. The measured body fat percentage using DXA for forwards and backs within this study were considerably lower than the predicted body fat percentage reported for elite South African players [14] but were similar to elite English players [13]. Additionally, forwards within the current study demonstrated greater total body lean and fat mass, but lower body fat percentage compared to elite Scottish female forwards. Meanwhile, backs demonstrated greater total body lean mass and considerably less fat mass and body fat percentage compared to elite Scottish female RU backs [16].

It is important to note that considerably less body mass was reported within the previous studies [14,16], but particularly within English players [13] compared to the current study. These comparisons highlight the substantial increases in size and in particular body mass within elite female RU players as the sport has progressed throughout the years [13–16]. Moreover, differences in size and body mass may also be attributed to cultural and ethnicity differences between countries [5,7,8,18]. Increases in body mass, but particularly lean mass, are desired due to the contractile element of muscle mass aiding force production, thus positively influencing power to weight ratio and the expression of strength, power, speed and momentum [7]. These are all important factors for attacking and defending within RU and may be further enhanced by limiting/reducing the amount of non-functional fat mass [12]. Too much fat mass may also negatively influence energy expenditure, thermoregulation, and the ability to repeatedly perform tasks within RU match-play [6]. This information supports the need for more current studies reporting the physical and fitness profiles of elite female RU players.

Until now, no research has been available regarding the regional body composition of elite female RU players. The results of this study align with previous research within elite male RU players which demonstrated significantly greater amounts of regional lean mass, fat mass, and BMC in forwards compared to backs [5,7]. When compared to elite female RL players, elite female RU forwards possess greater lean mass at all regional sites, while possessing similar amounts of fat mass at the arms and legs, but less fat mass at the trunk compared to elite female RL forwards [22]. Meanwhile, elite female RU backs demonstrated greater lean mass while possessing lower amounts of fat mass at all regional sites compared to elite female RL backs [22].

When comparing the positional differences within forwards and backs, only forward positional groups demonstrated significant differences. These findings suggest that positional groups within backs are more homogeneous than within forward positional groups. Therefore, more individualized training and nutrition programs may be required for forwards compared to backs. Moreover, TF forwards could potentially aim to decrease fat mass, particularly in the trunk and arms to improve power to weight ratio and acceleration capability [7]. However, further research is required to understand whether or not this extra fat mass demonstrated by TF players is important for the demands of the position. A general consensus is that greater fat mass within collision-based athletes may be required to better deal with impacts due to the "cushioning" effect of fat tissue [22]. Therefore, determining how much fat mass is optimal within female RU players would be valuable.

Interestingly, when comparing the percentage difference for all measures between forwards and backs within the current study to NZ elite male RU players [12], similar differences can be observed. The percentage difference for anthropometric and total body composition measures between forwards and backs within elite females were very similar to elite males [12]. This information suggests that regardless of sex, RU may produce similar positional differences in relation to anthropometrics and body composition. However, it is important to note that females possess unique physiological differences compared to males such as, constant changes in the female sex hormone milieu throughout the menstrual cycle and therefore, across the training program [32]. Due to the effect's hormones have on the body, training, and adaptation, these areas within female athletes need to be carefully considered when developing training and nutrition plans [32].

Future research could assess the physical characteristics derived from DXA alongside fitness measures to examine the associations between body composition and physical performance within elite female RU players. Furthermore, exploring the body composition changes using DXA and changes in fitness measures during pre-season and in-season phases would provide valuable information regarding seasonal changes in physical and fitness characteristics. Carrying out DXA scans to track longitudinal changes in body composition to inform training and nutrition programs also allows for the analysis of BMD. Although low BMD does not appear to be a concern within this group of elite athletes, DXA is valuable to identify any athletes with low BMD. Greater insight into the movement demands, training load, and energy requirements of elite female RU players would also be valuable due to the associations between training and nutrition for optimizing body composition [33,34].

A limitation within the current study was the relatively small sample size of elite players, particularly when exploring the within position differences for forwards and backs. A larger sample size would have provided a greater representation of the within position differences and would have allowed further exploration into forward (front row, second row, back row) and back (inside-back, midfield, outside-back) positions. However, this sample size should be appropriate to provide valuable information for talent identification, coaching, and sport science staff. Another limitation within this study was the fact that participants could not be in a fasted state before DXA scans. Researchers should strive to carry out DXA protocols in a fasted state, however within elite sporting environments this can be a challenging task. Although not optimal, all participants consumed less than 500 g of food and fluids which has been shown to maintain low biological measurement error when using DXA [35].

Conclusion

In conclusion, forwards were significantly larger than backs, possessing greater stature, body mass, skinfolds, and total and regional body composition measures. Total and regional BMD values are within normal ranges, with forwards demonstrating significantly greater arm and femoral neck BMD. This study presented novel findings regarding the significant differences between forward positional groups, in which TF were significantly larger than LF. However, no significant differences were observed between back positional groups. This information may be useful for coaches and sport science staff when developing training and nutrition programs for female RU players. It may also provide useful benchmarks that can assist talent identification staff and the development of future female RU players.

CHAPTER FIVE

Position Specific Anthropometrics and Body Composition Among Professional Male and Female Rugby Union Players

Posthumus, L., Driller, M., Winwood, P., & Gill, N. (2024). Position Specific Anthropometrics and Body Composition Among Professional Male and Female Rugby Union Players. *(Under Review)*

Prelude

Chapters Three and Four provided novel insights into the physical characteristics of elite male and female rugby union players from New Zealand using Dual-energy X-ray Absorptiometry (DXA). However, these studies were limited in size and only examined primary playing position (forwards and backs) among both males and females, and secondary positional groups (Tight-Five, Loose-Forwards, Inside-Backs, and Outside-Backs) among female players. The study in this chapter aimed to extend our understanding in this space by examining the body composition requirements by specific playing position and playing level among professional male and female rugby union players. Indeed, assessing body composition using DXA is often difficult for players and practitioners to administer. Therefore, this study also aimed to examine the relationship between skinfolds and DXA to develop a skinfold-based prediction equation to conveniently estimate body fat percentage among this population group. These are valuable measures to monitor given the strong correlations observed between skinfolds, fat mass, and BF% measures and speed, power, and aerobic fitness measures.

Abstract

The anthropometric and body composition characteristics among professional rugby union forward and back position groups is well documented. However, position specific characteristics and practical measures to predict body fat percentage (BF%) require further investigation. The aims of this study were to; assess the position specific anthropometric and body composition characteristics of elite and sub-elite male (n = 59, n = 45, respectively) and female (n = 47, n = 28, respectively) rugby union players and to develop a BF% prediction equation for both groups using the sum of eight-site skinfolds (Sum8SF). Body composition was measured via Dual-energy X-ray Absorptiometry. Elite players demonstrated significantly (p < 0.05) higher levels of lean mass (LM) than sub-elite players. Significant ($p < 0.05$) differences in anthropometric and body composition measures were present among male and female specific forward and back positions. Relationships (r = 0.67-0.88) between BF% and Sum8SF were *large* among female backs, and *very large* among male and female forwards and male backs. A new BF% prediction equation was developed using Sum8SF among male forward (R^2 = 0.57; SEE = 1.70) and back (R^2 = 0.62; SEE = 1.21) positions, and female forward (R^2 = 0.78; SEE = 2.20) and back (R^2 = 0.45; SEE = 2.35) positions. These equations can provide an estimation of BF% when a more direct measure may not be available helping practitioners optimise body composition and energy requirements. The position specific and playing level physical characteristics presented further support individual and/or position specific programming.

Keywords: skinfolds; lean mass; body fat percentage; fat mass; team-sport; DXA.

Introduction

Rugby Union (RU) has two primary playing positions consisting of forwards (numbers 1-8 for starting players) and backs (numbers 9-15 for starting players). Hookers (number 2), Props (numbers 1 and 3), Locks (numbers 4 and 5) and Loose-Forwards (numbers 6-8) make up the eight forwards. The seven backs comprise: Half-Back/Scrum-Half (number 9), First-Five-Eighth/Fly-Half (number 10), Midfielders (numbers 12 and 13), and Outsides (numbers 11, 14, and 15). For players to meet the demands of the sport, they possess particular anthropometric and body composition characteristics [1]. Given the relatively large physiques of elite RU players and the importance of these larger physiques on team success [17, 18], it is beneficial to assess the body composition of these players by position to provide further detail on how their body mass is comprised [159, 160].

When assessing a player's body composition using Dual-energy X-ray Absorptiometry (DXA); lean mass (LM), fat mass (FM), body fat percentage (BF%), and bone mineral content (BMC) can be determined. Promoting a body composition where lean mass is high and fat mass is as low as possible, is desired for optimising a range of fitness characteristics important in RU [160-162]. Previous studies using DXA to assess body composition among sub-elite and elite male RU players have only reported the anthropometric and body composition characteristics among forwards and backs as a group, rather than by individual position [3, 159, 160, 163, 164]. These studies have shown that elite male [3, 30-32, 34, 160, 163-165] and female [159, 166, 167] RU forwards are larger in stature, BM, LM, FM, and BF% compared to backs which is advantageous for their positional demands [1, 9, 20, 161, 162, 168].

However, in elite female RU players, a southern hemisphere study using DXA reported anthropometric and body composition characteristics among forwards and their broad sub-groups (Tight-Five and Loose-Forwards) and back sub-groups (Inside-Backs and Outside-Backs) [159]. Similarly, a northern hemisphere among elite female RU players using DXA reported more specific positions for forwards (Front-Row, Locks, and Back-Row) and backs (Scum-Half, Inside-Back, and Outside-Back) providing further insight into player position characteristics [161]. However, further classification for each individual playing position within RU can be achieved.

One study among amateur NCAA collegiate female RU players explored the positional differences for each playing position, which demonstrated significant variation between specific positions and provided insight into the anthropometric and body composition characteristics for each individual playing position within a team [169]. Similarly, a study among elite male rugby league players explored the specific positional differences for each playing position, which also demonstrated significant variation between positions [57]. Examining these position-specific differences among sub-elite and elite male and female RU players would be valuable to provide further insight into the differences and similarities between different playing positions and levels. This would assist in the individualisation of performance programmes as each specific position group possesses unique roles, skillsets, and positional demands [170-172].

It is important to note that, although the use of DXA for measuring body composition among RU players is progressing, body composition is more frequently assessed via skinfolds due to their convenience, acceptable reliability, and low cost [173]. Skinfolds are often used as a total sum of sites (total sum in mm) to track FM changes which has demonstrated good agreement alongside DXA in elite RU players [34]. Skinfold sites can also be entered into prediction equations to estimate BF% which has demonstrated less accuracy in elite male RU players [32]. Implementing DXA alongside skinfolds can provide further insight into the body composition of RU players to assist with their individual performance plans [173, 174]. Thus, exploring a relationship between skinfolds and BF% and developing a prediction equation would be useful among these groups to compare where an individual may be positioned following either assessment.

Therefore, the aims of this study were to; a) examine the anthropometric and body composition characteristics between both primary and specific playing position and playing level among male and female New Zealand RU players and b) examine whether BF% can be accurately predicted using demographic (age) and anthropometric variables (height, BM, and total sum of eight-site skinfolds [Sum8SF]). The hypotheses for this study were; a) significant differences would exist between primary and specific playing positions and playing level among both males and females due to the specific and unique roles each position plays, and b) BF% can be strongly predicted in male and female forwards and backs using Sum8SF.

Methodology

Study Design and Participants

A cross-sectional study design was utilised to assess the body composition of elite and sub-elite male and female rugby union players at the end of their pre-season phases. One hundred and seventy-nine players (104 males and 75 females) provided informed consent and ethical approval was obtained from the University of Waikato Human Research Ethics Committee (HREC2019#02).

Males

One-hundred and four male New Zealand (NZ) RU players (age = 25.9 ± 3.6 y, height = 185.9 ± 7.0 cm, body mass = 104.1 ± 13.3 kg) participated in this study. Elite players were from the NZ Super Rugby Championship (*n* = 59) and sub-elite from the NZ National Provincial Championship (*n* = 45). The Super Rugby Championship is classified as elite as it includes international players and international playing fixtures, while the National Provincial Championship is national level [175]. Players were categorised by their primary playing positions comprising 56 forwards (Hookers = 10, Props = 17, Locks = 14, Loose-Forwards [includes Flankers and No.8] = 15) and 48 backs (Half-Backs = 10, First-Five-Eighths = 10, Midfielders [includes Second-Five-Eighth and Centre] = 14, Outsides [includes Wing and Fullback] = 14).

Females

Seventy-five female NZ RU players (age = 24.2 ± 4.6 y, height = 170.4 ± 6.2 cm, body mass = 80.4 ± 13.9 kg) participated in this study. Elite players were from the NZ Super Rugby Championship (*n* = 47) and sub-elite from the NZ National Provincial Championship (*n* = 28), following the same level classifications as males above [175]. Players were categorised by their primary playing positions comprising 37 forwards (Hookers = 9, Props = 8, Locks = 9, Loose-Forwards [includes Flankers and No.8] = 11) and 38 backs (Half-Backs = 9, First-Five-Eighths = 9, Midfielders [includes Second-Five-Eighths and Centre] = 10, Outsides [includes Wing and Fullback] = 10).

Anthropometric and Body Composition Assessment

Participants were instructed to arrive at the laboratory in a rested and overnight-fasted state with all jewellery removed and wearing tight-fitting compression clothing free from zips, studs, metal and reflective objects. Participants were first measured for height using a fixed-to-wall stadiometer (SECA, Germany) measuring to the nearest 0.5 cm, followed by BM using a calibrated set of scales (SECA, Germany) measuring to the nearest 0.1 kg. A Level 1 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist collected Sum8SF measurements to 0.1 mm accuracy using Harpenden callipers (British Indicators, Hertfordshire, UK). Skinfold measures were taken from the right-hand side of the body from the following eight sites; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, anterior mid-thigh and medial mid-calf using ISAK protocols [41] and following the same methods previously described [159, 160].

Each participant then underwent whole-body fan-beam Dual-energy X-ray Absorptiometry (DXA) scans (Hologic QDR Series, Discovery A, Bedford, MA, USA) following the same methods previously described [159, 160] to provide LM, FM, BF%, and BMC measures. All scans were performed and analysed by the same trained operator and were reported as whole-body, which included the head. All anthropometric and DXA equipment were calibrated as per the manufacturers' guidelines.

Statistical Analyses

All statistical tests were analysed using the Statistical Package for the Social Sciences (SPSS, v28, IBM, New York, NY, USA). All measures are reported as means and standard deviation (mean ± SD). The Shapiro-Wilk test was used to test all measures for normality. Differences between primary playing position (forwards and backs) and playing level (elite and sub-elite) were compared using an independent *t*-test. Relationships between anthropometrics and body composition variables were determined using Pearson correlation coefficients (*r*) with the following thresholds; *trivial* (< 0.09), *small* (0.10-0.29), *moderate* (0.30-0.49), *large* (0.50-0.69), *very large* (0.70-0.89), or *nearly perfect* (0.90-0.99) [153]. Differences between specific playing positions for forwards (Hookers, Props, Locks, Loose-Forwards) and backs (Half-Backs, First-Five-Eighths, Midfielders, Outside-Backs) were analysed using a One-way analysis of variance (ANOVA) with Bonferroni *post-hoc*. Effect sizes were calculated using the Cohens *d* method with the following thresholds; *d* = *trivial* < 0.19, *small* 0.20-0.49, *medium* 0.50-0.79, and *large* > 0.80 [176].

Stepwise multiple regression analysis was carried out using relevant variables (age, height, BM, Sum8SF) to develop a new BF% prediction equation for male and female RU players. The significantly strongest predictor of BF% was Sum8SF alone for both male and female forwards and backs. This resulted in a Sum8SF equation being developed for male and female forwards and backs. Bland-Altman plots were used to identify the 95% limits of agreement between the measured and predicted BF%. Mean accuracy percentage and number of players predicted within 10% were presented for prediction equations. Significance was set as $p < 0.05$.

Results

Differences by Primary Playing Position

Male anthropometric and body composition differences between male and female forwards and backs are presented in Table 12.

Table 12. Anthropometric and body composition differences between forwards and backs among males and females.

	Males (n = 104)			**Females (n = 75)**		
	Forwards (n = 56)	**Backs (n = 48)**	**ES (d)**	**Forwards (n = 37)**	**Backs (n = 38)**	**ES (d)**
Demographics						
Age (yrs)	26.1 ± 3.6 [20 – 37]	25.6 ± 3.7 [20 – 33]	0.12	24.3 ± 4.3 [17 – 33]	24.1 ± 4.9 [18 – 34]	0.03
Height (cm)	188.8 ± 6.4* [175 – 203]	182.5 ± 6.2 [171 – 197]	1.00	173.2 ± 5.8* [16 – 186]	167.6 ± 5.2 [157 – 179]	1.02
BM (kg)	113.6 ± 9.1* [97 – 140]	93.4 ± 8.1 [73 – 109]	2.34	89.8 ± 13.8* [67 – 124]	71.8 ± 6.3 [57 – 83]	1.69
Sum8SF (mm)	83.0 ± 19.2* [52 – 132]	60.6 ± 10.1 [43 – 98]	1.43	114.1 ± 35.8* [65 – 176]	77.9 ± 14.8 [55 – 121]	1.33
Body Composition						
LM (kg)	88.1 ± 6.5* [77 – 103]	75.4 ± 7.0 [61 – 91]	1.88	62.5 ± 7.1* [50 – 80]	53.3 ± 5.1 [45 – 62]	1.50
FM (kg)	21.4 ± 4.0* [16 – 33]	14.5 ± 2.0 [11 – 21]	2.16	24.3 ± 7.5* [14 – 44]	15.8 ± 2.7 [10 – 22]	1.52
BF% (%)	18.8 ± 2.6* [14 – 24]	15.5 ± 1.9 [11 – 21]	1.42	26.6 ± 4.6* [19 – 36]	22.0 ± 3.1 [16 – 28]	1.17
BMC (kg)	4.0 ± 0.4* [3.1 – 4.9]	3.5 ± 0.4 [2.6 – 4.6]	1.23	3.0 ± 0.3* [2.3 – 3.6]	2.7 ± 0.2 [2.1 – 3.0]	1.07

Mean ± SD [Range]. ES = effect size (Cohen's d), BM = body mass, Sum8SF = sum of eight-site skinfolds, LM = lean mass, FM = fat mass, BF% = body fat percentage, BMC = bone mineral content. *Significant difference ($p < 0.01$) between forwards and backs among males and females.

Differences between Playing Levels for Primary Playing Positions

Males

Elite male forwards were significantly older ($p < 0.01$; $d = 0.79$) and possessed significantly greater BM ($p < 0.01$; $d = 1.31$) and LM ($p < 0.01$; $d = 1.86$) compared to sub-elite male forwards (Table 13). Elite male backs presented significantly greater BM ($p = 0.02$; $d = 0.72$), LM ($p < 0.01$; $d = 0.92$), and significantly lower Sum8SF ($p = 0.01$; $d = -0.79$) and BF% ($p = 0.01$; $d = -0.79$) compared to sub-elite male backs.

Females

Elite female forwards presented significantly greater stature ($p = 0.02$; $d = 0.83$), LM ($p = 0.04$; $d = 0.73$), and BMC ($p < 0.01$; $d = 1.11$) compared to sub-elite female forwards (Table 13). Elite female backs were significantly older ($p < 0.01$) and possessed significantly greater ($p < 0.01$) LM ($d = 1.02$), BMC ($d = 1.08$), and significantly lower BF% ($p < 0.01$; $d = -1.06$) compared to sub-elite female backs.

Table 13. Anthropometric and body composition differences between playing levels for primary playing positions.

	Males (*n* = 104)				Females (*n* = 75)			
	Forwards (*n* = 56)		Backs (*n* = 48)		Forwards (*n* = 37)		Backs (*n* = 38)	
	Elite (*n* = 35)	Sub-Elite (*n* = 21)	Elite (*n* = 24)	Sub-Elite (*n* = 24)	Elite (*n* = 20)	Sub-Elite (*n* = 17)	Elite (*n* = 27)	Sub-Elite (*n* = 11)
Demographics								
Age (yrs)	27.1 ± 3.2* [21 – 37]	24.4 ± 3.7 [20 – 33]	25.5 ± 3.9 [21 – 33]	25.8 ± 3.5 [20 – 26]	25.3 ± 3.8 [19 – 32]	23.1 ± 4.8 [17 – 33]	25.9 ± 4.7* [18 – 34]	19.8 ± 1.7 [18 – 24]
Height (cm)	189.2 ± 6.3 [181 – 203]	188.0 ± 6.6 [175 – 202]	183.5 ± 6.8 [171 – 197]	181.5 ± 5.5 [171 – 190]	175.3 ± 5.6* [165 – 186]	170.8 ± 5.2 [163 – 184]	167.3 ± 5.5 [157 – 179]	168.3 ± 4.6 [160 – 176]
BM (kg)	117.3 ± 8.8* [102 – 140]	107.3 ± 5.2 [97 – 117]	96.2 ± 8.0* [80 – 109]	90.7 ± 7.3 [73 – 106]	91.3 ± 11.8 [71 – 120]	88.1 ± 16.0 [67 – 124]	72.9 ± 6.2 [57 – 83]	69.3 ± 5.8 [61 – 79]
Sum8SF (mm)	81.6 ± 17.9 [52 – 125]	85.3 ± 21.4 [55 – 132]	56.8 ± 7.4* [43 – 69]	64.3 ± 11.2 [45 – 98]	109.2 ± 33.8 [65 – 176]	119.9 ± 38.2 [68 – 174]	75.9 ± 15.8 [55 – 121]	82.6 ± 11.4 [55 – 96]
Body Composition								
LM (kg)	91.5 ± 5.4* [82 – 103]	82.5 ± 3.7 [77 – 92]	78.3 ± 6.7* [66 – 91]	72.4 ± 6.1 [61 – 85]	64.8 ± 6.3* [54 – 80]	59.9 ± 7.3 [50 – 77]	54.7 ± 4.9* [45 – 62]	50.0 ± 3.9 [45 – 57]
FM (kg)	21.8 ± 4.3 [16 – 33]	20.8 ± 3.3 [16 – 26]	14.3 ± 1.6 [11 – 17]	14.7 ± 2.4 [11 – 21]	23.4 ± 6.0 [14 – 37]	25.5 ± 9.1 [14 – 44]	15.4 ± 2.5 [10 – 20]	16.8 ± 3.0 [12 – 22]
BF% (%)	18.5 ± 2.6 [14 – 24]	19.4 ± 2.6 [16 – 24]	14.8 ± 1.2* [13 – 17]	16.3 ± 2.3 [11 – 21]	25.3 ± 3.6 [19 – 32]	28.1 ± 5.2 [19 – 36]	21.1 ± 2.7* [16 – 25]	24.1 ± 3.2 [18 – 28]
BMC (kg)	4.0 ± 0.4 [3.3 – 4.9]	3.9 ± 0.4 [3.1 – 4.5]	3.6 ± 0.3 [3.0 – 4.6]	3.4 ± 0.4 [2.6 – 4.4]	3.1 ± 0.3* [2.3 – 3.6]	2.8 ± 0.3 [2.5 – 3.4]	2.7 ± 0.2* [2.3 – 3.0]	2.5 ± 0.3 [2.1 – 3.0]

Mean ± SD [Range]. BM = body mass, Sum8SF = sum of eight-site skinfolds, LM = lean mass, FM = fat mass, BF% = body fat percentage, BMC = bone mineral content. * Significant difference ($p < 0.05$) between elite and sub-elite male forwards and backs, and between elite and sub-elite female forwards and backs.

Differences by Specific Playing Position among Males

Differences between specific playing positions for demographics and anthropometrics among males can be observed in Table 14.

Height

There was a main effect of player position on stature for forwards ($F_{3,\ 52} = 28.40$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions. For backs there was a main effect of playing position on stature ($F_{3,\ 44} = 10.47$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Body Mass

There was a main effect of player position on BM ($F_{3,\ 52} = 15.17$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions. For backs there was a main effect of playing position on BM ($F_{3,\ 44} = 23.40$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Sum of Eight-Site Skinfolds

There was a main effect of player position on Sum8SF ($F_{3,\ 52} = 16.78$; $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions.

Lean Mass

There was a main effect of player position on LM ($F_{3,\ 52} = 4.87$, $p = 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions. For backs there was a main effect of playing position on LM ($F_{3,\ 44} = 21.57$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Fat Mass

There was a main effect of player position on FM ($F_{3,\ 52} = 33.40$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions.

Body Fat Percentage

There was a main effect of player position on BF% ($F_{3,\ 52} = 17.60$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions.

Bone Mineral Content

For backs there was a main effect of playing position on BMC ($F_{3,\ 44} = 7.28$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Table 14. Position specific differences for anthropometrics and body composition among males (n = 104).

	Forwards (*n* = 56)				Backs (*n* = 48)			
	Hookers (*n* = 10)	**Props (*n* = 17)**	**Locks (*n* = 14)**	**Loose-Forwards (*n* = 15)**	**Half-Backs (*n* = 10)**	**First-Fives (*n* = 10)**	**Midfielders (*n* = 14)**	**Outsides (*n* = 14)**
Demographics								
Age (yrs)	27.1 ± 2.8 [22 – 32]	26.3 ± 4.2 [21 – 37]	26.2 ± 3.3 [20 – 33]	24.9 ± 3.7 [20 – 33]	25.1 ± 3.8 [21 – 32]	25.3 ± 3.1 [21 – 32]	27.4 ± 3.8 [21 – 33]	24.4 ± 3.4 [20 – 32]
Height (cm)	183.8 ± 2.4[a] [181 – 187]	185.3 ± 5.1[b] [175 – 194]	196.9 ± 4.0[abc] [190 – 203]	188.5 ± 3.4[ac] [181 – 194]	176.2 ± 4.3[ef] [171 – 182]	180.0 ± 4.7[g] [171 – 186]	186.1 ± 5.7[eg] [175 – 194]	185.1 ± 4.5[f] [180 – 197]
BM (kg)	109.6 ± 5.2[a] [102 – 117]	121.1 ± 9.2[ab] [107 – 140]	115.6 ± 5.8[c] [107 – 130]	105.8 ± 5.1[bc] [97 – 115]	84.8 ± 5.9[ef] [73 – 93]	88.2 ± 3.8[gh] [80 – 92]	100.9 ± 4.8[eg] [92 – 109]	95.9 ± 5.8[fh] [87 – 107]
Sum8SF (mm)	76.4 ± 7.1[a] [62 – 83]	99.8 ± 16.9[ab] [77 – 132]	86.1 ± 18.1[c] [52 – 118]	65.5 ± 8.6[bc] [53 – 89]	59.8 ± 6.6 [49 – 69]	67.5 ± 16.9 [43 – 98]	59.7 ± 7.8 [43 – 71]	57.1 ± 5.8 [49 – 69]
Body Composition								
LM (kg)	86.3 ± 4.7 [80 – 94]	91.3 ± 7.7[a] [77 – 103]	90.0 ± 5.6[b] [83 – 101]	84.0 ± 4.4[ab] [78 – 93]	68.5 ± 4.7[ef] [61 – 76]	70.2 ± 3.5[gh] [65 – 75]	81.7 ± 4.3[eg] [73 – 91]	77.6 ± 5.5[fh] [69 – 89]
FM (kg)	19.4 ± 2.0[a] [16 – 23]	25.8 ± 2.9[abc] [21 – 33]	21.5 ± 2.7[bd] [17 – 26]	17.8 ± 1.5[cd] [16 – 22]	13.4 ± 1.4 [12 – 16]	14.6 ± 2.4 [11 – 18]	15.2 ± 2.4 [11 – 21]	14.5 ± 1.5 [12 – 17]
BF% (%)	17.7 ± 1.7[a] [16 – 21]	21.4 ± 2.0[abc] [18 – 24]	18.6 ± 2.2[b] [14 – 23]	16.8 ± 1.3[c] [15 – 21]	15.8 ± 1.6 [14 – 18]	16.5 ± 2.6 [13 – 21]	15.1 ± 2.0 [11 – 20]	15.1 ± 1.4 [13 – 17]
BMC (kg)	3.95 ± 0.30 [3.3 – 4.4]	3.96 ± 0.47 [3.3 – 4.9]	4.12 ± 0.27 [3.6 – 4.5]	3.90 ± 0.38 [3.1 – 4.5]	3.24 ± 0.25[ef] [2.9 – 3.6]	3.30 ± 0.19[gh] [2.9 – 3.6]	3.77 ± 0.42[eg] [3.1 – 4.6]	3.61 ± 0.33[fh] [2.6 – 4.0]

Mean ± SD [Range]. BM = body mass, Sum8SF = sum of eight-site skinfolds, LM = lean mass, FM = fat mass, BF% = body fat percentage, BMC = bone mineral content. Letters *a, b, c, d* denotes a significant difference between each other among male forwards. Letters *e, f, g, h* denotes a significant difference ($p < 0.05$) between each other among male backs.

Differences by Specific Playing Position among Females

Differences between specific playing positions for demographics and anthropometrics among males can be observed in Table 15.

Height

There was a main effect of player position on stature ($F_{3,\ 33} = 7.69$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions. For backs there was a main effect of playing position on stature ($F_{3,\ 34} = 10.64$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Body Mass

There was a main effect of player position on BM ($F_{3,\ 33} = 7.69$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions. For backs there was a main effect of playing position on BM ($F_{3,\ 34} = 3.97$, $p = 0.02$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Sum of Eight-Site Skinfolds

There was a main effect of player position on Sum8SF ($F_{3,\ 33} = 7.39$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions.

Lean Mass

There was a main effect of player position on LM ($F_{3,\ 33} = 14.67$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions. For backs there was a main effect of playing position on LM ($F_{3,\ 34} = 5.33$, $p = 0.01$), with *post-hoc* analyses revealing *large* significant differences between playing positions.

Fat Mass

There was a main effect of player position on FM ($F_{3,\ 33} = 13.60$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions.

Body Fat Percentage

There was a main effect of player position on BF% ($F_{3,\ 33} = 5.91$, $p < 0.01$), with *post-hoc* analyses revealing *large* significant differences between forward playing positions.

Table 15. Position specific differences for anthropometrics and body composition among females (n = 75).

	Forwards (*n* = 37)				Backs (*n* = 38)			
	Hookers (*n* = 9)	**Props (*n* = 8)**	**Locks (*n* = 9)**	**Loose-Forwards (*n* = 11)**	**Half-Backs (*n* = 9)**	**First-Fives (*n* = 9)**	**Midfielders (*n* = 10)**	**Outsides (*n* = 10)**
Demographics								
Age (yrs)	23.1 ± 3.6 [19 – 30]	24.5 ± 3.7 [20 – 29]	26.6 ± 3.9 [22 – 32]	23.2 ± 5.4 [17 – 33]	23.8 ± 4.5 [18 – 31]	22.8 ± 4.1 [18 – 29]	24.3 ± 5.9 [18 – 34]	25.5 ± 5.2 [20 – 32]
Height (cm)	169.8 ± 2.3^{a} [166 – 172]	173.6 ± 7.5 [165 – 186]	179.3 ± 2.7^{ab} [176 – 184]	170.8 ± 4.6^{b} [163 – 178]	162.3 ± 2.9^{ef} [157 – 166]	169.8 ± 3.7^{e} [163 – 176]	171.8 ± 4.2^{fg} [167 – 179]	166.3 ± 4.6^{g} [160 – 173]
BM (kg)	88.8 ± 8.2^{a} [79 – 99]	109.5 ± 8.0^{abc} [102 – 124]	85.4 ± 9.4^{b} [69 – 98]	80.0 ± 8.8^{c} [67 – 94]	67.8 ± 5.1^{e} [63 – 75]	70.3 ± 4.2^{f} [61 – 77]	76.4 ± 4.1^{ef} [67 – 81]	72.2 ± 8.0 [57 – 83]
Sum8SF (mm)	122.5 ± 38.5 [65 – 174]	151.1 ± 29.4^{ab} [91 – 176]	97.2 ± 24.0^{a} [76 – 133]	94.2 ± 22.5^{b} [68 – 126]	82.1 ± 8.4 [71 – 99]	82.6 ± 15.4 [65 – 110]	75.2 ± 9.0 [65 – 96]	72.4 ± 21.6 [55 – 121]
Body Composition								
LM (kg)	61.5 ± 4.6^{a} [56 – 69]	72.2 ± 4.7^{abc} [66 – 80]	61.1 ± 4.5^{b} [51 – 66]	57.6 ± 5.5^{c} [50 – 65]	49.1 ± 3.6^{e} [45 – 55]	52.3 ± 3.5 [46 – 58]	56.7 ± 4.3^{e} [47 – 62]	54.6 ± 5.5 [45 – 62]
FM (kg)	24.4 ± 5.6^{a} [16 – 33]	34.2 ± 6.1^{abc} [25 – 44]	21.3 ± 5.1^{b} [16 – 33]	19.6 ± 4.4^{c} [14 – 26]	16.2 ± 1.8 [14 – 18]	15.3 ± 2.3 [12 – 18]	16.9 ± 2.9 [12 – 22]	14.8 ± 3.4 [10 – 20]
BF% (%)	27.3 ± 4.5 [20 – 33]	31.1 ± 4.1^{ab} [25 – 36]	24.6 ± 3.3^{a} [21 – 29]	24.3 ± 3.6^{b} [19 – 29]	23.8 ± 1.7 [21 – 26]	21.8 ± 2.9 [18 – 27]	22.2 ± 3.8 [16 – 28]	20.4 ± 3.1 [17 – 25]
BMC (kg)	2.96 ± 0.36 [2.3 – 3.6]	3.04 ± 0.27 [2.7 – 3.4]	3.00 ± 0.24 [2.6 – 3.4]	2.85 ± 0.31 [2.5 – 3.4]	2.53 ± 0.23 [2.1 – 2.9]	2.64 ± 0.28 [2.2 – 3.0]	2.72 ± 0.22 [2.3 – 3.0]	2.73 ± 0.24 [2.3 – 3.0]

Mean ± SD [Range]. BM = body mass, Sum8SF = sum of eight-site skinfolds, LM = lean mass, FM = fat mass, BF% = body fat percentage, BMC = bone mineral content. Letters *a, b, c, d* denotes a significant difference between each other among female forwards. Letters *e, f, g, h* denotes a significant difference ($p < 0.05$) between each other among female backs.

Newly Developed Prediction Equation Compared to Measured Body Fat Percentage

Male Forwards and Backs BF% Prediction Equations

Stepwise multiple regression revealed that Sum8SF for both male forwards (R^2 = 0.57; Standard Error of Estimate [SEE] = 1.70) and backs (R^2 = 0.62; SEE = 1.21) was the strongest significant predictor of BF% (p < 0.05) accounting for 57% and 62% of the variation in BF%, respectively, and was the only predictor variable included in the novel prediction equations. All other variables (age, height, BM) were rejected as they did not significantly improve the fit of the models. The predicted BF% values are plotted against measured BF% values for male forwards (Figure 2b) and backs (Figure 2d). The *very large* relationships observed between measured BF% and Sum8SF for male forwards (r = 0.76; p < 0.01) and backs (r = 0.78; p < 0.01) are plotted (Figure 2a and Figure 2c, respectively). Bland-Altman plots displaying mean constant error and 95% limits of agreement among male forwards and backs can be observed in Figures 4a and 4b, respectively.

Male Forwards Sum8SF Prediction Equation (BF%) = 10.374 + (0.101 x Sum8SF [mm])

Male Backs Sum8SF Prediction Equation (BF%) = 6.466 + (0.150 x Sum8SF [mm])

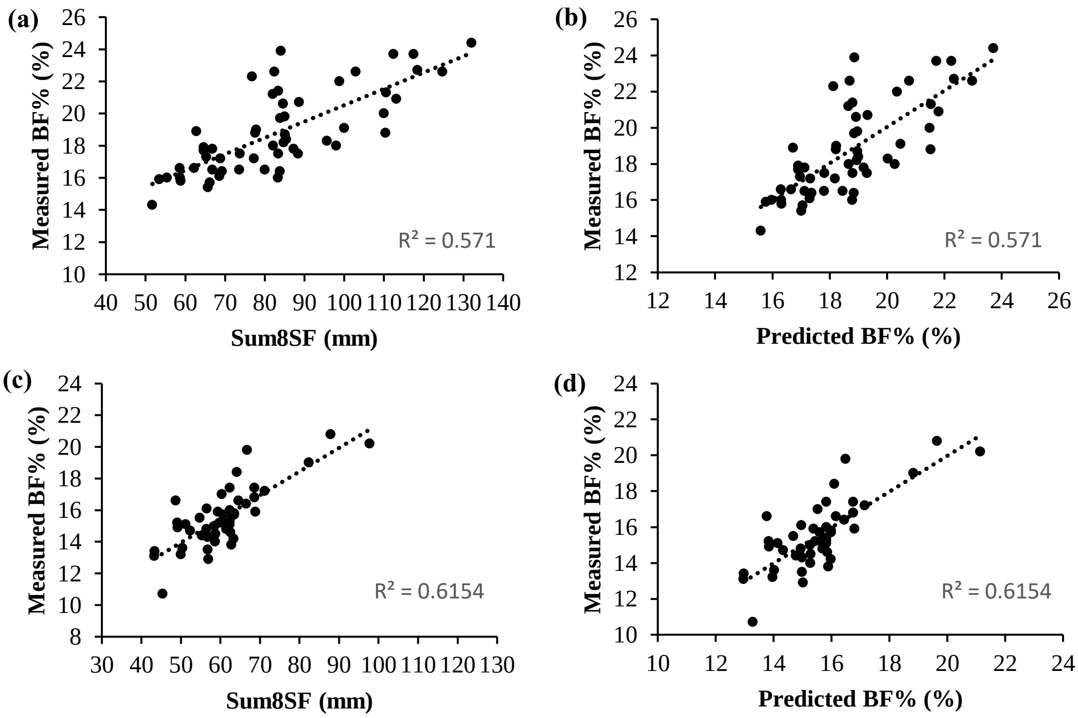

Figure 2. Relationship between Sum of Eight-Site Skinfolds (Sum8SF) and body fat percentage (BF%) among (a) Male Forwards and (c) Male Backs. Predicted BF% versus measured BF% among (b) Male Forwards and (d) Male Backs.

Female Forwards and Backs BF% Prediction Equations

Stepwise multiple regression revealed that Sum8SF for both female forwards (R^2 = 0.78; Standard Error of Estimate [SEE] = 2.20) and backs (R^2 = 0.45; SEE = 2.35) were the strongest significant predictor of BF% ($p < 0.05$) accounting for 78% and 45% of the variation in BF% and was the only predictor variable included in the novel prediction equations. All other variables (age, height, BM) were rejected as they did not significantly improve the fit of the models. The predicted BF% values are plotted against measured BF% values for female forwards (Figure 3b) and backs (Figure 3d). The *very large* and *large* relationships observed between measured BF% and Sum8SF for female forwards (r = 0.88; $p < 0.01$) and backs (r = 0.67; $p < 0.01$), respectively are plotted (Figure 3a and Figure 3c, respectively). Bland-Altman plots displaying mean constant error and 95% limits of agreement can be observed in Figures 4c and 4d, respectively.

Female Forwards Sum8SF Prediction Equation (BF%) = 13.661 + (0.113 x Sum8SF [mm])

Female Backs Sum8SF Prediction Equation (BF%) = 11.081 + (0.140 x Sum8SF [mm])

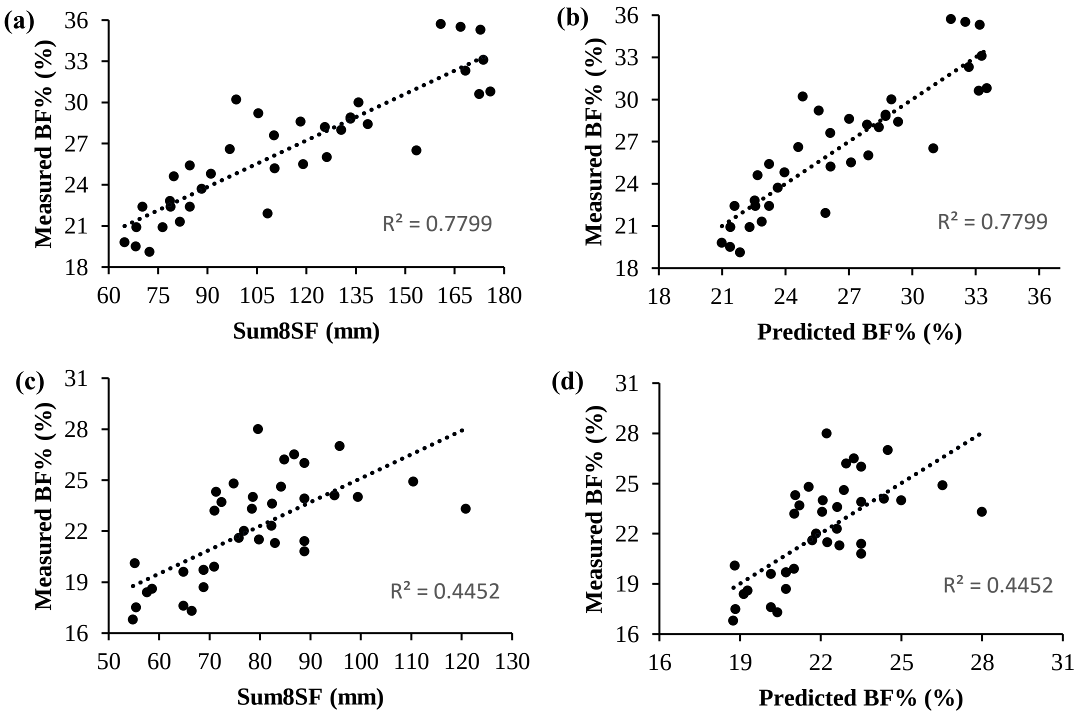

Figure 3. Relationship between Sum of Eight-Site Skinfolds (Sum8SF) and body fat percentage (BF %) among (a) Female Forwards and (c) Female Backs. Predicted BF % versus measured BF % among (b) Female Forwards and (d) Female Backs.

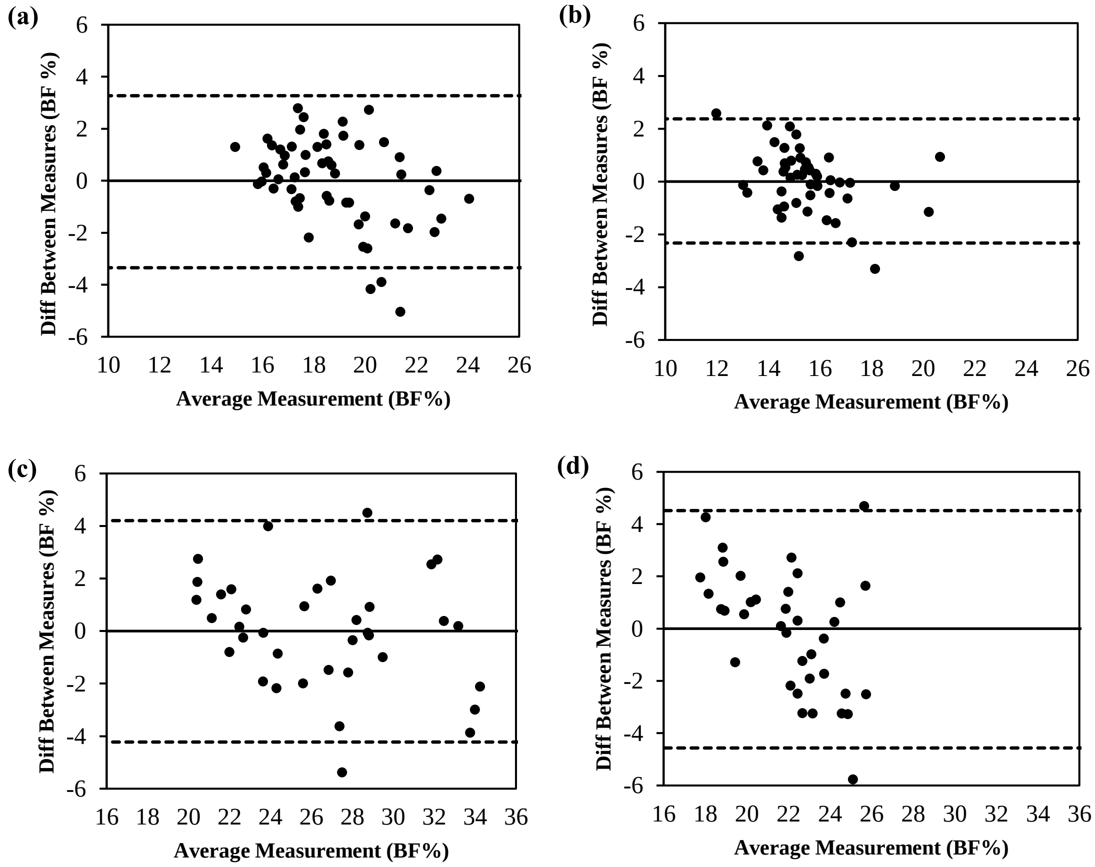

Figure 4. Bland-Altman Plots for Sum of Eight-Site Skinfolds (Sum8SF) equations; (a) Male Forwards, (b) Male Backs, (c) Female Forwards, and (d) Female Backs. The middle solid horizontal line represents the constant error. The lower and upper dashed horizontal lines represent the 95% limits of agreement.

Percentage Accuracy of Prediction Equations

The percentage accuracy of prediction for the male and female forward and back equations can be observed in Figure 5. The mean accuracy percentage for male forwards and backs was 93% and 94%, respectively. The mean accuracy percentage for female forwards and backs was 94% and 91%, respectively. Of the 56 male forwards, 45 (80%) were predicted within 10% of measured values and of the 48 male backs, 40 (83%) were predicted within 10% of measured values. For female forwards, 32 out of 37 (87%) were predicted within 10% of measured values and 27 out of 38 female backs (71%) were predicted within 10% of measured values.

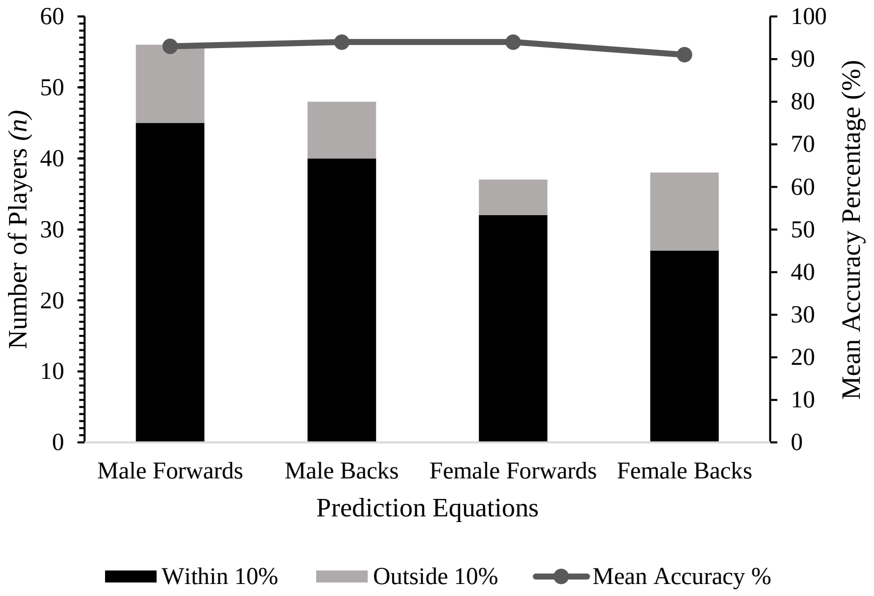

Figure 5. Number of players predicted within 10% accuracy and the mean accuracy percentage for each prediction equation compared to measured body fat percentage among male forwards (n = 56) and backs (n = 48) and female forwards (n = 37) and backs (n = 38).

Conversion Table Between Sum of Eight-Site Skinfolds and Body Fat Percentage

Using the newly developed Sum8SF prediction equations a predicted conversion chart between total Sum8SF and BF% was created for practitioners (see Table 16). Corresponding Sum8SF and BF% for forward and back positions for both males and females are presented.

Table 16. Predicted conversion table between sum of eights-site skinfolds and body fat percentage using the newly developed skinfold prediction equations.

Males				**Females**			
Forwards		**Backs**		**Forwards**		**Backs**	
Sum8SF (mm)	**BF% (%)**	**Sum8SF (mm)**	**BF% (%)**	**Sum8SF (mm)**	**BF% (%)**	**Sum8SF (mm)**	**BF% (%)**
160	26.53	160	30.47	160	31.74	160	33.48
150	25.52	150	28.97	150	30.61	150	32.08
140	24.51	140	27.47	140	29.48	140	30.68
130	23.50	130	25.97	130	28.35	130	29.28
120	22.49	120	24.47	120	27.22	120	27.88
110	21.48	110	22.97	110	26.09	110	26.48
100	20.47	100	21.47	100	24.96	100	25.08
90	19.46	90	19.97	90	23.83	90	23.68
80	18.45	80	18.47	80	22.70	80	22.28
70	17.44	70	16.97	70	21.57	70	20.88
60	16.43	60	15.47	60	20.44	60	19.48
50	15.42	50	13.97	50	19.31	50	18.08
40	14.41	40	12.47	40	18.18	40	16.68
30	13.40	30	10.97	30	17.05	30	15.28

Predicted using the newly developed body fat percentage (BF%) equations using sum of eight-site skinfolds (Sum8SF); Male Forwards = 10.374 + (0.101 x Sum8SF in mm); Male Backs = 6.466 + (0.150 x Sum8SF in mm); Female Forwards = 13.661 + (0.113 x S8SF in mm); Female Backs = 11.081 + (0.140 x Sum8SF in mm).

Discussion

This study was the first to compare the differences in body composition between playing level and specific playing position group among high-level male and female RU players using DXA and Sum8SF. There were significant anthropometric and body composition differences present between primary playing positions (forwards vs backs) and playing level (elite vs sub-elite forwards and backs) among both males and females. Significant differences and large variations were observed between specific playing position groups among forwards and backs for both male and female players. A *large* relationship between Sum8SF and BF% for female backs was present*,* meanwhile *very large* relationships for male and female forwards and male backs were observed. This led to the development of a novel prediction equation using Sum8SF to predict BF%, which accounted for 57-62% and 78-45% of the variation in BF% among male forwards and backs, and female forwards and backs, respectively. This supports our hypotheses; that significant differences exist between primary and specific playing position and playing level among males and females due to the specific and unique roles each position plays; and BF% can be strongly predicted in male and female forwards and backs using Sum8SF.

It is well reported that RU forwards are significantly larger than backs among both males [160, 163] and females [159, 166], and indeed, our results also demonstrate significantly higher anthropometric and body composition measures for all variables between forwards and backs among both males and females. The results of our study also align with Smart and colleagues [20], who demonstrated that as playing level increases, players have greater fat-free mass (FFM), LM, and lower BF%. The same study also demonstrated that strength and power measures were greater as playing level increased [20]. This highlights the importance of promoting LM whilst maintaining low levels of FM to increase a player's chances of playing at a higher level or at least possessing the body composition required to compete at a higher level [39, 174, 177-179]. The strong relationships observed between physical characteristics and strength, power, speed, aerobic measures, and playing performance among elite male [9, 160] and female [161, 162] RU players further emphasise the importance of higher LM and minimal FM.

A clear trend observed among both male and female forwards were the significantly heavier Props and significantly taller locks compared to other forward positions. Which appear to be important characteristics for Props due to their scrummaging [180] and close-quarter ball carrying demands, and for Locks due to being the main jumping option in line-outs and kick re-starts [17]. However, it appears beneficial for all forwards to possess as larger BM as optimally possible due to the associations between the size of a team and win success [17, 18]. Greater BM has also been shown to favour forwards due to the many contacts and collisions they are exposed to from; scrums, offensive carries, defensive tackles and turnover attempts at the breakdown [19, 161, 162, 168, 179]. For both male and female backs, Midfielders were generally taller, heavier, and possessed the greatest LM, FM, and BMC compared to all other back positions. These traits appear important for Midfielders due to their greater number of collisions and high-speed impacts compared to other back positions [19, 170]. Similar observations were also reported among female collegiate RU players [169] and NZ male RU players [20].

Interestingly, among male forwards, Sum8SF shared the same significant differences between positions as BM. Props had the highest Sum8SF while Loose-Forwards had the lowest among forwards. Although Hookers are positioned in the 'Front-Row', they demonstrate significantly lower Sum8SF and BM than Props. Therefore, among male forwards, Hookers would benefit by having their own body composition classification rather than simply 'Front-Row' alongside Props. In contrast, when comparing Sum8SF among female forward positions, Hookers were not significantly different to Props even though they were significantly lighter. Another difference to male forwards, female Locks possessed a significantly lower BM and Sum8SF compared to Props and were more like Loose-Forwards. Regarding Sum8SF among female forwards, it may be more suitable to group Hookers into the 'Front-Row' alongside Props, while Locks and Loose-Forwards could be suitably grouped together. Conversely, among both male and female backs, although significant differences were present between positions for BM, no significant differences were present for Sum8SF, suggesting both male and female back positions are more homogenous than forward positions regarding Sum8SF. Where male Hookers, Props and Locks were not significantly different and were homogenous, was LM. These positions together are often referred to as the 'Tight-Five' [159] and appear to be suitably grouped when comparing LM.

In general, all positions that reported the greatest BM generally possessed the greatest LM and FM. Among both male and female forwards, FM and BF% were significantly greater in Props compared to all other forward positions, except for Hookers among female forwards. Like FM, both male and female backs demonstrated no significant differences between positions for BF%. These differences in BF% between positions among males and females were similarly aligned with Sum8SF, suggesting good sensitivity and agreement for comparing body composition differences between positions.

Compared to NZ male RU players from ~20 years ago [20], all forward positions have demonstrated considerable increases in BM and decreases in Sum8SF when compared to our current study. It is difficult to compare FFM, FM and BF% between our study and Smart et al. [20] due to doubly indirect measures of BF% being reported compared to indirect (more closely determined) measures in our study [173]. Due to Sum8SF demonstrating good agreement among our group and other male RU players [34], this would suggest that a large proportion of the increased BM observed over the years is due to increases in FFM and potentially lower or minimal increases FM. Despite these increases in BM over the years, differences between positions have remained similar [20]. Indeed, our sample sizes were much smaller than Smart and Colleagues [20] which should be taken into account when comparing these results, but our findings are similar to recent studies examining the evolution of RU players over the years [19, 179].

Compared to a recent study among collegiate female RU players [169], all female forward and back positions within our study were substantially larger in BM and FFM, but similar in BF%. Hookers among collegiate female RU players were the only position that was substantially different to our findings, reporting substantially lower BM and FFM, but higher BF% [169]. Harty et al. [169] also observed very similar positional differences between Flankers (numbers 6 and 7) and Number 8's, suggesting these positions can be suitably grouped together as 'Back-Row' [159] or 'Loose-Forwards' with minimal difference as they appear to possess similar body composition characteristics.

Given Sum8SF are commonly used and share similar differences to FM and BF% among both male and female positional groups, a regression equation was developed to provide a body composition comparison table for convenient estimation of BF% from Sum8SF. This can be beneficial for practitioners to estimate FFM which can then be used in other equations such as rugby specific resting metabolic rate prediction equations [164] or to determine energy availability to help further optimise energy requirements and nutrition plans. The forward and back prediction equation for males and females predicted BF% with a mean accuracy of 93%. Previous studies among elite male RU players that have developed skinfold prediction equations for BF% have suggested that the accuracy of such equations may not be adequate [32]. With the accuracy demonstrated within our study, the Sum8SF to BF% table using the developed equations may provide adequate reference standards for elite and sub-elite RU players. However, the values and demonstrated accuracy of these prediction equations were developed using a Hologic fan-beam DXA machine, with the head included in all scans to measure body composition and thus BF%. Comparison with other machines or scanning methods should be interpreted with caution due to differences in measures between devices and scanning methods [173].

Other limitations within our study were not using individual sites for skinfold-based prediction equations. This was implemented for convenience and quick reference for practitioners in the field who can collect the total Sum8SF and immediately use this number to convert to a predicted BF%. No movement demands (via Global Positioning Systems), strength, or fitness data were collected which would have been useful for determining relationships between body composition and fitness characteristics for specific playing positions, similar to what has been observed for primary playing positions (forwards and backs) [160-162]. A larger sample size for each specific playing position would be beneficial, however, the current sample from this study is a large proportion of the professional NZ rugby population.

Conclusion

Among both males and females, elite forwards and backs possessed significantly greater amounts of LM and lower Sum8SF, FM, and BF% compared to sub-elite. Props and Midfielders were the largest among male and female forwards and backs, respectively. Among males, Hookers may be more appropriately grouped for body composition alongside Loose-Forwards rather than 'Front-Row' with Props. Whereas, Hookers were more similar to Props among female forwards. Male Locks and Props shared similar amounts of LM, whereas among females, Locks were more similar to Loose-Forwards. Both male and female backs were more homogenous for body composition measures between specific playing positions than forwards. The newly developed BF% prediction equation demonstrated a mean accuracy percentage of ~93% overall, and ~80% of all players were predicted within 10% of the measured BF%. This study provides position specific physical characteristics for male and female RU players and the newly developed BF% prediction equations and conversion table can help practitioners more easily and conveniently predict BF% from Sum8SF measures.

CHAPTER SIX

Competition Nutrition Practices of Elite Male Professional Rugby Union Players

Posthumus, L., Fairbairn, K., Darry, K., Driller, M., Winwood, P., & Gill, N. (2021). Competition nutrition practices of elite male professional rugby union players. *International Journal of Environmental Research and Public Health*, *18*(10), 5398. https://doi.org/10.3390/ijerph18105398

Prelude

Chapters Two, Three, and Five report that elite male professional RU players are large, strong, and require high-intensity efforts in training and game-play. To maintain and/or develop these large physiques and continue to emphasise the development of fat-free mass whilst minimising surplus fat mass, nutrition strategies during a competition week is important to enhance training adaptations and performance on game-day. Furthermore, given players do not have long off-season periods as highlighted in Chapter Two, adaptations during in-season competition periods are vital. This study was the first to assess the competition nutrition practices of elite male professional rugby union players in New Zealand, and the first to examine nutrition practices on game-day and around game-time.

Abstract

Thirty-four elite male professional rugby union players from the New Zealand Super Rugby championship completed dietary intakes via the Snap-N-Send method during a seven-day competition week. Mean seven-day absolute energy intake was significantly higher for forwards (4606 ± 719 kcal·day^{-1}) compared to backs (3761 ± 618 kcal·day^{-1}; $p < 0.01$; $d = 1.26$). Forwards demonstrated significantly higher mean seven-day absolute macronutrient intakes compared to backs ($p < 0.03$; $d = 0.86$–1.58), but no significant differences were observed for mean seven-day relative carbohydrate (3.5 ± 0.8 vs. 3.7 ± 0.7 g·kg·day^{-1}), protein (2.5 ± 0.4 vs. 2.4 ± 0.5 g·kg·day^{-1}), and fat (1.8 ± 0.4 vs. 1.8 ± 0.5 g·kg·day^{-1}) intakes. Both forwards and backs reported their highest energy (5223 ± 864 vs. 4694 ± 784 kcal·day^{-1}) and carbohydrate (4.4 ± 1.2 vs. 5.1 ± 1.0 g·kg·day^{-1}) intakes on game day, with ~62% of total calories being consumed prior to kick-off. Mean pre-game meal composition for all players was 1.4 ± 0.5 g·kg^{-1} carbohydrate, 0.8 ± 0.2 g·kg^{-1} protein, and 0.5 ± 0.2 g·kg^{-1} fat. Players fell short of daily sports nutrition guidelines for carbohydrate and appeared to “eat to intensity” by increasing or decreasing energy and carbohydrate intake based on the training load. Despite recommendations and continued education, many rugby players select what would be considered a “lower” carbohydrate intake. Although these intakes appear adequate to be a professional RU player, further research is required to determine optimal dietary intakes.

Keywords: dietary analysis; game day; macronutrients; energy intake; fuelling; team-sport.

Introduction

Rugby union (RU) is a high-contact, field-based team sport contested by two teams over an 80-min game which is divided into two 40-min halves separated by a break no longer than 15-min [1]. Each team has 15 players on the field at a time comprising eight forwards (numbers 1–8) and seven backs (numbers 9–15), with each positional group having their own unique physical and fitness characteristics [160] and game-play demands [1]. Game-play encompasses both high-intensity (sprinting, tackling, lifting, rucking, mauling, scrumming) and low-intensity activities (standing, walking, jogging). Players typically cover distances of ~5–7 km during a game with an average heart rate of ~172 bpm [7, 181] and are involved in numerous high-impact collisions (~0.4 per minute) depending on playing position [182, 183]. Meanwhile, distances of ~8–10 km and a total weekly internal training load of ~1500–1800 arbitrary units (AU) from all training sessions during an in-season competition week have previously been reported among professional RU players [12].

Professional rugby players are exposed to considerable training loads in season, resulting in substantial energy outputs [12, 65, 66], glycogen utilisation [129, 130], exercise-induced muscle damage from training and game-play, and extensive impact-induced muscle damage, particularly from collisions during game-play [11, 99, 100, 182-184]. In order to optimally prepare, fuel, and recover from the in-season training and game-play demands within professional RU, players must consume adequate amounts of food in order to meet energy and macronutrient requirements to promote muscle regeneration, glycogen restoration, and immune support, as well as to reduce fatigue [121].

Currently, studies among professional RU players have assessed dietary intakes during pre-season [13, 185] and in-season [12] periods. During the in-season, mean energy intakes for forwards (~3966 kcal·day^{-1}) and backs (~3392 kcal·day^{-1}) have been observed alongside what would be considered a "relatively low" carbohydrate (~3.5 g·kg·day^{-1}), high-protein (~2.7 g·kg·day^{-1}), and moderately high fat (~1.5 g·kg·day^{-1}) macronutrient intake [12] compared to team-sport nutrition recommendations (carbohydrate = ~5–7; protein = ~1.6; fat = ~1.3 g·kg·day^{-1}) [16,19,20] and general sport nutrition recommendations for carbohydrate on intense training and competition days (6–10 g·kg·day^{-1}) [60, 122].

Although dietary intakes have been observed in season [12], no data have been published regarding the dietary intakes of professional RU players on game day (GD). Assessing dietary intake on GD will help provide further understanding of the energy and macronutrient intakes during an entire competition week and will demonstrate how GD compares to training and rest days during the week. Moreover, no data are currently available on how dietary intake is distributed prior to and following a game in professional RU. It is also important to note that no in-season dietary intakes have been reported within southern hemisphere professional RU players. Being able to compare in-season dietary intakes between northern [12] and southern hemisphere professional RU players would provide valuable insights regarding global nutritional approaches for RU [75].

Therefore, the aim of this study was to investigate the in-season dietary intakes of elite male professional RU players during a seven-day competition week. Dietary intake on GD was captured to determine how GD compares to other days during the competition week and how energy and macronutrient intake is distributed pre- and post-game. It was hypothesised that forwards would have a significantly higher mean seven-day energy and macronutrient intake compared to backs and that both positions would consume significantly more energy and macronutrient intakes on GD compared to training and rest days during the week. The quantification of field, gym training loads, and game loads were calculated and presented to help provide context for the observed dietary intakes.

Methodology

Study Design

A cross-sectional observational study design was utilised to assess the in-season dietary intakes of elite male professional RU players during a competition week including GD. Seven-day remote photographic food diaries (Snap-N-Send method) with two-way communication to confirm measures and descriptions were recorded. Dietary intake across the competition week was catalogued as days away from GD (GD-5, GD-4, GD-3, GD-2, GD-1, GD, GD+1), as previously reported [12, 65]. It is important to note that GD-3 and GD+1 were rest days (Table 17). Kick-off on GD was ~7:00 p.m., which was preceded by a pre-game eating window from first food consumed that day right up until kick-off, with a pre-game meal consumed 3–4 h prior to kick-off. The post-game eating window commenced immediately following the game (~9:00 p.m.) until players went to sleep. All players within this study competed on GD.

Table 17. Seven-day overview, training, and game load during the competition week.

	GD-5	GD-4	GD-3	GD-2	GD-1	GD	GD+1	Total
All Players								
Intensity	Low	High	Rest and Recovery	High	Low	High	Rest and Recovery	
Field sessions	1	1		2	1	0		5
Gym sessions	1	1		1	0	0		3
sRPE (AU)	784 ± 123	1277 ± 108		1367 ± 90	242 ± 42	716 ± 94		4386 ± 457
Distance (km)	2.4 ± 1.0	6.7 ± 0.8		5.1 ± 0.7	2.7 ± 0.5	6.1 ± 0.7		23.0 ± 3.7
Forwards								
sRPE (AU)	781 ± 118	1266 ± 114		1377 ± 97	238 ± 41	695 ± 99		4357 ± 469
Distance (km)	2.1 ± 0.8	5.7 ± 0.7		4.4 ± 0.7	2.5 ± 0.4	5.5 ± 0.8		20.2 ± 3.4
Backs								
sRPE (AU)	788 ± 132	1289 ± 104		1356 ± 84	247 ± 44	737 ± 86		4416 ± 449
Distance (km)	2.8 ± 1.2	7.6 ± 0.9		5.7 ± 0.7	2.9 ± 0.5	6.7 ± 0.6		25.7 ± 3.9

Mean ± standard deviation. GD = game day (GD-5 – GD-1 refers to days prior to GD, GD+1 refers to day following game), sRPE = session rate of perceived exertion, AU = arbitrary unit. Low intensity = mean day RPE < 6, high intensity = mean day RPE > 6.

Participants

Thirty-four elite male professional RU players (age: 27.6 ± 2.8 y, height: 187.5 ± 8.5 cm, body mass: 103.0 ± 13.6 kg) from New Zealand Super Rugby Championship teams participated in this study. Players were categorised by their primary playing position, which comprised 17 forwards (27.8 ± 2.4 y, 193.4 ± 6.7 cm, 114.3 ± 6.8 kg) and 17 backs (27.5 ± 3.3 y, 181.5 ± 5.3 cm, 91.8 ± 8.2 kg). Mean years of professional playing experience and sum of eight-site skinfolds for all players were 8.5 ± 2.8 y and 61.0 ± 13.2 mm, respectively. All participants provided informed consent and the research was approved by the University of Waikato Human Research Ethics Committee (HREC 2019#04).

Anthropometrics

Following methods previously described [160], we assessed body mass upon waking with bladder voided at the start of the competition week using electronic scales (SECA, Birmingham, UK) to 0.1 kg accuracy. Height was assessed using a stadiometer (SECA, Birmingham, UK) to 0.5 cm accuracy. A level 1 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist carried out the sum of eight-site skinfold measurements on all players using Harpenden callipers (British Indicators, Hertfordshire, UK) to 0.1 mm accuracy. Duplicate measures were taken on the right side of the body at the following sites: triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, anterior mid-thigh, and medial mid-calf [41]. All anthropometric equipment were calibrated as recommended by the manufacturer's guidelines.

Training Load

Quantification of field, gym, and game internal loads were assessed using sRPE [186], wherein the participants' rated each session on the basis of intensity using a modified 10-point Borg Scale [187] which was then multiplied by the total training or game time in minutes (RPE x total training time = sRPE), providing the sRPE in the form of an AU. Session values were then summed for each player to provide a daily and seven-day total for internal training load (Table 17). This method has previously been used in professional RU [12, 13] and rugby league (RL) [8,27,28]. External training load from field sessions and game-play were collected for each player via 10-Hz global positioning system (GPS) units (VX Sport, Wellington, NZ) and software (VX Sport, Wellington, NZ) providing daily and seven-day total distance (Table 17).

Dietary Intake Assessment and Analysis

Dietary intake was assessed using seven-day remote photographic food diaries recently referred to as the "Snap-N-Send" method [87, 88, 95, 188]. The "Snap-N-Send" method is a dietary assessment tool that has been validated for use within elite adolescent rugby athletes and has demonstrated enhanced validity (mean bias for under-reporting = ~4% vs. ~14%) and reliability (typical error of estimates = ~5% vs. ~11%) over traditional dietary assessment tools [87] and may provide greater compliance while reducing burden on players [64, 95]. The smartphone application MealLogger® (version 4.7.4, Wellness Foundry, Helsinki, Finland) was used to photograph and record what participants consumed [189]. Players provided a brief description of what foods were in each photograph, outlining brand names; cooking methods; ingredient amounts; and items difficult to quantify and identify within the photo such as oils, sauces, and condiments. Players were encouraged to measure out food amounts whenever possible. As part of their regular sports nutrition servicing to enhance their food literacy, all players had received prior education regarding the quantification of the foods they were consuming in grams or in cups.

Once meal entries were received, the picture and description were checked to ensure suitability for analysis. Any images or entries received that required further clarification were followed up via MealLogger messaging where players provided further details as required. For quality inputs to be ensured, all players received training to teach them how to use the software and practice the process prior to data collection. Dietary intakes were captured, entered, and analysed by a single registered sports dietitian with extensive experience in analysing photograph food diaries and working with RU players. To enhance the accuracy of the information collected [190], we provided the resulting seven-day food record to the players' sports nutritionist to enable in-person validation with the player for any errors in representation of foods and beverages consumed. Any corrections were returned to the sports dietitian analyst who then adjusted the record accordingly. All meals were entered into the dietary analysis software FoodWorks 10 Professional (Xyris, Australia).

Statistical Analyses

All statistical tests were analysed using the Statistical Package for the Social Sciences (SPSS, v25, IBM, New York, NY, USA). All data were checked for normality using the Shapiro–Wilk test ($p > 0.05$). Differences between forwards and backs for mean seven-day and pre-game meal energy and macronutrient intakes were assessed using independent *t*-tests. Repeated measures analysis of variance (ANOVA) using pairwise comparisons with a Bonferroni adjustment was used to analyse differences in energy and macronutrient intake on GD compared to the remaining days of the competition week among forwards and backs. Mauchly's test of sphericity was assessed and accounted for using methods previously described [12]. Differences between pre- and post-game energy and macronutrient intakes for forwards and backs were analysed using paired samples *t*-tests. An alpha level of $p \leq 0.05$ was used for all tests. Effect sizes were calculated using the Cohen's *d* method with the following thresholds; d = *trivial* < 0.19, *small* 0.20–0.49, *medium* 0.50–0.79, and *large* > 0.80 [176]. All data are expressed as mean ± standard deviation.

Results

Seven-Day Energy and Macronutrient Intake

Mean seven-day energy and macronutrient intakes among forwards and backs are presented in Table 18. Forwards demonstrated significantly higher mean seven-day absolute energy (p < 0.01), carbohydrate (p = 0.02), protein (p < 0.01), and fat (p = 0.03) intakes compared to backs. No significant differences were observed for mean seven-day relative energy and relative macronutrient intakes between positions.

Table 18. Seven-day mean energy and macronutrient intakes among forwards and backs.

Dietary Intake		Forwards (n = 17)	Backs (n = 17)	Effect Size
Energy	kcal·day^{-1}	4606 ± 719 (3500–6132) *	3761 ± 618 (2465–4978)	1.26
	kcal·kg·day^{-1}	40.5 ± 7.2 (28.4–56.3)	41.9 ± 7.2 (29.8–53.8)	0.19
Carbohydrate	g·day^{-1}	399 ± 77 (268–525) *	340 ± 59 (174–415)	0.86
	g·kg·day^{-1}	3.5 ± 0.8 (2.5–4.8)	3.7 ± 0.7 (2.1–4.6)	0.27
	% TEI	35 ± 5 (28–44)	36 ± 5 (30–48)	0.20
Protein	g·day^{-1}	280 ± 39 (227–372) *	220 ± 37 (155–302)	1.58
	g·kg·day^{-1}	2.5 ± 0.4 (1.8–3.4)	2.4 ± 0.5 (1.7–3.3)	0.22
	% TEI	24 ± 2 (21–28)	23 ± 3 (19–29)	0.39
Fat	g·day^{-1}	210 ± 43 (144–288) *	169 ± 41 (103–242)	0.98
	g·kg·day^{-1}	1.8 ± 0.4 (1.1–2.5)	1.8 ± 0.5 (1.1–2.6)	0.00
	% TEI	41 ± 4 (33–45)	41 ± 5 (28–47)	0.00

Mean ± standard deviation (range). % TEI = percentage of total energy intake. * Indicates a significant difference between forwards and backs (p < 0.05).

Daily Energy Intake

Mean daily energy intake among forwards and backs can be observed in Figure 6. There was a significant difference between days for absolute (F(6, 96) = 6.81, p < 0.01) and relative (F(6, 96) = 6.65, p < 0.01) energy intakes among forwards. Significantly higher absolute and relative energy intakes were observed on GD compared to GD-3 (p < 0.01; d = 0.90–0.85, respectively) and GD+1 (p < 0.01; d = 0.98–0.90, respectively) among forwards. There was a significant difference between days for absolute and relative energy intakes among backs (F(6, 96) = 9.42, p < 0.01). Backs demonstrated significantly higher absolute energy intake on GD compared to GD-5 (p < 0.01; d = 0.90), GD-4 (p < 0.05; d = 0.74), GD-3 (p < 0.01; d = 1.51), GD-1 (p <

0.01; d = 0.68), and GD+1 (p < 0.01; d = 0.95). Relative energy intake among backs was significantly higher on GD compared to GD-5 (p < 0.01; d = 0.87), GD-3 (p < 0.01; d = 1.35), GD-1 (p = 0.01; d = 0.66), and GD+1 (p < 0.01; d = 0.96).

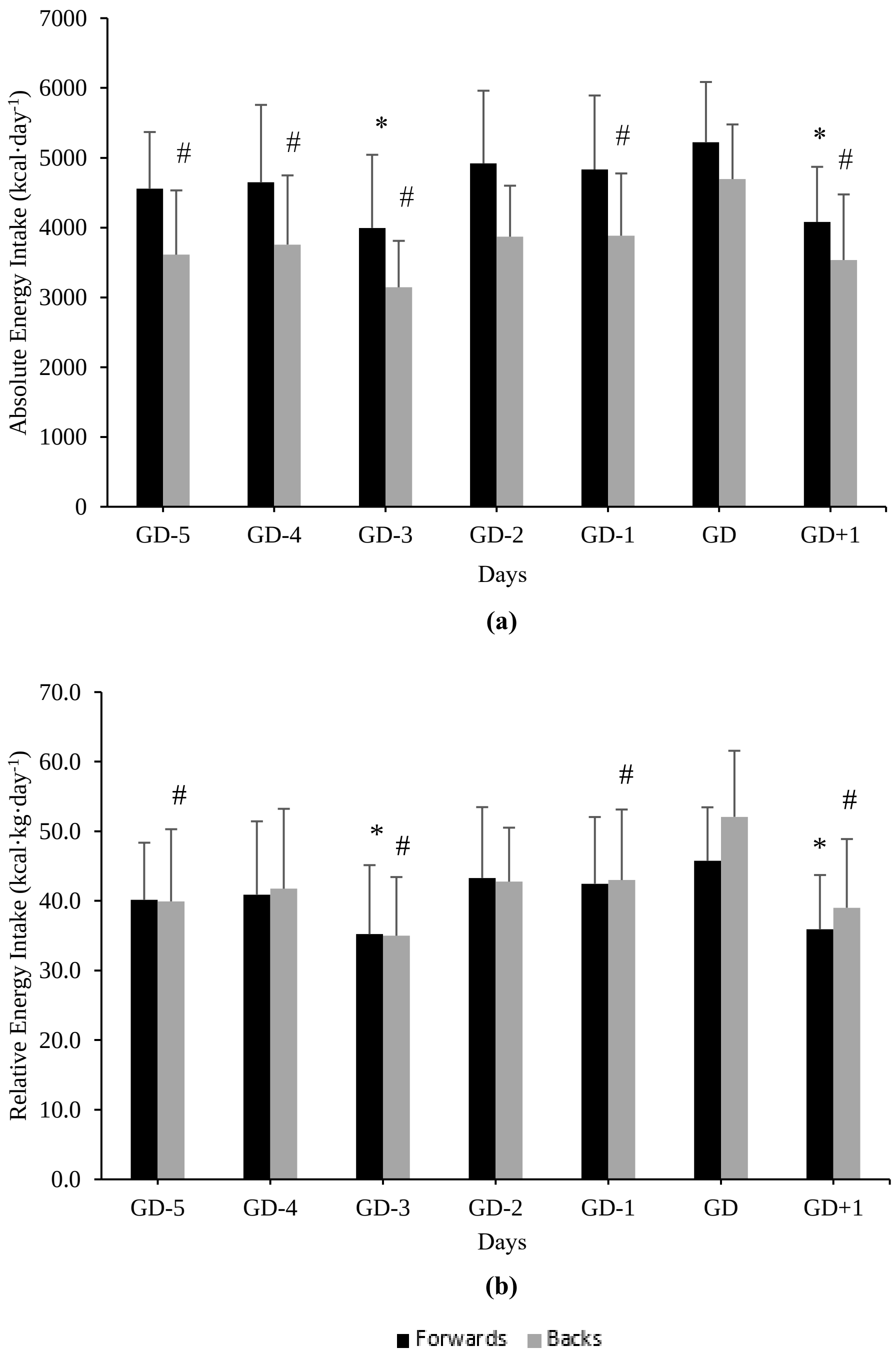

Figure 6. Mean daily energy intakes across a seven-day competition week (GD-5, -4, -3, -2, -1, GD, GD+1) among forwards and backs. (a) Absolute energy intake; (b) relative energy intake. Error bars represent standard deviation. * Indicates a significant difference to GD for forwards ($p < 0.05$). # Indicates a significant difference to GD for backs ($p < 0.05$).

Daily Macronutrient Intake

Mean daily macronutrient intakes among forwards and backs can be observed in Figure 7. There was a significant difference between days for absolute ($F(6, 96) = 8.55$, $p < 0.01$) and relative ($F(6, 96) = 8.26$, $p < 0.01$) carbohydrate intakes among forwards. Significantly higher absolute and relative carbohydrate intakes on GD compared to GD-5 ($p = 0.03$; $d = 0.65$–0.60, respectively), GD-4 ($p = 0.02$; $d = 0.74$–0.70, respectively), GD-3 ($p = 0.02$; $d = 0.84$–0.77, respectively), GD-1 ($p = 0.01$; $d = 0.79$–0.72, respectively), and GD+1 ($p < 0.01$; $d = 1.08$–1.04, respectively) were observed among forwards. There was a significant difference between days for absolute ($F(6, 96) = 7.29$, $p < 0.01$) and relative ($F(6, 96) = 7.22$, $p < 0.01$) protein intakes among forwards. Absolute protein intake was significantly higher on GD compared to GD-3 ($p = 0.04$; $d = 0.73$) and GD+1 ($p = 0.02$; $d = 0.75$) among forwards, but relative protein intake on GD was only significantly higher than GD+1 ($p = 0.03$; $d = 0.71$).

Backs demonstrated significant differences between days for absolute ($F(6, 96) = 12.53$, $p < 0.01$) and relative ($F(6, 96) = 12.75$, $p < 0.01$) carbohydrate intakes, with significantly higher absolute and relative carbohydrate intakes on GD compared to all other days ($p < 0.01$; $d = 0.96$–1.65). There was a significant difference between days for absolute ($F(6, 96) = 4.50$, $p < 0.01$) and relative ($F(6, 96) = 4.50$, $p < 0.01$) protein intakes among backs, with significantly higher absolute and relative protein ($p < 0.01$; $d = 1.33$–1.15, respectively) intakes observed on GD compared to GD-3. Backs also demonstrated significant differences between days for absolute ($F(6, 96) = 3.23$, $p = 0.01$) and relative ($F(6, 96) = 3.00$, $p = 0.01$) fat intake, with significantly higher absolute and relative fat ($p = 0.03$; $d = 0.75$–0.77, respectively) intakes observed on GD compared to GD-3.

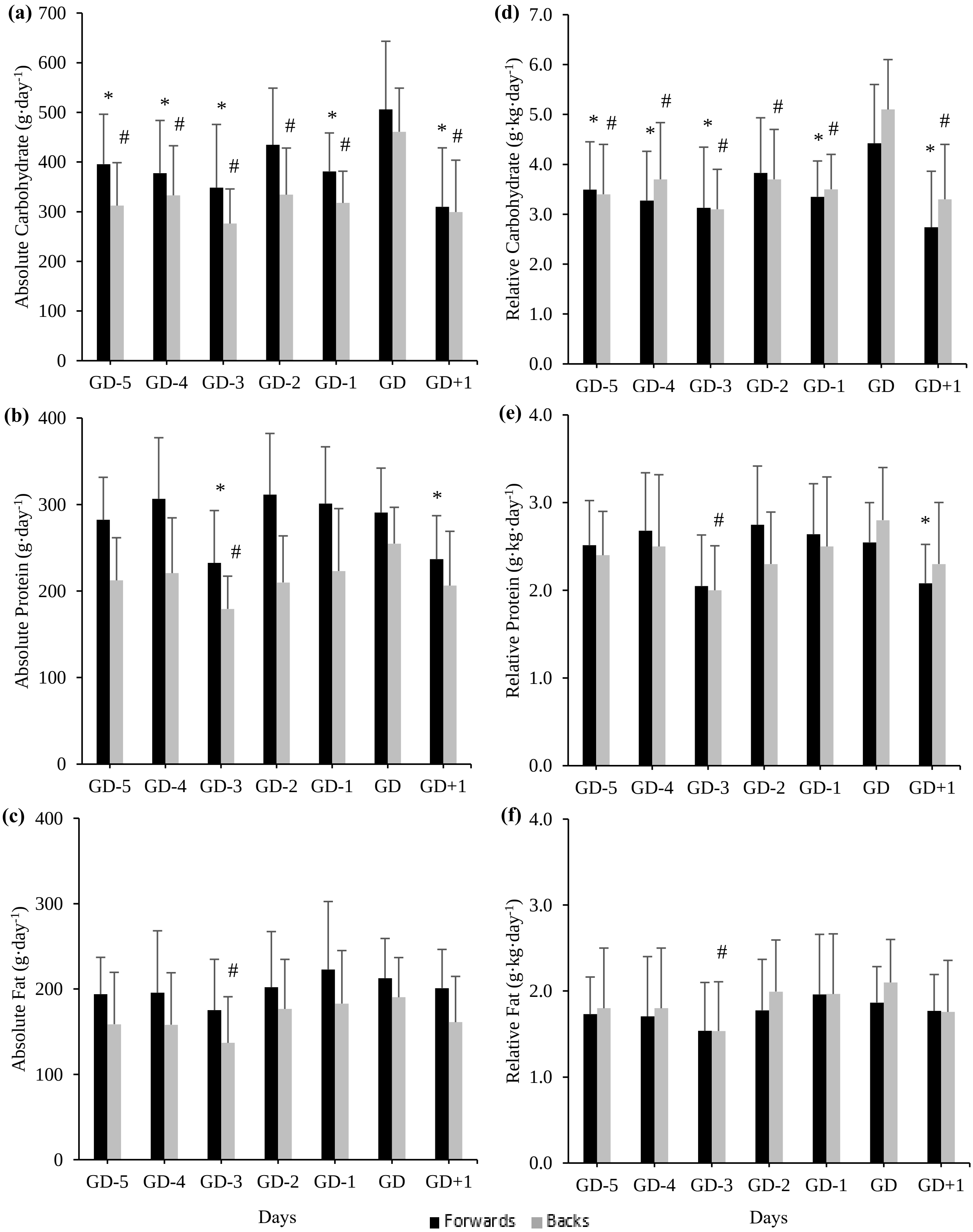

Figure 7. Mean daily macronutrient intake across a seven-day competition week (GD-5, -4, -3, -2, -1, GD, GD+1) among forwards and backs. (a) Absolute carbohydrate intake; (b) absolute protein intake; (c) absolute fat intake; (d) relative carbohydrate intake; (e) relative protein intake; (f) relative fat intake. Error bars represent standard deviation. * Indicates a significant difference to GD for forwards ($p < 0.05$). # Indicates a significant difference to GD for backs ($p < 0.05$).

Pre- and Post-Game Energy and Macronutrient Intake

Mean energy and macronutrient intakes for pre- and post-game among forwards and backs are presented in Table 19. Both forwards and backs demonstrated significantly higher absolute and relative energy and macronutrient intakes pre-game compared to post-game ($p < 0.01$).

Table 19. Energy and macronutrient intakes pre-game (first meal of day to last meal prior to kick-off) and post-game within forwards and backs.

Dietary Intake		Forwards (n = 17)			Backs (n = 17)		
		Pre-Game	Post-Game	ES	Pre-Game	Post-Game	ES
Energy	kcal^{-1}	3363 ± 759 †	1860 ± 601	1.55	2786 ± 496 ‡	1908 ± 661	1.06
	kcal·kg^{-1}	29.4 ± 6.5 †	16.3 ± 5.5	1.54	30.8 ± 5.6 ‡	21.3 ± 7.9	0.98
Carbohydrate	g^{-1}	339 ± 102 †	167 ± 84	1.30	271 ± 55 ‡	190 ± 74	0.88
	g·kg^{-1}	3.0 ± 0.9 †	1.5 ± 0.7	1.32	3.0 ± 0.5 ‡	2.1 ± 0.8	0.95
Protein	g^{-1}	185 ± 57 †	106 ± 26	1.26	144 ± 27 ‡	111 ± 35	0.75
	g·kg^{-1}	1.6 ± 0.5 †	0.9 ± 0.2	1.30	1.6 ± 0.3 ‡	1.2 ± 0.4	0.80
Fat	g^{-1}	132 ± 36 †	81 ± 36	1.00	119 ± 35 ‡	71 ± 31	1.03
	g·kg^{-1}	1.2 ± 0.3 †	0.7 ± 0.3	1.18	1.3 ± 0.4 ‡	0.8 ± 0.4	0.88

Mean ± standard deviation. ES = effect size. † Indicates a significant difference to post-game among forwards ($p < 0.01$). ‡ Indicates a significant difference to post-game among backs ($p < 0.01$).

Pre-Game Meal Energy and Macronutrient Intake

Mean relative energy and relative macronutrient intakes for the pre-game meal within forwards and backs can be observed in Figure 8. No significant differences in energy or macronutrient intake were present for the pre-game meal between positions.

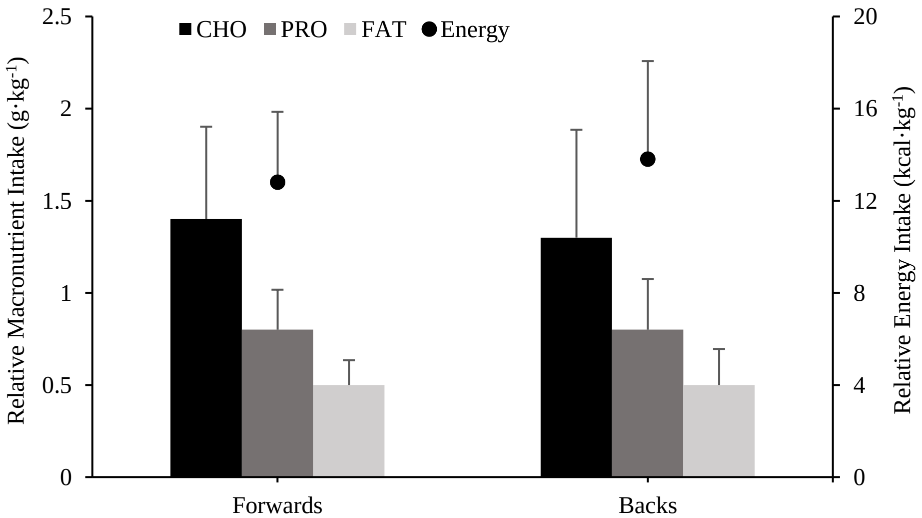

Figure 8. Relative energy and macronutrient intakes of pre-game meal 3–4 hr prior to kick off among forwards and backs. CHO = carbohydrate, PRO = protein, FAT = fat. Error bars represent standard deviation. No significant differences observed ($p > 0.05$).

Discussion

This study is the first to report the dietary intakes of elite male professional RU players on GD, including pre-game, pre-game meal, and post-game dietary intakes and how GD compares to other days during the competition week. Within this study, forwards consumed significantly higher mean seven-day absolute energy and absolute macronutrient intakes compared to backs. Interestingly, relative to body mass, no significant differences were observed between positions regarding seven-day mean relative energy and relative macronutrient intakes. In fact, backs demonstrated higher mean seven-day relative energy and relative carbohydrate intakes compared to forwards. Significantly higher absolute and relative energy intakes were observed on GD compared to rest days and numerous training days among backs, but only compared to rest days for forwards. However, both positions demonstrated significantly higher relative and absolute carbohydrate intakes on GD compared to all training (except GD-2 for forwards) and rest days. Both forwards and backs consumed significantly higher absolute and relative energy and macronutrient intakes pre-game compared to post-game, with no significant difference in pre-game meals between positions.

Our study reported higher mean absolute energy intakes for forwards (4606 ± 719 vs. 3966 ± 299 kcal·day^{-1}) and backs (3761 ± 618 vs. 3392 ± 287 kcal·day^{-1}) compared to a previous study measuring dietary intakes within professional RU players during the in-season competition period [12]. When comparing macronutrient intakes within our study to those reported by Bradley et al. [12], we observed identical mean relative carbohydrate intakes among forwards (3.5 ± 0.8 vs. 3.5 ± 0.8 g·kg·day^{-1}), while backs consumed slightly more carbohydrate in our study (3.7 ± 0.7 vs. 3.4 ± 0.7 g.kg·day^{-1}). Mean relative protein intake was slightly lower within our study for both forwards (2.5 ± 0.4 vs. 2.7 ± 0.5 g·kg·day^{-1}) and backs (2.4 ± 0.5 vs. 2.7 ± 0.3 g·kg·day^{-1}), while mean relative fat intake was higher within our study for both forwards (1.8 ± 0.4 vs. 1.4 ± 0.2 g·kg·day^{-1}) and backs (1.8 ± 0.5 vs. 1.4 ± 0.3 g·kg·day^{-1}) compared to Bradley et al. [12]. In comparison to dietary intakes reported during the pre-season period among professional RU players, mean absolute energy intakes were higher within our in-season study, yet relative macronutrient intakes were similar regardless of seasonal period [13, 185].

Despite differences in game-play [1] and physical and fitness characteristics [160] between positions, forwards and backs had similar dietary intakes relative to body mass, although forwards demonstrated significantly higher absolute dietary intake. Similar to previous studies in professional RU [126], players were found to be consuming a relatively low carbohydrate

(~3.6 g·kg·day^{-1}), high protein (~2.5 g·kg·day^{-1}), and moderate–high fat (~1.8 g·kg·day^{-1}) intake compared to recommendations for team sport athletes [16,19,20,37]. Although a range of players within this study are meeting the mean intake of ~3.5 g·kg·day^{-1} or greater, there are still players who are not meeting these values, which highlights the range of individual differences and the potential continued education required to ensure appropriate fuelling is occurring. Furthermore, the lower relative carbohydrate intakes within professional RU players could partly be due to the large body mass of these players, as discussed in a recent review [75].

The protein intakes observed in our study seem appropriate for professional RU players given their training and match demands that generate high levels of exercise-induced and impact-induced muscle damage [11]. These intakes may also be suitable for players who need to lose unwanted fat mass while maintaining or gaining lean muscle mass [139, 191-194]. These higher protein intakes may also be contributing to the relatively high fat intakes observed, although players also attempt to select foods containing healthy fats. Due to the caloric density of dietary fat, these relatively high fat intakes may be beneficial in helping meet energy requirements of professional RU players [195] due to the large body mass [160] and high energy expenditures reported [65, 66].

Mean daily absolute energy intake followed a similar trend to previously reported in-season data [12] where players consumed slightly less energy at the start of the week, which then increased closer to GD. The higher mean energy intakes observed within our study may partly have been due to the greater total distances covered (~17 km) and higher total sRPE (~3670 AU) reported from training sessions alone, which are more than double the training loads observed by Bradley et al. [12] and are also greater than loads previously reported during the pre-season period [13]. These perceived internal training loads followed the same trend as daily dietary intake across the competition week, which indicate that the RU players observed within this study "eat to intensity". As perceived internal training load (sRPE) increases and decreases, energy and macronutrient (particularly carbohydrate) intake follows the same trend to "fuel for the work required" [196]. However, "eating to intensity" or increasing dietary intake only when exercise intensity increases does not necessarily mean optimal fuelling is occurring, as there may be lower-intensity days when increasing dietary intake is desired to optimise fuel stores such as the day before a game (GD-1) [125]. While periodising carbohydrate in this manner may increase glycogen adaptations [119], it is likely players are selecting this eating pattern to fuel performance while attempting to control body composition [12, 13].

Compared to northern hemisphere players, carbohydrate intake was higher on GD-5 within our study but similar across the rest of the days except GD-1, which was considerably higher for both forwards and backs in northern hemisphere players [12]. Other than GD, players within our study prioritised high energy and carbohydrate intake on GD-2, which is logical due to this day having the highest training load for the week, but then decreased energy and most notably carbohydrate intake on GD-1. Although logical from an intensity perspective, as GD-1 has the lowest training load for the week other than rest days (GD-3 and GD+1), from a fuelling perspective, due to GD being the following day, higher carbohydrate intake may be optimal [125].

Current recommendations for athletes are to consume between 6 and 10 $g{\cdot}kg{\cdot}day^{-1}$ of carbohydrate, particularly around GD-1 in order to optimise glycogen stores [122, 125]. However, mean carbohydrate intakes of ~3.4 $g{\cdot}kg{\cdot}day^{-1}$ on GD-1 were observed within our group, with the highest intakes recorded for a forward and back on GD-1 being ~4.7 $g{\cdot}kg{\cdot}day^{-1}$. In contrast, RU players in the northern hemisphere [12] were closer to the lower end of these recommendations [122] with considerably higher mean carbohydrate intakes on GD-1 for forwards (~5.1 $g{\cdot}kg{\cdot}day^{-1}$) and backs (~4.2 $g{\cdot}kg{\cdot}day^{-1}$) compared to our study. Unfortunately, Bradley et al. [12] were unable to measure dietary intake on GD, which would have been interesting to observe whether GD carbohydrate and energy intakes were higher than on GD-1 as reported within our study.

The carbohydrate amounts observed within this study may be adequate to replenish glycogen stores. Bradley et al. [129] reported no significant differences in pre-match, half-time, and post-match glycogen stores within RL players who consumed 3 or 6 $g{\cdot}kg{\cdot}day^{-1}$ of carbohydrate 36 h prior to an 80-min game. Although glycogen stores appeared more homogenous within the 6 $g{\cdot}kg{\cdot}day^{-1}$ group, no clear differences were observed in GPS and workload metrics between the two groups [129]. However, similar research within RU players is required to provide further insight regarding glycogen utilisation. Interestingly, these "lower" carbohydrate intakes (~3.5 $g{\cdot}kg{\cdot}day^{-1}$) have supported improvements in physical performance and body composition measures during pre-season phases composed of high-intensity and high-volume glycogen depleting training sessions [13, 185], suggesting these intakes may be adequate.

On GD, it has been suggested that athletes may eat less and therefore consume less carbohydrate due to game stress, potential travel, and match schedules. Thus, increased fuelling on GD-1 has been suggested to offset this potential decrease in dietary intake on GD [125].

This was not the case within the players we studied, with GD demonstrating higher dietary intake compared to the rest of the week. Later start times (~7:00 p.m. kick-off) are likely a large contributor to these higher intakes, allowing players adequate time to fuel prior to the game, demonstrated by players consuming ~62% of their total energy intake for the day during that time. The pre-game meal (3–4 h prior to kick-off) consisted of approximately 1.4 $g \cdot kg^{-1}$ carbohydrate, 0.8 $g \cdot kg^{-1}$ protein, and 0.5 $g \cdot kg^{-1}$ of fat for both positions, meeting suggested pre-match fuelling requirements for carbohydrate [122].

Within the ~3 h eating window post-game, players were near the suggested refuelling requirements with ~1–1.2 $g \cdot kg^{-1}$ of carbohydrate consumed immediately after the game followed by another ~0.5–1 $g \cdot kg^{-1}$ of carbohydrate an hour later to optimise glycogen replenishment, which may have been further enhanced by the amount of protein ingested (~1.1 $g \cdot kg^{-1}$) by the players during this period [121, 125]. The absolute carbohydrate intakes observed post-game within this study were similar to the amounts (180 g) and timings (immediately and 1 h post-game) suggested to promote glycogen replenishment in RL players [130]. Immediate re-feed strategies may be crucial during these night-time games due to the limited post-game eating window, with players still attempting to get to sleep at a reasonable hour following the game. On GD+1, energy intake was higher than a normal day off during the middle of the week (GD-3), which may help offset the higher resting metabolic rates observed post-game due to the physical demands and collisions experienced during game-play [100, 184].

A limitation to this study was that no measure of energy expenditure was implemented to determine energy requirements and daily energy balance. Given the large internal and external training loads observed, future research should examine the energy expenditures of these elite professional RU players. Another limitation is that we were unable to measure muscle glycogen stores alongside dietary intakes, which would better inform the adequacy of carbohydrate consumption across the competition week. It is also important to note that assessing dietary intake is subject to error by both the analyst and the participant [29,32,33,35]. Therefore, there may be some error in our dietary data due to under- or over-reporting, even though we put processes in place to mitigate errors as much as possible.

Conclusion

The dietary intakes observed within this study are similar to those previously reported in male professional RU players, demonstrating relatively low carbohydrate, high protein, and moderate–high fat intakes compared to sports nutrition recommendations. Although these RU players appear to meet fuelling requirements in the pre-game meal and post-game eating window, they do not meet the suggested daily carbohydrate fuelling requirements. This information is useful for practitioners working with RU players, given that successful and experienced elite professional RU players have been studied and appear to perform adequately with these dietary intakes observed given their selection in elite professional teams. However, to ensure "optimal" rather than "adequate" fuelling is being achieved, we require more studies examining energy balance and carbohydrate intake alongside changes in glycogen stores and performance measures within professional RU players. This will help guide practitioners as to whether (a) players are meeting energy requirements; (b) more education and strategies around helping RU players increase carbohydrate intake to meet recommendations are required; or (c) the recommendations are too high for this population group, and therefore the "relatively lower" carbohydrate intakes reported in the literature are sufficient given the large body mass and physical demands of rugby players.

CHAPTER SEVEN

Dietary Intakes of Elite Male Professional Rugby Union Players in Catered and Non-Catered Environments

Posthumus, L., Driller, M., Darry, K., Winwood, P., Rollo, I., & Gill, N. (2022). Dietary Intakes of Elite Male Professional Rugby Union Players in Catered and Non-Catered Environments. *International Journal of Environmental Research and Public Health*, *19*(23), 16242. https://doi.org/10.3390/ijerph192316242

Prelude

In Chapter Six, a greater understanding of the competition nutrition practices of elite male professional RU players was presented. However, this was in an environment where players were exposed to a range of provided meals (mainly in catered hotel environments) and meals they were required to provide for themselves (mainly in their home environment). It is unclear in the literature what environments previous studies have examined professional rugby union players in, and whether any differences exist. Therefore, this study was the first to examine dietary intakes during competition weeks in catered (hotel-setting) and non-catered (home-setting) environments among elite male professional rugby union players from New Zealand.

Abstract

In professional rugby union, it is common for players to switch between catered and non-catered dietary environments throughout a season. However, little is known about the difference in dietary intake between these two settings. Twelve elite male professional rugby union players (28.3 ± 2.9 y, 188.9 ± 9.5 cm, 104.1 ± 13.3 kg) from the New Zealand Super Rugby Championship completed seven-day photographic food diaries with two-way communication during two seven-day competition weeks in both catered and non-catered environments. While no significant differences were observed in relative carbohydrate intake, mean seven-day absolute energy intakes (5210 ± 674 vs. 4341 ± 654 kcal·day^{-1}), relative protein (2.8 ± 0.3 vs. 2.3 ± 0.3 g·kgBM·day^{-1}) and relative fat (2.1 ± 0.3 vs. 1.5 ± 0.3 g·kgBM·day^{-1}) intakes were significantly higher in the catered compared to the non-catered environment (respectively) among forwards (*n* = 6). Backs (*n* = 6) presented non-significantly higher energy and macronutrient intakes within a catered compared to a non-catered environment. More similar dietary intakes were observed among backs regardless of the catering environment. Forwards may require more support and/or attention when transitioning between catered and non-catered environments to ensure that recommended dietary intakes are being achieved.

Keywords: dietary analysis; body composition; macronutrients; energy intake; team-sport

Introduction

Rugby Union (RU) is a high-intensity collision-based team sport contested all over the world at the amateur, semi-professional, and professional levels. During the in-season period, professional RU players are exposed to substantial training and game demands [75, 197]. Within a competition week, players can cover total distances of ~23 km and present relatively high internal training loads [197]. Throughout an 80 min game (comprising two 40 min halves), players cover total distances of ~6 km [197] and are involved in numerous collisions [198]. During both training and game-play, players are exposed to substantial exercise and impact-induced muscle damage [11, 137] and expend considerable amounts of energy during a competition week [12, 65, 66]. Due to the collisions experienced during a game, players may have additional energy requirements, evident through elevated resting metabolic rates following game-play [99, 100, 184, 199].

Currently, the nutritional practices of professional RU players have reported common trends regarding dietary intake. Players consume a relatively low carbohydrate (~3.5 g·kg of Body Mass [BM] per day^{-1}), high protein (>2.0 g·kgBM·day^{-1}) and moderate-high fat diet (>1.4 g·kgBM·day^{-1}) [1,6,10,13,14] compared to nutritional recommendations for team-sport athletes (carbohydrate = 5–8 g·kgBM·day^{-1}; protein = 1.7–2.2 g·kgBM·day^{-1}; fat = 30–50% of total energy intake) [60, 126]. It is recommended that team-sport athletes consume an adequate energy and macronutrient intake in order to offset energy expenditure, increase glycogen stores and repair body tissues [126]. To this end, sufficient dietary intake plays an integral role in player health and is also required to drive positive adaptations from training and game demands [121].

Studies have examined dietary intakes in-season among professional RU players [12, 197] and various team-sport athletes [126]. However, to our knowledge, no studies have examined the effects of a catered versus non-catered environment on dietary intakes among elite male professional RU players. It is important to understand the impact of the food environment on dietary intakes among professional RU players since transitioning between catered and non-catered environments is common [200]. Depending on the rugby club and its resources, professional players may be required to prepare their own meals when playing home games, but may be catered for when playing away games due to staying in hotels when travelling. Furthermore, players may be in a catered (hotel) environment routinely or for extended periods of time. Hotel catering represents a significantly altered dietary environment compared to home catering, with buffet options for main meals and a team room with various snack options available at all times.

Players in a catered (hotel or fully catered team facility) environment may better achieve dietary intake recommendations for team-sports [126] compared to a non-catered (preparing own meals) environment. This is because, in a catered environment, players need only focus on appropriate food selection and portion sizes, as long as suitable food options are provided [201]. Conversely, in a non-catered environment players must also focus on food shopping, budgeting, family requirements, and cooking skills [201], which are common barriers to the implementation of nutrition plans [202, 203]. Understanding the ad libitum energy intake of RU players in catered and non-catered environments would provide valuable information on how the environment influences dietary intake. These insights may also be valuable for academy and semi-professional rugby players who transition into the professional game, where the exposure to catered environments is increased.

Therefore, the aim of this study was to examine the dietary intakes of elite professional RU players in catered and non-catered environments during two seven-day competition weeks. It was hypothesised that players would consume significantly greater energy and macronutrient intakes in a catered compared to a non-catered environment due to the greater availability of and access to food.

Methodology

Study Design

A comparative repeated-measures design was utilised to assess the in-season dietary intakes of twelve elite professional RU players during two seven-day competition weeks in both catered and non-catered environments. Seven-day photographic food diaries were used to capture the dietary intakes during the competition weeks in both catered and non-catered environments. The same forwards and backs took part in the non-catered (FNC and BNC, respectively) environment first, followed by the catered (FC and BC, respectively) environment two weeks later. All players were experienced and familiar with recording dietary intakes and had experience in both catered and non-catered environments prior to the commencement of the study, reducing the risk of learning and/or order effects. Dietary intake across the competition week was conveyed as days away from game day (GD [GD-5, GD-4, GD-3, GD-2, GD-1, GD, GD + 1]) as previously presented [1,6,8].

All players within this study competed on GD in both the catered and non-catered competition weeks, with the game starting at ~1900 h. The catered environment involved a hotel which provided breakfast, lunch, and dinner. Snacks consisting of a range of food choices, were also available ad libitum via a team room whenever required. The non-catered environment involved players' personal homes, where the players were required to cater for themselves at breakfast, lunch, dinner, and snacks. In both conditions, players were provided with pre- and post-training meals optimised for fuelling and recovery around training. On GD, all players were provided with pre- and post-game meals which were similar to those previously reported [197]. Players were provided with the same supplements in both conditions which consisted of multi-vitamins, fish oils, protein powders, pre-workouts, and sports drinks.

All players were provided with nutrition education in both catered and non-catered environments, focusing on the intake of macronutrients to meet energy requirements for the maintenance of body mass and fuelling for performance. The food in the catered environment was designed and selected by the team's sports nutritionist. A buffet-style system was provided at breakfast, lunch, and dinner for players to serve themselves. Catering followed best practice principles, both regarding hand sanitisation prior to handling plates and cutlery and the provision of information cards labelling foods [201]. Vegetable/salads and carbohydrate options were available first in the buffet selections alongside healthy nuts, seeds, and oils in order to promote these foods prior to protein-based options [19,22,23]. Players were encouraged to explore buffet choices before serving up in order to pre-select food choices and avoid overloading [201].

Participants

Twelve elite male professional RU players from the New Zealand Super Rugby Championship participated in the current study. Players were categorised by their primary playing position, which comprised six forwards (F; Hookers = 1, Locks = 3, Loose = 2) and six backs (B; Half-Back/Scrum-Half = 1, First-Five/Fly Half = 1, Mid-Field = 2, Outside = 2). Years of professional experience (quantified by when players were first selected for a professional rugby team) for forwards and backs were 9.0 ± 2.8 and 9.2 ± 2.7 y, respectively. One additional forward (prop) and one additional back (outside) were initially recruited for this study but were withdrawn due to team selection changes. For players to be included in this study, they had to be selected and compete on GD in both competition weeks/environments. Informed consent was obtained from all participants involved in the study. The study was conducted according to the guidelines of the University of Waikato and approved by the University of Waikato Human Research Ethics Committee (HREC 2019#04).

Anthropometrics and Body Composition

Player's stature and body mass (BM) were collected at the start of the competition week (GD-5). Upon waking with bladder voided, BM was assessed using electronic scales (SECA, Birmingham, UK) configured to 0.1 kg accuracy. Stature was then immediately assessed using a stadiometer (SECA, Birmingham, UK) configured to 0.5 cm accuracy. Sum of eight-site skinfolds (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, anterior mid-thigh, and medial mid-calf) were collected using Harpenden callipers (British Indicators, Hertfordshire, UK), configured to 0.1 mm accuracy by a level 1 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist following the same methods as previously described [160]. Total fat-free mass (FFM) and body fat percentage (BF%) were collected one week prior to the commencement of the study using a fan-beam Dual-energy X-ray Absorptiometry (DXA) scanner (Hologic Discovery A, Hologic, Bedford, MA, USA) using the same methods previously described [160].

Training and Game Load

Quantification of internal game load, as well as field and gym training loads, were expressed using session rate of perceived exertion (sRPE) to provide arbitrary units (AU) using methods described previously [65, 197]. Quantification of external game load and field training load were expressed using total distance values, collected via 10 Hz global positioning systems (GPS) units (VX Sport, Wellington, NZ) and software (VX Sport, Wellington, NZ), following methods previously described [197, 204]. These internal and external training and game loads were collected to provide context alongside the seven-day dietary intakes collected (Table 20).

Table 20. Overview of the seven-day competition week in catered and non-catered environments.

	GD-5	GD-4	GD-3	GD-2	GD-1	GD	GD + 1	Total
All Players								
Intensity	Low	High		High	Low	High		
Field Sessions	1	1		2	1	0		5
Gym Sessions	1	1		1	0	0		3
Distance (km)			Rest and Recovery				Rest and Recovery	
FC	2.7 ± 1.2	5.7 ± 0.9		4.2 ± 1.0	3.0 ± 1.1	5.1 ± 0.7		20.6 ± 3.9
FNC	2.6 ± 0.9	5.7 ± 0.7		4.4 ± 0.5	2.5 ± 0.7	5.3 ± 0.6		20.4 ± 2.5
BC	3.7 ± 1.0	7.7 ± 1.6		5.4 ± 1.0	3.8 ± 0.7	6.4 ± 0.6		26.9 ± 4.3
BNC	3.8 ± 0.8	7.6 ± 1.3		5.3 ± 0.9	3.7 ± 0.8	6.3 ± 1.1		26.7 ± 4.1
sRPE (AU)								
FC	719 ± 87	1258 ± 72		1368 ± 94	243 ± 45	688 ± 95		4276 ± 132
FNC	840 ± 138	1281 ± 163		1365 ± 131	229 ± 43	655 ± 55		4369 ± 293
BC	767 ± 106	1270 ± 100		1375 ± 91	239 ± 39	777 ± 57		4427 ± 205
BNC	781 ± 138	1349 ± 129		1347 ± 74	242 ± 46	743 ± 89		4463 ± 206

Mean ± Standard Deviation. FC = forwards catered, FNC = forwards non-catered, BC = backs catered, BNC = backs non-catered, sRPE = session rate of perceived exertion, AU = arbitrary unit. Low intensity = mean day RPE < 6, high intensity = mean day RPE > 6. No significant differences were present for distance or training load between catered and non-catered environments.

Dietary Intake Assessment and Analysis

A seven-day remote photographic food diary/Snap-N-Send method was utilised to examine dietary intakes using methods previously described [1,26,27]. Players used the smartphone application 'WhatsApp' to photograph what they consumed at every eating/drinking occasion and provided a brief description of any foods, brand names, cooking methods, or items difficult to quantify and/or identify for the analyser. All players received appropriate training to ensure they were proficient at capturing this information. Two-way communication between player and the teams sports nutritionist were implemented to ensure that all details were correct [197]. These photographs and descriptions were then analysed and manually entered into a dietary analysis software (FoodWorks 10 Professional, Xyris, Australia) by a single registered sports dietitian.

Statistical Analyses

All statistical tests were analysed using the Statistical Package for the Social Sciences (SPSS, v28, IBM, New York, NY, USA). All data were checked for normality using the Shapiro–Wilk test. Differences between catered and non-catered environments within forwards and backs for mean seven-day energy and macronutrient intakes were assessed using paired *t* tests. A two-way repeated measures analysis of variance was utilised to determine differences between absolute energy and relative macronutrient intakes across time for forwards (FC vs. FNC) and backs (BC vs. BNC) in catered and non-catered environments. An alpha value of $p \leq 0.05$ was utilised for all tests. Effect sizes were calculated using the Cohens *d* method with the following thresholds: d = *trivial* < 0.19, *small* 0.20–0.49, *medium* 0.50–0.79, and *large* > 0.80 [176]. All data are expressed as mean ± SD.

Results

Demographics

Demographics and body composition can be observed in Table 21. Forwards demonstrated significantly greater stature (p = < 0.01; d = 2.13), BM (p = < 0.01; d = 3.02), FFM (p = < 0.01; d = 2.87), and BF% (p = 0.02; d = 1.65) compared to backs.

Table 21. Player demographics and body composition.

Demographics	**All Players (*n* = 12)**	**Forwards (*n* = 6)**	**Backs (*n* = 6)**
Age (y)	28.3 ± 2.9	28.2 ± 2.9	28.5 ± 3.2
Professional Experience (y)	9.1 ± 2.6	9.0 ± 2.8	9.2 ± 2.7
Stature (cm)	188.9 ± 9.5	195.8 ± 7.3 *	182.0 ± 5.6
Body Mass (kg)	104.1 ± 13.3	115.0 ± 6.8 *	93.2 ± 7.6
Fat-Free Mass (kg)	88.2 ± 10.3	96.5 ± 5.4 *	79.8 ± 6.2
BF% (%)	15.2 ± 1.3	16.1 ± 1.4 *	14.4 ± 0.6
Sum8SF (mm)	64.2 ± 11.9	69.9 ± 14.8	58.4 ± 3.5

Mean ± Standard Deviation. BF% = body fat percentage, Sum8SF = sum of eight-site skinfolds.
* Indicates a significant difference between forwards and backs.

Seven-Day Dietary Intakes

Mean seven-day energy and macronutrient intakes can be observed in Table 22. Significantly greater absolute (p = < 0.01; d = 1.86), relative to BM (p = < 0.01; d = 1.84) and relative to FFM (p = < 0.01; d = 1.85) energy intakes were observed for FC compared to FNC.

Significantly greater absolute (p = < 0.01; d = 2.29–2.04), relative to BM (p = < 0.01; d = 2.07–2.10), and relative to FFM (p = < 0.01; d = 2.37–2.17) protein and fat intakes were observed for FC compared FNC. No significant differences were observed in energy and macronutrient intakes among BC and BNC.

All forwards reported higher mean seven-day energy intakes in the catered compared to non-catered environment. Meanwhile, two out of the six backs consumed less in a catered (3922 ± 648 and 3335 ± 731 kcal·day^{-1}) compared to a non-catered environment (4191 ± 697 and 3490 ± 563 kcal·day^{-1}). No significant differences were observed in the mean number of meals consumed per day between environments among forwards and backs.

Table 22. Mean seven-day dietary intakes among catered and non-catered forwards and backs.

Dietary Intake		Forwards (n = 6)		Backs (n = 6)	
		Catered (n = 6)	**Non-Catered (n = 6)**	**Catered (n = 6)**	**Non-Catered (n = 6)**
Energy	kcal·day^{-1}	5210 ± 674 *	4341 ± 654	3952 ± 765	3445 ± 610
	kcal·kg^{BM}·d^{-1}	45.8 ± 7.2 *	38.2 ± 6.6	42.8 ± 8.4	37.6 ± 5.9
	Kcal·kg^{FFM}·d^{-1}	54.2 ± 8.2 *	45.1 ± 7.6	49.6 ± 9.5	43.1 ± 7.1
CHO	g·d^{-1}	408 ± 85	411 ± 89	328 ± 65	317 ± 75
	g·kg^{BM}·d^{-1}	3.6 ± 0.9	3.6 ± 0.8	3.5 ± 0.6	3.4 ± 0.7
	g·kg^{FFM}·d^{-1}	4.2 ± 1.0	4.3 ± 1.0	4.1 ± 0.7	3.9 ± 0.8
	% TEI	34 ± 4	40 ± 4	37 ± 5	40 ± 8
Protein	g·d^{-1}	318 ± 33 *	260 ± 29	223 ± 46	188 ± 11
	g·kg^{BM}·d^{-1}	2.8 ± 0.3 *	2.3 ± 0.3	2.4 ± 0.5	2.0 ± 0.1
	g·kg^{FFM}·d^{-1}	3.3 ± 0.4 *	2.7 ± 0.3	2.8 ± 0.6	2.4 ± 0.2
	% TEI	25 ± 2	25 ± 2	23 ± 4	23 ± 3
Fat	g·d^{-1}	244 ± 34 *	183 ± 47	183 ± 47	149 ± 50
	g·kg^{BM}·d^{-1}	2.1 ± 0.3 *	1.5 ± 0.3	2.0 ± 0.5	1.6 ± 0.6
	g·kg^{FFM}·d^{-1}	2.5 ± 0.4 *	1.8 ± 0.3	2.3 ± 0.6	1.9 ± 0.6
	% TEI	41 ± 3	35 ± 2	40 ± 5	37 ± 8
Fibre	g·d^{-1}	52.2 ± 9.9	48.4 ± 11.7	44.9 ± 11.6	41.3 ± 11.4
Meal #	meals·d^{-1}	5.2 ± 0.6	5.1 ± 0.8	4.9 ± 0.3	4.6 ± 0.7

Mean ± Standard Deviation. BM = body mass, CHO = carbohydrate, FFM = fat-free mass, % TEI = percentage of total energy intake, Meal # = number of meals per day. * Indicates a significant difference between forwards catered and non-catered.

Daily Absolute Energy Intake and Relative Macronutrient Intakes

Mean daily averages for absolute energy intake and relative macronutrient intake can be observed in Figures 9 and 10 for forwards and backs, respectively. Significantly greater absolute energy intakes were observed on GD-4 (p = 0.03; d = 1.30), GD-3 (p = 0.03; d = 1.29), GD-2 (p = 0.04; d = 1.05), and GD-1 (p = 0.04; d = 1.08) for FC compared to FNC. Significantly greater relative protein intakes on GD-3 (p = 0.01; d = 1.59) and significantly greater relative fat intake on GD-3 (p = 0.03; d = 1.24), GD-2 (p = 0.02; d = 1.43), and GD-1 (p = < 0.01; d = 2.05) were observed for FC compared to FNC. No significant differences were observed between BC and BNC.

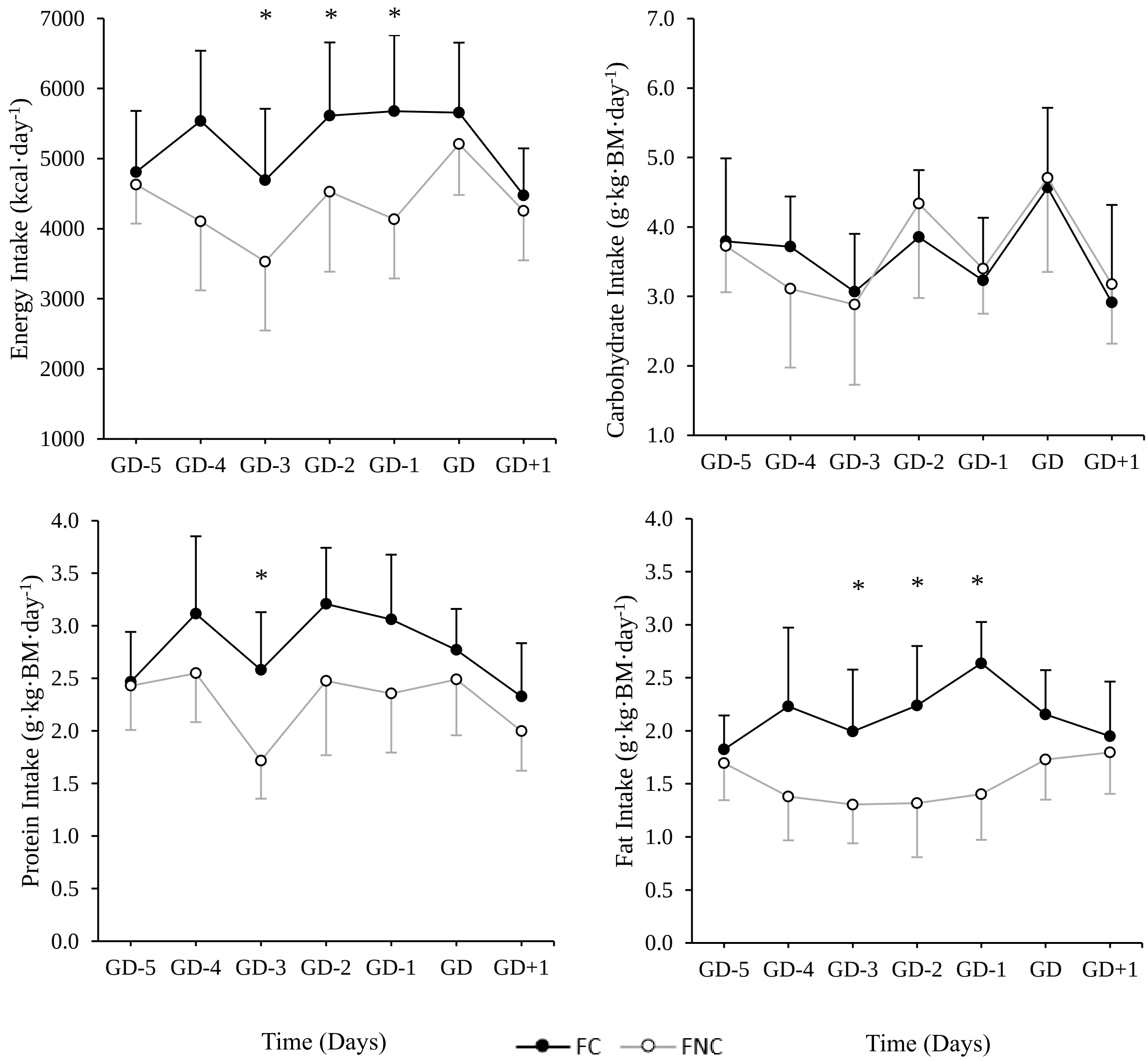

Figure 9. Daily absolute energy intake and relative macronutrient intake during competition weeks (GD-5, GD-4, GD-3, GD-2, GD-1, GD, GD + 1) among forwards within a catered (FC) and non-catered (FNC) environment. Error bars represent standard deviation. * Indicates a significant difference between FC and FNC.

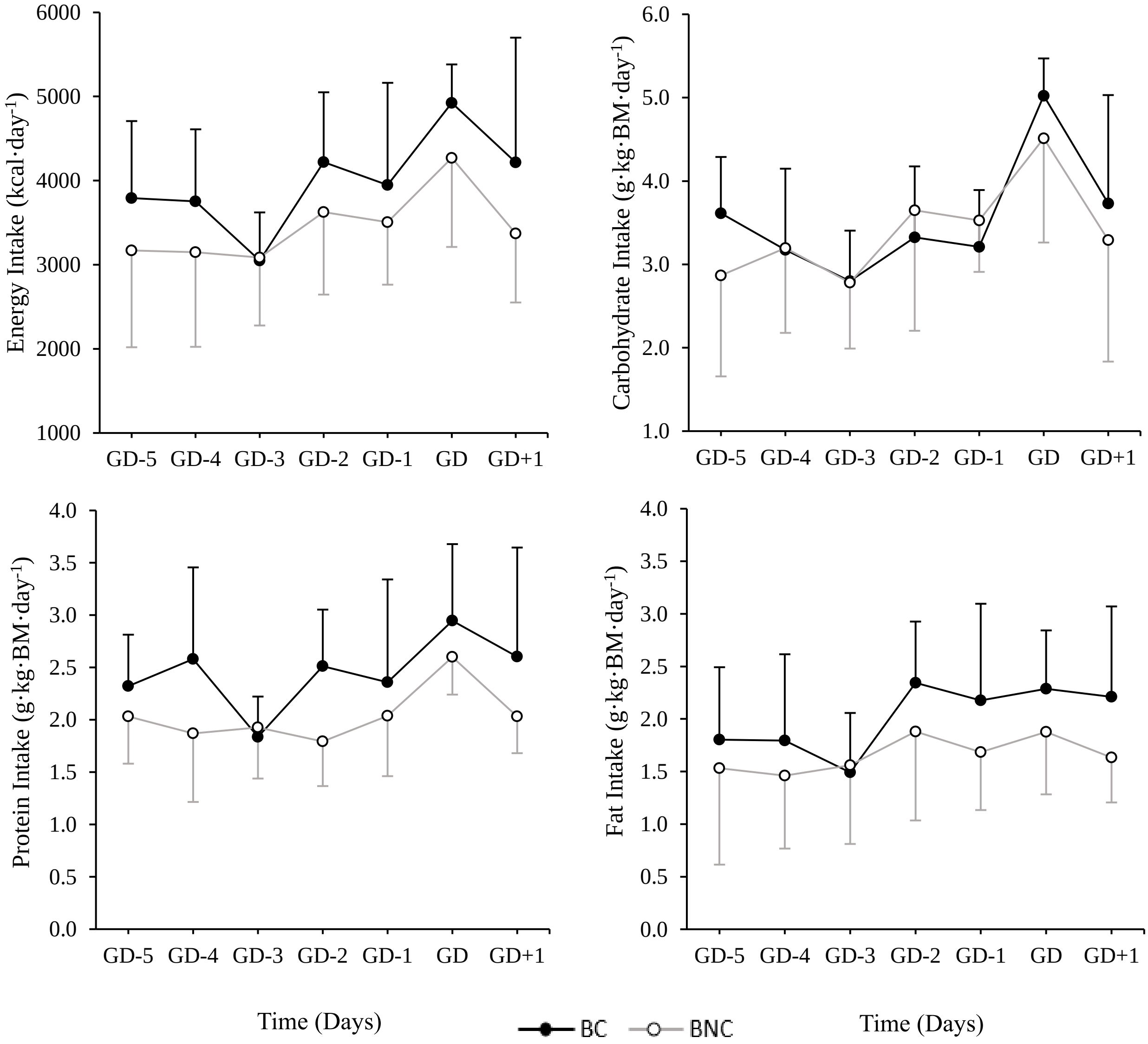

Figure 10. Daily absolute energy intake and relative macronutrient intake during competition weeks (GD-5, GD-4, GD-3, GD-2, GD-1, GD, GD+1) among backs within a catered (BC) and non-catered (BNC) environment. Error bars represent standard deviation.

Discussion

This study was the first to compare the dietary intakes of elite male professional RU players during competition weeks in both catered and non-catered environments. Forwards in a catered environment consumed significantly greater mean seven-day energy, protein, and fat intakes compared to a non-catered environment. Additionally, significant differences were present among forwards for daily absolute energy and relative protein and fat intakes between catered and non-catered environments. Backs demonstrated no significant differences in mean seven-day or daily energy and macronutrient intakes between environments. The mean seven-day energy intakes observed within catered environments for both forwards and backs were higher than previously reported among southern [197] and northern [12] hemisphere players during an in-season period. However, the non-catered energy intakes among forwards and backs were lower than previously reported in the southern hemisphere [197], but higher than those for northern hemisphere [12] players during the in-season.

Mean seven-day relative carbohydrate intakes were alike for both forwards and backs in catered and non-catered environments, which was similar to previously reported intakes [12, 197]. Relative carbohydrate intakes were slightly higher in catered forwards and backs compared to non-catered, however these differences were negligible. When expressed as a percentage of total calorie intake, carbohydrates were 6% and 3% higher in non-catered environments for both forwards and backs, respectively. This may be due to carbohydrate-rich foods being more cost-effective and convenient to fill the plate with when self-catering at home compared to more expensive, labour-intensive protein-rich foods [202, 203]. Whereas, multiple protein options and larger quantities are often available in catered compared to non-catered environments [201, 205].

Regardless of catering or geographic location, ~3.5 g·kgBM·day^{-1} is the average carbohydrate intake reported for professional RU players [1,2,6,10,13,14], which represents the lower value in the range recommended for team-sport athletes [126]. However, average carbohydrate intakes were higher (4–5g·kgBM) on intense training days (particularly GD-2) for forwards in both environments and on GD for both forwards and backs in both environments, as seen in previous studies [1,6,10]. These data demonstrate evidence of carbohydrate intake periodisation based on training load [1,29,30]. Additionally, though carbohydrate intakes were relatively low across the competition weeks, mean seven-day dietary fibre intakes among forwards and backs were high compared to recommended daily intakes (> 30 g·day^{-1}) and other team-sport athletes [206, 207]. This information suggests good quality food sources are being consumed in both environments, which may promote a range of health benefits while reducing the risk of nutrition-related lifestyle diseases [208].

Mean seven-day relative protein intakes were higher in the catered compared to the non-catered environment among forwards and backs. These protein intakes align with current reported ranges among professional RU players during the in-season period (2.0–2.7 g·kgBM·day^{-1}) [1,6,10,34], with catered forwards and backs being towards the higher end of this range. Protein intakes may be higher in catered environments due to greater variety and multiple options of different protein sources being available to players [201]. These higher protein intakes are substantial given that an additional 0.4–0.5 g·kgBM can have positive effects in promoting muscle protein synthesis among certain populations [60, 194]. Higher protein intakes may be important for supporting growth and recovery in professional RU players given the considerable exercise and impact-induced muscle damage experienced from gym and field training sessions and gameplay [11, 99, 100, 137, 184, 198, 199].

Mean seven-day fat intakes were higher for catered compared to non-catered forwards and backs. These fat intakes within a catered environment were substantially higher than previously reported in-season among northern (1.4 ± 0.3 g·kgBM·day^{-1}) [12, 199] and southern hemisphere (1.8 ± 0.4 g·kgBM·day^{-1}) players [197], but similar to those of players with a weight gain goal in a southern hemisphere pre-season study (2.0 ± 0.4 g·kgBM·day^{-1}) [185]. Fat intakes within a non-catered environment were more similar to those of northern hemisphere players [12]. These higher fat intakes from the catered environments may derive from greater protein intake and players selecting a greater amount of healthy fat options such as; olive oil, avocado, nuts and seeds at meal times. A potential positive regarding these increased fat intakes is that it may help some players meet energy requirements without the feeling of having to consume too much food. For example, with similar carbohydrate intakes between catered and non-catered conditions, the greater mean energy intakes observed in a catered environment are mainly due to higher protein and fat intakes, with fat contributing substantially more absolute energy difference between FC and FNC (549 kcal) and BC and BNC (306 kcal).

Over the course of the competition weeks there were no significant differences in daily energy and macronutrient intakes between environments for backs. Whereas, absolute energy intake was significantly higher for catered compared to non-catered forwards on GD-4, GD-3, GD-2, and GD-1. Relative protein intake was significantly higher on GD-3 (rest and recovery day) in catered compared to non-catered forwards. Meanwhile, relative fat intake was significantly higher on GD-3, GD-2, and GD-1 in catered compared to non-catered forwards. This would indicate that backs have more similar dietary intakes regardless of the food environment, while forwards may require more support or attention when changing between catered and non-catered environments to ensure recommended and consistent dietary intakes are being achieved.

All together, these observations suggest that even when food is catered for, players still consume a similar carbohydrate intake to previously reported data [126]. To this end, food selection and preparation for carbohydrate does not seem to be an issue between environments, making it a matter of choice. In contrast, players consumed more protein and fat in the catered environment compared to non-catered. These higher protein and fat intakes observed within catered compared to non-catered environments, may be due to multiple protein and fat sources being available [201]. This could potentially be an area to help increase calorie intake (once carbohydrate and protein intake are sufficient first and foremost) in non-catered environments to try better meet the energy demands of rugby players, who have shown typically high energy expenditures [7,8,14,36]. However, the contrary must also be considered in that, players who need to reduce calorie intake should be guided carefully or the environment may need to be modified further for these players.

A limitation of the current study was that exercise energy expenditure was not collected, and therefore energy availability could not be determined. Male athletes are recommended to achieve energy intakes > 40 kcal·kgFFM·day^{-1} after exercise energy expenditure has been taken into account (dietary energy intake (kcal)—exercise energy expenditure (kcal)/FFM (kg)) to optimise physiological functions [209, 210]. Our results suggest that some players may be at risk of low energy availability. This is due to our reported measures only being ~50–55 kcal·kgFFM·day^{-1} in catered players and ~40–45 kcal·kgFFM·day^{-1} in non-catered players, prior to factoring in exercise energy expenditure. In particular, forwards and backs within non-catered environments may be at greater risk, however those in catered environments also need to be diligent with their dietary intake strategies. Measuring energy expenditure from exercise is highly recommended in these groups to provide a greater understanding of energy availability.

Other limitations within this study were; granted distance and training load were very similar between environments, there may always be certain activities performed in training that cannot be accounted for or replicated across training weeks that may influence a player's energy intake, such as specific skills, drills and game plans required in a competition week when preparing for different opposition. However, all efforts were made to ensure training activity was controlled and replicable as best as possible. Lastly, another limitation that is present among dietary analysis studies, is the likelihood of misreporting by players [64] and/or the analyst when assessing photographic food diaries [26,40,41]. Once again, all efforts were made to reduce error in the reporting of dietary intakes within this study.

Conclusion

Forwards in a catered environment demonstrated significantly greater absolute and relative energy intakes and significantly greater absolute and relative protein and fat intakes compared to a non-catered environment. Conversely, no significant differences were observed among backs in catered and non-catered environments. Significant differences in daily absolute energy intakes and relative protein and fat intakes were observed among forwards between catered and non-catered environments, but no significant differences were observed among backs between environments. Forwards and backs in both catered and non-catered environments achieved team-sport nutritional recommendations for protein and fat intakes, however carbohydrate intake was still on the lower end of recommendations regardless of environment. For teams that have players exposed to both catered and non-catered environments during a season, it may be important to compare dietary intakes within each environment to optimise and align nutritional habits in order to meet appropriate nutritional requirements. Future studies could explore the nutritional intakes of professional RU players when competing away from home, with significant travel compared to regular home games alongside measures of exercise energy expenditure. Studies could also compare macronutrient distribution and food product differences across meals throughout the day between different environments.

CHAPTER EIGHT

The Development of a Resting Metabolic Rate Prediction Equation for Professional Male Rugby Union Players

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Prelude

Chapters Six and Seven report relatively high energy intakes among professional rugby union players. It is important to assess energy expenditure to understand if these energy intakes are suitable. The first step in determining accurate energy requirements is through the assessment of resting metabolic rate (RMR), given it substantially contributes to total daily energy expenditure. Chapters Three and Five reported that professional rugby union players are relatively large and possess substantial amounts of fat-free mass compared to general populations and participants used in previous resting metabolic rate (RMR) prediction equations. Therefore, professional rugby union players may require their own population specific prediction equations. This study aimed to examine the RMR of professional rugby union players using indirect calorimetry and compare these measures to commonly used prediction equations and develop a population specific prediction equation if commonly used equations were not suitable. This will allow more individualised nutrition and body composition prescription for professional rugby union players.

Abstract

Determining resting metabolic rate (RMR) is an important aspect when calculating energy requirements for professional rugby union players. Prediction equations are often used for convenience to estimate RMR. However, the accuracy of current prediction equations for professional rugby union players remains unclear. The aims of this study were to examine the RMR of professional male rugby union players compared to nine commonly used prediction equations and develop and validate RMR prediction equations specific to professional male rugby union players. One hundred and eight players (body mass (BM) = 102.9 ± 13.3 kg; fat-free mass (FFM) = 84.8 ± 10.2 kg) undertook Dual-energy X-ray Absorptiometry scans to assess body composition and indirect calorimetry to determine RMR. Mean RMR values of 2585 ± 176 $kcal \cdot day^{-1}$ were observed among the group with forwards (2706 ± 94 $kcal \cdot day^{-1}$), demonstrating significantly ($p < 0.01$; $d = 1.93$) higher RMR compared to backs (2465 ± 156 $kcal \cdot day^{-1}$), which appeared to be due to their higher BM and FFM measures. Compared to the measured RMR for the group, seven of the nine commonly used prediction equations significantly ($p < 0.05$) under-estimated RMR (−104–346 $kcal \cdot day^{-1}$), and one equation significantly ($p < 0.01$) over-estimated RMR (192 $kcal \cdot day^{-1}$). This led to the development of a new prediction equation using stepwise linear regression, which determined that the strongest predictor of RMR for this group was FFM alone ($R^2 = 0.70$; SEE = 96.65), followed by BM alone ($R^2 = 0.65$; SEE = 104.97). Measuring RMR within a group of professional male rugby union players is important, as current prediction equations may under- or over-estimate RMR. If direct measures of RMR cannot be obtained, we propose the newly developed prediction equations be used to estimate RMR within professional male rugby union players. Otherwise, developing team- and/or group-specific prediction equations is encouraged.

Keywords: energy demands; body composition; indirect calorimetry; resting energy expenditure

Introduction

Over the course of a typical seven-day competition week, professional male rugby union (RU) players have been observed to train up to four days per week, comprising three resistance-training sessions, five field-training sessions, and if selected, a match on game day [163, 197]. To support the training and game demands of RU players, it is important to optimise energy intake in relation to energy expenditure to meet individual player needs and enhance performance and recovery [126]. A squad of RU players present a diverse range of physical and fitness characteristics [160] and therefore possess unique individual energy requirements.

Often, players may need to achieve a higher body mass (in the desired form of lean muscle mass), which is typically achieved by being in an energy surplus for an extended period of time alongside appropriate training and macronutrient composition [211, 212]. In contrast, players may need to acquire a lower body mass (BM) and/or lower body fat mass (FM) while preserving as much lean muscle mass as possible, which is often achieved by being in an energy deficit for an extended period of time [213] and also combined with specific training and macronutrient composition [193, 214]. Players considered to be at an appropriate/optimal BM, body composition, and fitness level according to the athlete and/or coaching staff, may simply be aiming to meet energy requirements to optimise performance, recovery, and overall well-being [25, 126].

Measuring or predicting resting metabolic rate (RMR) is often the first step in determining energy intake in general and in athletic populations because RMR substantially contributes (~50–60%) to total daily energy expenditure [25]. By definition, RMR is the amount of energy required to satisfy physiological processes in a rested, fasted, and inactive condition [215]. Direct measurement of RMR using indirect calorimetry is desired to individualise energy requirements with the most certainty [25]. However, this process requires expensive equipment, trained personnel, and time. The burden on athletes and coaches is also considerable due to the athlete needing to be in a well-rested and overnight-fasted state to collect accurate and reliable measures [112, 113]. Therefore, practitioners often seek RMR prediction equations to provide an estimate of the athletes' RMR using physical characteristic variables, such as age, height, BM, and fat-free mass (FFM) [25].

Prediction equations based on BM have been used for well over a century with many more being developed over recent years to save time and money for both the practitioner and the athlete [216]. However, many of these prediction equations have been generated using non-athletes or athletes with substantially lower stature, body mass, and in particular, FFM than those of professional RU players [217]. Previous studies among rugby players have demonstrated that current prediction equations can considerably misreport RMR compared to direct measures [65, 66, 217]. Other sports involving similarly large athletes [24, 216] have also suggested that prediction equations that are not sport-specific may not be appropriate for athletes with substantially more FFM and may therefore under-estimate RMR. This could result in deficiencies in energy, which are associated with performance decrements, losses in FFM, and increased susceptibility to illness and/or injury [60]. Consequently, sport-specific prediction equations are strongly encouraged to better estimate energy requirements among specific athletes in their respective sports [24, 218-220].

A population-specific prediction equation is likely important for RU players due to the large body and FFM these athletes possess and the substantial energy requirements these athletes demonstrate [126]. MacKenzie-Shalders et al. [217] presented a prediction equation among a small sample (n = 18) of young developing RU players. Popular and well-used prediction equations have used sample sizes of 50 to over 100 participants [25, 116]. Using a large sample size of professional RU players across a range of positions and ages is desired to accurately predict RMR and inform energy requirements within this population group.

Therefore, the aims of this study were to a) measure the RMR of professional male RU players and compare them to currently established prediction equations, and b) develop and validate a population-specific prediction equation for professional male RU players if current prediction equations are not suitable. It was hypothesised that the currently established prediction equations would significantly under-estimate RMR in professional RU players due to the larger BM and FFM associated with the sporting demands of these athletes.

Methodology

Study Design

A cross-sectional study design was utilised to assess the body composition and RMR of professional male RU players under standardised conditions; >8 h fast and >12 h after exercise [25, 112, 113] between 05:00 and 09:00 h. Body composition and RMR testing were assessed a week apart from each other during the pre-season phase. Measured RMR was then compared to commonly used prediction equations, followed by the development and internal validation of a new population-specific prediction equation for RMR.

Participants

One hundred and eight male professional RU players participated in this study. Players were from New Zealand teams competing in the Super Rugby Pacific Championship (n = 64), and are classified as elite worldclass for team sports as they are from Super Rugby and International levels [175]. Players were also from the New Zealand National Provincial Championship (n = 44), and are classified as highly trained/national level for team sports [175]. Players were categorised according to their primary playing positions, comprising 54 forwards and 54 backs. All participants provided informed consent, and ethical approval was obtained from the University of Waikato Human Research Ethics Committee (HREC2019#04).

Anthropometric and Body Composition Assessment

Players were instructed to arrive at the laboratory in a rested (>12 h following exercise or strenuous physical activity) and fasted (>8 h) state, with all jewellery removed and wearing underwear and/or tight-fitting compression clothing free from zips, studs, metal, and reflective objects [52]. Players were measured for height using a fixed-to-wall stadiometer (SECA Scales, Hamburg, Germany) measuring to the nearest 0.5 cm, and BM was measured using a calibrated set of scales (SECA Scales, Hamburg, Germany) measuring to the nearest 0.1 kg.

Each player then underwent a whole-body fan-beam Dual-energy X-ray Absorptiometry (DXA) scan (Hologic QDR Series, Discovery A, Bedford, MA, USA) following methods previously described [160] to provide FFM, FM, and body fat percentage (BF%). All scans were performed and analysed by the same trained operator. Body composition measures were reported as whole-body, which included the head.

RMR Assessment

One week following the anthropometric and body composition assessment, players were again instructed to arrive at the laboratory in a rested (>12 h) and fasted (>8 h) state [25, 112, 113]. Players underwent a 20 min rest period in a reclined, seated position wearing a face mask (7450 Series Silicone V2, Hans Rudolph, KS, USA), which allowed the players to familiarise themselves and settle their breathing before the beginning of a 20 min indirect calorimetry RMR assessment. The assessment took place in a dimly lit and temperature-controlled room (21–23 °C), with players lying quietly in a supine position [25, 112, 113].

Expired gas was analysed using a breath-by-breath gas analyser (MetaLyzer 3B-R3, Cortex Biophysik GmbH, Leipzig, Germany), which has demonstrated good accuracy for respiratory parameters and total energy expenditure [221]. The gas analyser was calibrated as per the manufacturer's guidelines using two known concentrations of each gas (ambient and 15% O_2 and ambient and 5% CO_2), daily barometric pressure, and a 3 L volume syringe. The player's face mask was then connected to a gas analyser for high-resolution, breath-by-breath analysis. The first five minutes of the RMR test were discarded [112]. A 5 min steady state interval was achieved during the remaining 15 min, providing an accurate assessment of RMR with a coefficient of variation < 10% [113]. The Weir equation [222] was used to calculate RMR.

Current Commonly Used Prediction Equations

Resting metabolic rate was estimated for each player using nine different prediction equations from six studies [114-116, 216, 217, 223] (Table 23). These equations were selected as they have been routinely used to predict RMR in rugby players [65, 66, 217] and have been shown to under- or over-estimate RMR in this population. Moreover, these prediction equations were developed using a similar sample size to that used in the present study.

Table 23. Commonly used resting metabolic rate prediction equations among rugby union players.

Study	Sample	RMR Prediction Equation (kcal·day^{-1})
Commonly Used Equations		
Harris–Benedict [115]	M = 136 F = 103	M: 66.47 + (13.75 × BM) + (5.00 × H) − (6.75 − age)
Cunningham [114]	M = 120 F = 103	500 + (22 × FFM)
ten Haaf ^{FFM} [116]	M = 53 F = 37	484.26 + (22.77 × FFM)
ten Haaf ^{BM} [116]	M = 53 F = 37	29.28 + (11.94 × BM) + (5.88 × H) − (8.13 × age) + (191.03 × sex (M = 1, F = 0))
Jagim [223]	M = 68	M: 775.33 + (19.46 × BM)
Tinsley ^{FFM} [216]	M = 17 F = 10	284 + (25.9 × FFM)
Tinsley ^{BM} [216]	M = 17 F = 10	10 + (24.7 × BM)
RU Specific Equations		
Mackenzie-Shalders ^{LBM} [217]	M = 18	24.56 − (29.71 × FFM)
Mackenzie-Shalders ^{BM} [217]	M = 18	775.32 + (15.95 × BM)
Newly Developed Equations		
Posthumus (FFM equation)	M = 108	M: 1351.74 + (14.53 × FFM in kg)
Posthumus (BM equation)	M = 108	M: 1489.93 + (10.63 × BM in kg)

RMR = resting metabolic rate, M = male, F = female, BM = body mass, H = height, FFM = fat-free mass, RU = rugby union, LBM = lean body mass. Units for these equations are as follows: BM = kg, H = cm, age = years, FFM = kg, LBM = kg.

Statistical Analyses

All data were analysed using the Statistical Package for the Social Sciences (SPSS, v28, Chicago, IL, USA). Data were checked for normality using the Shapiro–Wilk test. Differences in anthropometrics, body composition, and RMR between positions and levels were analysed using independent *t* tests. Relationships between physical characteristics and measured RMR were determined using Pearson correlation coefficients (*r*) with the following thresholds: *trivial* (<0.09), *small* (0.10–0.29), *moderate* (0.30–0.49), *large* (0.50–0.69), *very large* (0.70–0.89), or *nearly perfect* (0.90–0.99) [153]. Comparisons between the measured RMR value and predicted values were analysed using repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc. Effect sizes were calculated using the Cohen's *d* method with the following thresholds: *d* = *trivial* < 0.19, *small* 0.20–0.39, *moderate* 0.40–0.59, *large* 0.60–0.79, and *very large* > 0.80 [176].

Stepwise multiple regression analysis was carried out using relevant variables (age, height, BM, FFM, and FM) to develop a new RMR prediction equation for professional male RU players. The significantly strongest predictors of RMR were both FFM and BM alone, resulting in an FFM-based and BM-based RMR prediction equation. The root mean squared error (RMSE) was calculated as the expected absolute deviation (kcal·day^{-1}) of the predicted RMR from the measured RMR. Bland–Altman plots were used to identify the 95% limits of agreement between the measured RMR and the predicted RMR. Internal validation of the newly developed prediction equations were carried out using k-fold cross-validation ($k = 10$) where the data set was randomly separated into 10 folds. Nine folds were used to develop/train the prediction equation and was then tested on the 10th fold. This process was repeated until all folds were used in both the development and testing of each model [224]. The average of the mean difference, mean absolute percentage error (MAPE), RMSE, r, R^2, and p values for the 10 folds were reported [225]. The statistical significance was set at $p < 0.05$.

Results

Demographics, Body Composition, and RMR

Demographics, body composition, and resting metabolic rate are presented in Table 24. Forwards demonstrated significantly greater height ($p < 0.01$; $d = 1.06$), BM ($p < 0.01$; $d = 2.34$), FFM ($p < 0.01$; $d = 2.04$), FM ($p < 0.01$; $d = 1.64$), BF% ($p < 0.01$; $d = 0.78$), and RMR ($p < 0.01$; $d = 1.93$) compared to backs. No significant differences were observed in RMR between Super Rugby and National Provincial Union forwards (2709 ± 101 versus 2699 ± 75 kcal·day^{-1}, respectively, $p = 0.74$; $d = 0.10$) and backs (2499 ± 128 versus 2437 ± 172 kcal·day^{-1}, respectively, $p = 0.15$; $d = 0.40$).

Table 24. Demographics, body composition, and resting metabolic rate.

Measures	All Players (n = 108)	Forwards (n = 54)	Backs (n = 54)
Age (y)	25.7 ± 4.1	26.1 ± 3.7	25.3 ± 4.4
Height (cm)	185.8 ± 6.8	189.0 ± 6.3 *	182.6 ± 5.7
BM (kg)	102.9 ± 13.3	113.0 ± 9.2 *	92.8 ± 8.1
FFM (kg)	84.8 ± 10.2	92.0 ± 6.6 *	77.6 ± 7.6
FM (kg)	18.0 ± 4.6	20.9 ± 4.1 *	15.0 ± 3.0
BF% (%)	17.3 ± 3.0	18.4 ± 2.6 *	16.3 ± 3.0
RMR (kcal·day^{-1})	2585 ± 176	2706 ± 94 *	2465 ± 156

Mean ± SD. BM = body mass, FFM = fat-free mass, FM = fat mass, BF% = body fat percentage, RMR = resting metabolic rate. * Indicates significant difference between forwards and backs ($p < 0.05$).

Relationship Between Predictor Variables and RMR

Correlation coefficients between potential predictor variables and RMR can be observed in Table 25. The strongest correlations observed were *very large* between FFM and RMR (r = 0.84; p < 0.01) and BM and RMR (r = 0.81; p < 0.01). A *nearly perfect* relationship (r = 0.96; p < 0.01) was also observed between FFM and BM among this group.

Table 25. Correlation matrix between predictor variables and resting metabolic rate among all players (n = 108).

	Age	**Height**	**BM**	**FFM**	**FM**	**Fat%**	**RMR**
Age	1.00						
Height	0.17	1.00					
BM	0.18	0.56 **	1.00				
FFM	0.24 *	0.61 **	0.96 **	1.00			
FM	−0.00	0.30 **	0.79 **	0.59 **	1.00		
BF%	−0.14 *	0.04	0.40 **	0.12	0.87 **	1.00	
RMR	0.14	0.54 **	0.81 **	0.84 **	0.49 **	0.10	1.00

BM = body mass, FFM = fat-free mass, FM = fat mass, BF% = body fat percentage, RMR = resting metabolic rate. * Correlation is significant at p < 0.05. ** Correlation is significant at p < 0.01.

Measured RMR Compared to Current and Newly Developed Prediction Equations

Comparisons between measured RMR and predicted RMR values can be observed in Table 26. There was a significant difference between measured and predicted RMR ($F(2.77, 295.88)$ = 350.84, p < 0.01). Of the nine commonly used prediction equations from six studies, seven significantly (p < 0.01) under-estimated RMR [114-116, 216, 217] compared to measured values, except for Tinsley^{BM} [216], which only marginally under-estimated RMR. However, Jagim [223] significantly (p < 0.01) over-estimated RMR compared to measured RMR values.

Both newly developed prediction equations from the current study demonstrated the lowest RMSE (FFM = 96 kcal·day^{-1}, BM = 104 kcal·day^{-1}) compared to all commonly used equations. Out of the nine selected commonly used prediction equations, the Tinsley^{FFM} [216] equation demonstrated the next lowest RMSE (182 kcal·day^{-1}). Upon visual inspection of the limits of agreement using Bland–Altman plots, the newly developed prediction equations demonstrated the lowest fixed and proportional bias compared to the commonly used prediction equations (Figures 11e and 12f).

Table 26. Comparisons between measured resting metabolic rate in the current study (n = 108 professional male rugby union players) and resting metabolic rates derived from the prediction equations.

RMR Method	RMR (kcal·day^{-1})	Mean Difference (mean ± SD)	95% CI of MD	Effect Size (*d*)	Sig (*p*)	RMSE (kcal·day^{-1})
Measured (IC)	2584 ± 176					
Harris–Benedict [115]	2238 ± 201	−346 ± 120	−323 to −369	−2.89	<0.001	366
Cunningham [114]	2330 ± 211	−254 ± 133	−228 to −279	−1.91	<0.001	286
ten Haaf ^{FFM} [116]	2378 ± 219	−206 ± 137	−179 to −232	−1.50	<0.001	247
ten Haaf ^{BM} [116]	2332 ± 181	−252 ± 113	−230 to −273	−2.23	<0.001	276
Jagim [223]	2778 ± 259	194 ± 157	164 to 224	1.23	<0.001	249
Mackenzie-Shalders ^{LBM} [217]	2447 ± 285	−137 ± 185	−102 to −172	−0.74	<0.001	229
Mackenzie-Shalders ^{BM} [217]	2417 ± 213	−167 ± 126	−143 to −191	−1.32	<0.001	209
Tinsley ^{FFM} [216]	2480 ± 263	−104 ± 150	−75 to −132	−0.69	<0.001	182
Tinsley ^{BM} [216]	2562 ± 331	−22 ± 216	19 to −63	−0.10	0.295	216
Newly Developed Equations						
Posthumus ^{FFM}	2585 ± 146	1.6 ± 96	−20 to 17	0.02	0.861	96
Posthumus ^{BM}	2585 ± 140	1.6 ± 105	−22 to 18	0.02	0.875	104

Resting metabolic rate (RMR) presented as mean ± standard deviation (SD). Mean difference (MD) in RMR between measured and prediction equations presented as mean ± SD, and 95% CI of MD = 95% confidence interval of mean difference (lower bound to upper bound). IC = indirect calorimetry, FFM = fat-free mass, BM = body mass, LBM = lean body mass, Sig = significance, RMSE = root mean squared error. Significance = $p < 0.05$.

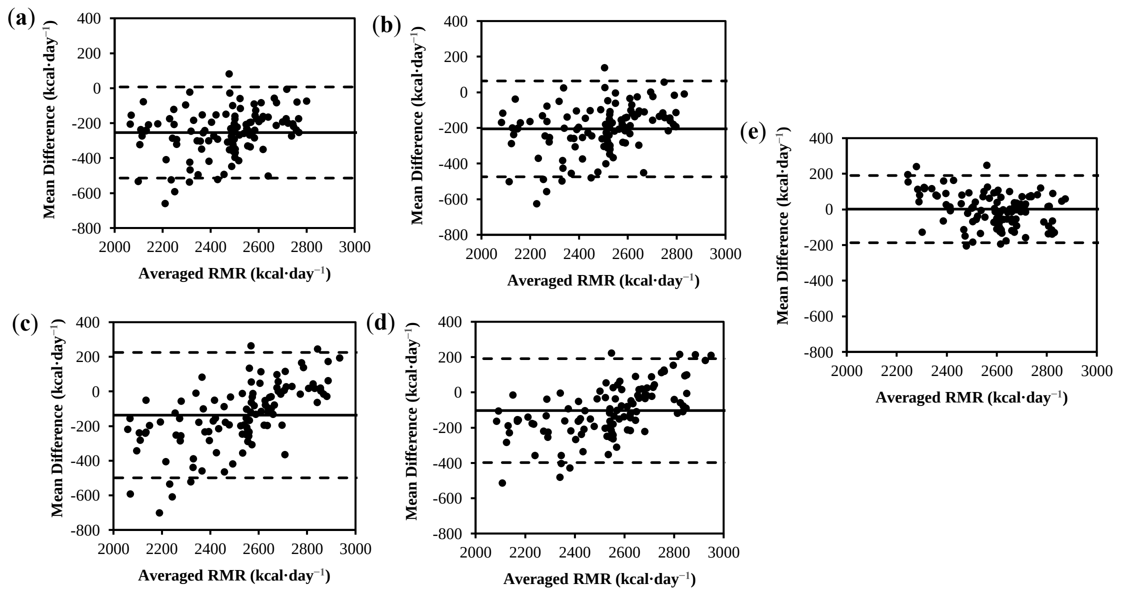


Figure 11. Bland–Altman plots for FFM equations: (a) Cunningham, (b) ten Haaf FFM, (c) Mackenzie-Shalders LBM, (d) Tinsley FFM, (e) Posthumus FFM. The middle, solid, horizontal line represents the constant error. The lower and upper dashed horizontal lines represent the 95% limits of agreement.

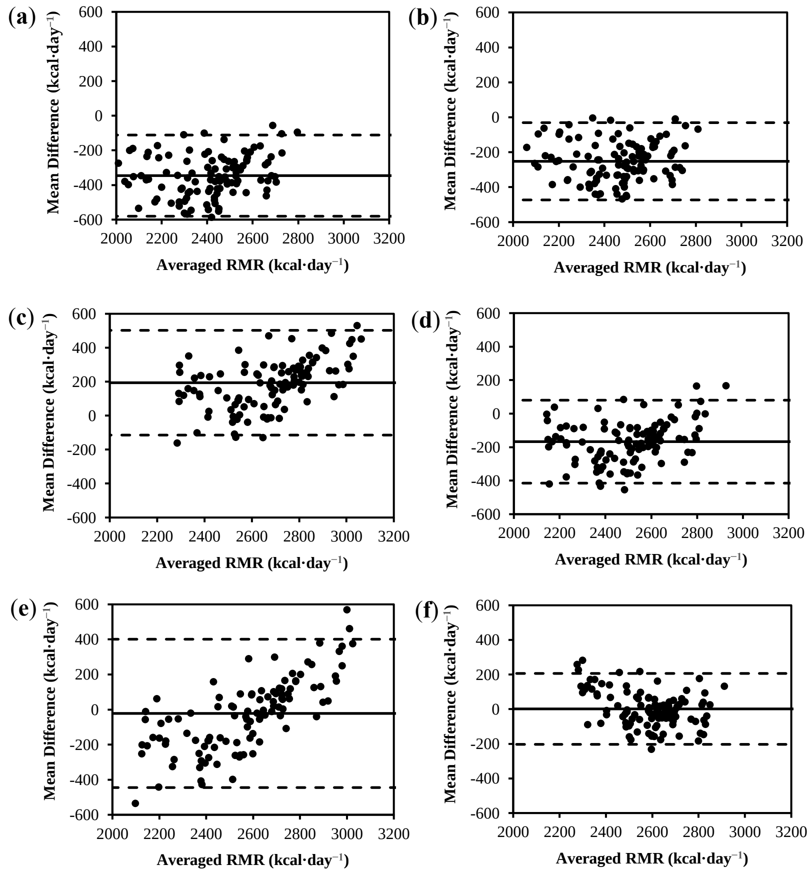


Figure 12. Bland–Altman plots for BM equations: (a) Harris–Benedict, (b) ten Haaf BM, (c) Jagim, (d) Mackenzie-Shalders BM, (e) Tinsley BM, (f) Posthumus BM. The middle, solid, horizontal line represents the constant error. The lower and upper dashed horizontal lines represent the 95% limits of agreement.

Newly Developed Prediction Equation Compared to Measured RMR

Stepwise multiple regression revealed that FFM ($R^2 = 0.70$; Standard Error of Estimate (SEE) = 96.65) was the strongest significant predictor of RMR ($p < 0.05$), accounting for 70% of the variation in RMR, and was the only predictor variable included in the novel prediction equation. All other variables (age, height, BM, and FM) were rejected as they did not significantly improve the fit of the model. The predicted RMR values are plotted against measured RMR values (Figure 13c), and the relationship between measured RMR and FFM is plotted (Figure 13a).

Fat-Free Mass RMR Prediction Equation (kcal·day^{-1}) = 1351.74 + (14.53 × FFM in kg)

A second prediction equation using BM was derived due to the ease of assessment compared to the need for specialised equipment to obtain accurate FFM measures. A second stepwise multiple regression was carried out with age, height, and BM entered as predictor variables, with BM being the single best predictor (R^2 = 0.65; SEE = 104.97; $p < 0.05$), accounting for 65% of the variation in RMR. Both age and height were rejected as they did not significantly improve the fit of the model. The predicted RMR values are plotted against measured RMR values (Figure 13d), and the relationship between measured RMR and BM are plotted (Figure 13b).

Body Mass RMR Prediction Equation (kcal·day^{-1}) = 1489.93 + (10.63 × BM in kg)

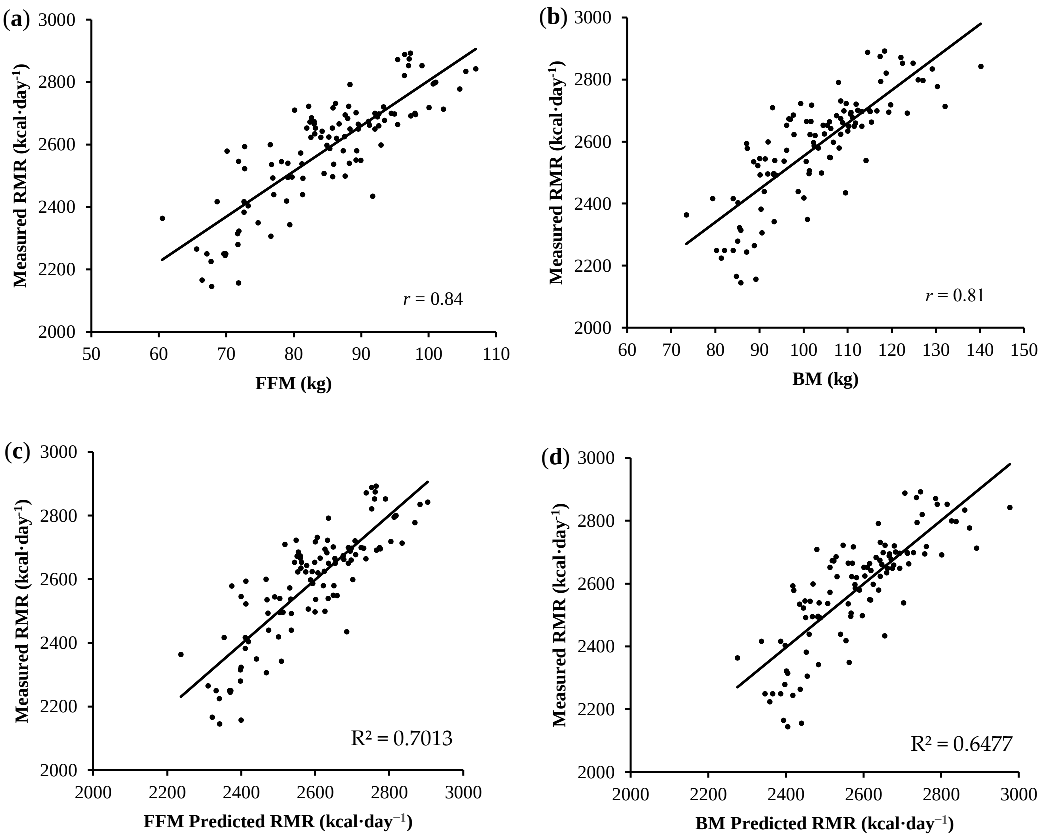


Figure 13. Relationship between (a) fat-free mass (FFM), (b) body mass (BM), and measured resting metabolic rate (RMR). The newly developed (c) FFM and (d) BM prediction equations plotted against measured RMR.

Internal Validation of the Newly Developed Prediction Equations

Following *k*-fold (k = 10) cross-validation, no significant differences were present between measured RMR and the newly developed FFM (p = 0.44) and BM (p = 0.42) prediction equations. *Very large* relationships were observed between measured RMR and the prediction equations based on FFM (r = 0.82) and BM (r = 0.82). The FFM-based prediction equation demonstrated marginally better MAPE (3.2 ± 2.4% vs. 3.4 ± 2.7%), R^2 (0.69 vs. 0.68), and RMSE (98 vs. 105 kcal·day^{-1}) than the BM prediction equation when compared to measured RMR. Comparing the results from the validation data set with the whole data set used to develop the prediction equations, R^2 only decreased by 0.01 for the FFM-based equation (R^2 = 0.69 vs. 0.70). However, the BM-based equation demonstrated an increase in R^2 by 0.03 (R^2 = 0.68 vs. 0.65). The RMSE was also similar between the validation and whole group data for FFM (RMSE = 98 vs. 97 kcal·day^{-1}) and BM (RMSE = 104 vs. 105 kcal·day^{-1}).

Discussion

The current study measured the RMR of professional male RU players using indirect calorimetry and compared them to commonly used prediction equations [114-116, 216, 223] and one RU-specific prediction equation [217]. Our findings support our initial hypothesis where the majority of the selected current prediction equations significantly under-estimated [114-116, 217] RMR in our group of professional RU players. The existing prediction equations were deemed inappropriate for this population; therefore, stepwise linear regression was carried out to develop a new, population-specific prediction equation for professional male RU players. The development of an FFM-based prediction equation was implemented due to FFM generating the significantly strongest model on its own by accounting for 70% of the variation in RMR. Due to the challenges of obtaining accurate and user-friendly measures of FFM, a BM-based prediction equation was also developed to allow RMR to be calculated conveniently for players and practitioners, with BM still presenting a strong model, accounting for 65% of the variation in RMR.

Our study observed a mean RMR of 2585 ± 176 kcal·day^{-1}, which was higher than baseline measures observed in 22 English premiership RU players (2318 ± 182 kcal·day^{-1}) [184] and 18 Australian young developing RU players (2389 ± 263 kcal·day^{-1}) [217], but was similar to RMR measures observed one day following an English premiership RU game (2544 ± 397 kcal·day^{-1}) [184]. We also reported higher RMR measures compared with 26 Under-16 to Under-24 RU (2123 ± 269 kcal·day^{-1}) and Rugby League (2366 ± 296 kcal·day^{-1}) players [66]. However, higher RMR measures were observed in young developing English Rugby League players (~2655 ± 516 kcal·day^{-1}) [88, 99] compared to our study.

Interestingly, player RMR generally increased linearly alongside FFM and BM, which was similar to observations reported by Costello et al. [88] in which the heaviest players presented the highest RMR. In contrast, Morehen et al. [65] reported that players with the lowest body mass and lean mass presented the highest RMR. In our study, we observed that although players could present a relatively high RMR with a relatively low body mass and/or FFM, typically as a player's body mass and FFM increased, so did RMR. Given the larger sample size observed within our study, a linear trend was more present. Provided how much FFM has been shown to contribute to individual variations in RMR (25–70%) [226], this was expected. We also observed *nearly perfect* relationships between FFM and BM, which may explain why BM is also such a strong predictor for RMR in this group. Generally, as professional RU players grow larger, they demonstrate greater amounts of FFM with minimal increases in FM [20, 160]. Meanwhile, when increases in BM are observed among the general population or lower playing levels, substantially more FM and less FFM is generally observed [20, 25]. Therefore, in non-professional RU players, general prediction equations may be more accurate due to lesser amounts of FFM being present [20, 160]. However, further studies are required to determine this.

After examining differences between positions within this study, we observed significantly higher RMR values among forwards (2706 ± 94 kcal·day^{-1}) compared to backs (2465 ± 156 kcal·day^{-1}). However, forwards also demonstrated significantly greater amounts of both FFM (92.0 ± 6.6 kg vs. 77.6 ± 7.6 kg) and BM (113.0 ± 9.2 kg vs. 92.8 ± 8.1 kg) compared to backs. Although these differences were observed between positions, when a stepwise linear regression was run separately among forwards and backs, the strength and significance of the prediction equation was not improved further. If position were included in the final model, this would have added another categorical step in the process by having to designate position which may not reflect what is being measured. This is because some RU backs, such as midfielders and outside backs, could be a similar size to or larger than a loose forward. Therefore, a position-specific prediction equation is likely not appropriate within this group, given increases in FFM and BM are predominantly linear (r = 0.96) across the group and account for a considerable amount of variation in RMR (FFM = 70% and BM = 65%).

When comparing the measured RMR within this study to current prediction equations, the Tinsley ^{BM} [216] equation demonstrated the smallest mean difference compared to the other equations used, but it demonstrated the largest variation in regards to standard deviation. The Tinsley ^{FFM} [216] and Mackenzie-Shalders ^{LBM} [217] equations were significantly lower than measured RMR, but given only *small* to *moderate* differences were observed, respectively, these equations were the next closest to predicting RMR in this group of RU players. It is likely that these two prediction equations [216, 217] are more similar to the measured RMRs within our study because the participants had substantially greater amounts of FFM compared to the non-sport-specific prediction equations [114, 115]. However, the Jagim [223] male prediction equation was also developed using heavier athletes (93.7 ± 16.3 kg) with considerable amounts of FFM (77.3 ± 8.1 kg) compared to older prediction equations [114-116], yet when using this equation within our group, RMR was significantly over-estimated (2778 ± 259 $kcal \cdot day^{-1}$) compared to our measured values (2584 ± 176 $kcal \cdot day^{-1}$). This may partly be due to the greater BM (102.9 ± 13.3 kg vs. 93.7 ± 16.3 kg) and FFM (84.8 ± 10.2 kg vs. 77.3 ± 8.1 kg) observed within our study compared to Jagim [223]. Additionally, we observed *very large* correlations between FFM and RMR ($r = 0.84$) and a *nearly perfect* relationship between FFM and BM ($r = 0.96$) compared to *moderate* correlations ($r = 0.45$) and *large* correlations ($r = 0.69$) observed by Jagim [223], respectively. Suggesting that, as BM increased within our group, RMR did not necessarily increase unless FFM was associated with the increase in BM, which could be another reason for the over-estimation by Jagim [223] and further justifies the importance of population-specific prediction equations.

It is also important to note that the non-team-sport-specific prediction equations [114-116] may have under-estimated RMR in our group due to our players likely being exposed to substantially greater training and sport-specific activities around RMR measurements compared to less active individuals. Aerobic exercise has demonstrated non-significant increases in RMR and resistance training has demonstrated significantly increased RMR measures [226]. Furthermore, the sport-specific activities of RU players involve high-intensity efforts (e.g., rapid accelerations and decelerations, high-speed running, and jumping), collisions (e.g., tackling, ball carrying, and colliding at breakdowns/rucks), and maximal-effort static exertions (scrumming and wrestling players in contact and at breakdowns/rucks) [1, 4]. These sporting activities observed in rugby have been shown to elevate levels of RMR [100, 184] and total daily energy expenditure [99].

Although every effort was carried out to ensure best-practice collection of RMR under stable conditions [112, 113], RU players may possess an elevated RMR due to training and sport-specific demands. This further promotes the need for assessing RMR within the specific population group or developing sport-specific prediction equations to determine RMR. Future studies could assess the RMR of professional RU players in the off-season period to determine if RMR levels change due to fewer sporting and training demands. However, the practical application of assessing or determining RMR in athletes is to optimise energy requirements for their specific goal, which makes collecting RMR in the pre- and in-season phases important. Furthermore, when examining RMR, it is also important to take note of which device is used to directly assess RMR, as differences in mean values between measuring devices have been reported [216] and may also lead to differences observed between prediction equations and measures.

Conclusion

The results of this study demonstrate the importance of measuring RMR within athletes and in particular, professional male RU players as RMR can vary greatly between individuals and may be substantially under- or over-estimated using prediction equations that were not developed for this population group. This could lead to inaccuracies and inefficiencies when determining energy requirements for individual players' nutrition goals and plans. Collecting or determining a more accurate measure of RMR may reduce the amount of initial energy adjustments required by the nutritionist and therefore lead to positive results sooner. If direct measures of RMR are difficult to obtain due to time or accessibility, the prediction equations developed within this study may be suitable for professional male RU players. If devices such as DXA are available to assess FFM, then the FFM-based equation should be used. However, if FFM is inconvenient to acquire due to limited access, the need for trained technicians, high cost, and limited time, then the BM-based equation should be used. Otherwise, developing team- or group-specific prediction equations is recommended.

CHAPTER NINE

In-Season Energy Demands of Elite Male Professional Rugby Union Players

Posthumus, L., Driller, M., Darry. K., Winwood, P., Rollo, I., & Gill, N. (2024). In-Season Energy Demands of Elite Male Professional Rugby Union Players. *(Under Review)*

Prelude

The previous studies carried out in Chapters Three to Eight provide reference values for body composition, macronutrient intake, and resting metabolic rate (RMR). Chapters Five and Eight also provide prediction equations to estimate body fat percentage (providing an estimation of fat-free mass [FFM]), and RMR to help optimise body composition and energy requirements. However, to inform energy requirements further, the exercise energy expenditure (EEE) from specific training sessions and game-play is required. Chapter Seven assessed FFM and determined relative energy intake per kg of FFM, which based on the findings suggest that some players may be at risk of low energy availability. Therefore, this was the first study to examine the EEE of all training sessions and game-play, alongside dietary intake and FFM assessment using Dual-energy X-ray Absorptiometry to determine energy availability and specific energy requirements for specific days, training sessions, and game-play during a competition week. This study also aimed to examine how body mass and skinfolds change over a four-week in-season period based on their measured state of energy availability.

Abstract

To optimise the health and performance of elite male professional rugby union players, understanding the energy demands for specific days and exercise sessions over a competition week is critical. Although the current literature has explored mean daily total energy expenditure, session-specific exercise energy expenditure requires further investigation. This study examined the daily and session specific energy demands over a competition week and analysed changes in body mass and skinfolds over a four-week in-season period among 24 elite male professional rugby union players, comprising 14 forwards and 10 backs. Body composition was assessed using Dual-energy X-ray Absorptiometry and resting metabolic rate was measured using indirect calorimetry. Total energy intake, exercise energy expenditure, and energy availability were recorded over a seven-day competition week and body mass and skinfolds were assessed four-weeks apart. Mean seven-day energy availability was significantly ($p < 0.05$) lower for forwards (29.4 ± 8.2 kcal·kg^{FFM}·day^{-1}) compared to backs (38.6 ± 6.3 kcal·kg^{FFM}·day^{-1}). The low and high energy availability groups demonstrated decreases (-0.5 kg) and increases (0.7 kg) in body mass, respectively, with both groups significantly ($p < 0.05$) reducing skinfolds (6.6 and 5.2 mm, respectively) following the four-week in-season period. Game-Day (GD) +1 resting metabolic rate was significantly ($p < 0.05$) higher than GD-3 among both forwards and backs. Significant differences ($p < 0.01$) in exercise energy expenditure were observed between various sessions, with game-play and high-field sessions showing higher energy demands than low-field and gym sessions. Notably, the greatest energy expenditures occurred on GD-4 and GD-2, where low mean energy availability was observed for forwards on both days. These findings suggest the need for tailored energy requirement strategies for professional rugby union players based on the significant differences in session and daily energy demands.

Keywords: dietary intake; fuelling; skinfolds; fat-free mass; team-sport; DXA.

Introduction

Determining the energy demands of training and game-play during a competition week in professional Rugby Union (RU) is important to optimise fuelling by appropriately matching energy intake and expenditure [75]. Ingesting sufficient energy to achieve greater outputs during training and drive adaptation in recovery from training will optimise the competition week and readiness for game-day (GD) [121]. Optimising the competition week is important both acutely for players performance on GD and chronically, given it needs to be replicated many times over the course of a competition period. Optimising this routine enables players to be in the best condition possible during the final rounds of competition when contending for championships [227].

Previous research among senior male professional [12] and male academy [66] RU players, has demonstrated mean daily total energy expenditures over six and 14-day in-season periods, respectively. However, energy expenditure has not been assessed on GD with a whole team or for specific training sessions during the week. Every week, day, and training session can be unique dependent on factors within a particular RU team and/or competition week. Determining how much energy is expended during different training sessions is valuable to inform dietary intakes appropriate to player demands and goals.

Training sessions during a RU competition week vary in intensity and modality which generally include gym and low and high intensity field sessions [12, 163, 197]. Low intensity field sessions (low-field) are generally learning and/or correction sessions performed at a slower pace and cover less distance than high intensity field sessions (high-field) [163, 197]. In contrast, high-field sessions generally involve executing rugby content at a faster pace and cover greater distances than low-field sessions [163, 197]. Portions of training within these high-field sessions are generally performed at or similar to game demands in terms of running load, but are lower in contact (collisions and impacts) compared to the game [170, 171].

Teams are likely to have their own categorisation for different types of field training sessions. Regardless, it is important to quantify the difference in movement and energy demands between types of field sessions to further inform energy and macronutrient requirements. Gym training sessions which include resistance training to develop various fitness characteristics [160], are also an integral part of the RU players competition week and may vary depending on the day of the week and the goal of the session. Therefore, energy demands for gym sessions are also required to determine total exercise energy expenditure (EEE).

Quantifying EEE during the week and collating alongside total energy intake (TEI) and fat-free mass (FFM), will help indicate each player's state of energy availability (EA). Determining EA is important to ensure players have energy reserves remaining at the end of the day (>40 $kcal \cdot kg^{\cdot FFM} \cdot day^{-1}$ for males) after EEE has been accounted for, to support optimal physiological function [228]. Assessing macronutrient intake alongside EEE is also important, given low carbohydrate intake relative to EEE has been shown to disrupt optimal physiological function independent of low energy availability (LEA) [62, 229-231]. Tracking body mass (BM) and skinfold changes among players in different states of EA would provide further insight into the relationships between dietary intake, EA, and body composition. Given previous research has demonstrated significant increases in resting metabolic rate (RMR) the day after a game compared to during the training week [100, 184], it is important to assess RMR during the training week (game-day [GD] -3) and the day after the game (GD+1) to better reflect changing energy demands.

Therefore, the aims of this study were to; a) examine the energy demands of elite male professional RU players during a competition week by measuring EEE from specific training sessions and game-play alongside dietary intake to provide EA; and b) compare RMR during the training week compared to post-game. It was hypothesised that significant differences in EEE would exist between different training sessions and game-play and that significant differences in EA would exist between different days and positions. It was also hypothesised that RMR would be significantly different between GD-3 and GD+1 among forwards and backs.

Methodology

Study Design

A cross-sectional study design was used to assess the in-season energy and macronutrient demands of elite male professional RU players during a seven-day competition week. The competition week (see Table 27) was categorised as days away from GD (GD-5, GD-4, GD-3, GD-2, GD-1, GD, GD+1), as previously described [163, 197]. All players underwent anthropometric (height, BM, sum of eight-site skinfolds [Sum8SF]) and body composition (FFM, fat mass [FM], body fat percentage [BF%], bone mineral content [BMC], and bone mineral density [BMD]) assessment one week prior to the start of the competition week. Four weeks later, BM and Sum8SF were assessed again. During the training week (GD-3) and the day after the game (GD+1), player RMR was assessed. During the seven-day competition week, all players were situated in a hotel where all meals and dietary supplements were catered for. All players within this study competed on GD, providing an accurate and reliable record of the energy and macronutrient demands in a competition week leading into and recovering from GD.

Table 27. Competition Week Overview.

Sessions	GD-5	GD-4	GD-3	GD-2	GD-1	GD	GD+1
Field Sessions	1	1	Rest & RMR	2	1	-	Rest & RMR
Gym Sessions	1	1		1		-	
Game	-	-		-	-	1	

GD = game-day and how many days prior (-) or after (+), RMR = resting metabolic rate.

Participants

Twenty-four male elite/world class [175] professional RU players from New Zealand participated in this study. Mean years of professional playing experience for all players was 9.1 ± 2.5 y. Players were grouped into their primary playing position comprising forwards (*n* = 14) and backs (*n* = 10). All players provided informed consent and the research was approved by the University of Waikato Human Research Ethics Committee (HREC 2019#04).

Anthropometrics and Body Composition

Each player underwent height, BM, Sum8SF and Dual-energy X-ray Absorptiometry (DXA) assessment with bladder voided following an overnight fast (> 8-hr) and in a rested state (> 12-hr) [164]. Using methods previously described [160], height was assessed using a portable stadiometer (SECA, Birmingham, UK) to 0.5 cm accuracy and BM was assessed using calibrated electronic scales (SECA, Birmingham, UK) to 0.1 kg accuracy. The Sum8SF were performed by a level 1 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist using Harpenden callipers (British Indicators, Herforshire, UK) to 0.1 mm accuracy. Measures were taken in duplicate from the right-hand side of the body at the following sites; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, mid-thigh, and medial calf [41, 159, 160, 163].

Body composition was assessed using total and regional body scans using a fan-beam DXA scanner (Hologic QDR Series, Discovery A, Bedford, MA, USA) following methods previously described [159] to provide FFM, FM, BF%, BMC, and BMD. All scans were performed and analysed by the same trained operator. Body composition measures using DXA were reported as whole-body and included the head. All anthropometric and body composition equipment were calibrated as recommended by the manufacturer's guidelines.

Resting Metabolic Rate

Resting metabolic rate was assessed in a temperature controlled (21-23 °C) and dimly lit hotel room using a breath-by-breath gas analyser (MetaLyzer 3B-R3, Cortex Biophysik GmbH, Leipzig, Germany). Players woke and had a short walk from their hotel room to the RMR assessment room situated on the same floor of the hotel and performed their RMR test in an overnight fasted (> 8-hr) and rested (12-hr) state with a 20-min rest period prior in a reclined seated position wearing a face mask (7450 Series Silicone v2, Hans Rudolph, KS, USA). The gas analyser calibration and methods were carried out as previously described [164].

Dietary Intake

Seven-day remote photographic food diaries (Snap-N-Send method) were used to examine daily and weekly energy and macronutrient intake as previously described [87, 163, 197]. Players used the smartphone application 'WhatsApp' to photograph what they consumed at every meal and/or drinking occasion and provided a description of what they consumed including any food brands, cooking methods, amounts where possible and items difficult to identify and/or quantify. The players sports nutritionist had two-way communication via WhatsApp and daily discussions to review the players food log and to ensure all entries were accounted for and correct. The photographic food diaries were then analysed and entered into the dietary analysis software FoodWorks (FoodWorks 10 Professional, Xyris, Australia) to provide TEI (kcal) and macronutrient (carbohydrate, protein, and fat) intakes.

Exercise Energy Expenditure

The EEE from gym, low-field, high-field, and the game were collected using Polar H10 heart rate monitors (Polar, H10, Kempele, Finland). During gym sessions, Polar H10 heart rate monitors were connected to a Polar H10 heart rate strap (Polar, H10, Kempele, Finland) and electrodes were moistened with water as recommended by the manufacturer, prior to being worn just below the players chest. Tracking of heart rate and EEE during the gym session began at the end of a general preparation to train window, until players had finished their prescribed programme.

During field sessions and game-play, the same Polar H10 heart rate monitors were connected to a STATSports heart rate conductive vest (STATSports, Newry, Northern Ireland) where the heart rate sensor was attached next to the players STATSports GPS unit (STATSports, Apex Pro Series, Newry, Northern Ireland) situated in the centre of the back between and slightly above the shoulder blades. Collection of heart rate, EEE and field duration began when training was scheduled to start which players and staff were notified with a whistle and team huddle. The Polar heart rate algorithm was used to estimate each player's EEE ($kcal \cdot day^{-1}$) and kilocalories per minute per kg of BM (KPM).

Energy Availability

The EA for each player was calculated as; TEI – EEE (kcal) / FFM (kg). The following thresholds (<30, 30-40, >40 $kcal \cdot kg^{FFM} \cdot day^{-1}$) were used to determine LEA, moderate EA (MEA) and high EA (HEA), respectively [22].

Movement Demands and Training Load

Movement demands/external load from field training sessions and game-play were analysed using GPS (STATSports, Apex Pro Series, Newry, Northern Ireland) to provide total distance, high-metabolic load distance (HMLD) and session duration for each player. All data was visually inspected to ensure no speed spikes or abnormal data was present, any abnormal data found was removed. Internal training load was assessed using heart rate to determine how each player responded to the demands of training and game-play. Following each session, session rate of perceived exertion (sRPE) was also collected to understand training load and the players subjective measure of intensity for the training sessions and game-play reported as arbitrary units (AU) as previously described [163, 197].

Statistical Analyses

Statistical analyses were conducted using SPSS v28. All data were tested for normality using the Shapiro Wilk test ($p > 0.05$). Independent sample *t*-tests were used to compare demographics, anthropometrics, body composition and mean seven-day energy and macronutrient measures between forwards and backs. Paired samples *t*-tests were used to compare RMR on GD-3 and GD+1 among forwards and backs. Repeated measures ANOVA was performed to determine whether any significant differences existed between GD and other days for energy and macronutrient measures. The energy, physiological and movement demands between different sessions were also analysed using a repeated measures ANOVA. Differences between EA groups were analysed using a one-way ANOVA with Bonferroni *post hoc*. Effect sizes were calculated using the Cohens *d* method with the following thresholds; *d* = *trivial* < 0.19, *small* 0.20-0.49, *medium* 0.50-0.79, and *large* > 0.80 [176]. Significance was set at $p < 0.05$.

Results

Training Load and Resting Metabolic Rate During the Competition Week

Total sRPE for the week was 4405 ± 448 and 4431 ± 463 AU among forwards and backs, respectively. Significantly ($p < 0.05$; $d = 1.64$-1.84) less total distance and HMLD was covered during the week by forwards (19.9 ± 3.7 km, 2152 ± 868 m) compared to backs (26.3 ± 4.2 km, 3836 ± 979 m), respectively. Both forwards ($p < 0.02$; $d = 1.44$) and backs ($p < 0.05$; $d = 2.34$) demonstrated significantly greater RMR on GD+1 (2946 ± 176 & 2659 ± 158 $\text{kcal}\cdot\text{day}^{-1}$, respectively) compared to GD-3 (2767 ± 114 & 2473 ± 124 $\text{kcal}\cdot\text{day}^{-1}$, respectively).

Comparison Between Different Training Sessions and Game-Play

Mean seven-day training session and game-play metrics are presented in Table 28 for both forwards and backs. High-field sessions possessed significantly ($p < 0.05$; $d = 1.50$-8.43) greater duration, energy, and movement demands compared to low-field sessions among both forwards and backs. Game-play possessed significantly ($p < 0.05$; $d = 1.14$-6.44) greater average heart rate and KPM compared to all other sessions among both forwards and backs. Forwards demonstrated significantly ($p < 0.01$; $d = 2.27$-2.62) lower total distance, HMLD, and KPM among all field sessions and game-play compared to backs.

Table 28. Mean training session and game-play metrics during the seven-day competition week among all forwards (n = 14) and backs (n = 10).

Variables	Position	Gym (3x Sessions)	Low-Field (3x Sessions)	High-Field (2x Sessions)	Game-Play (1x Game)
Duration (mins)	Forwards	55 ± 9^{a}	60 ± 21^{b}	107 ± 19^{abc}	72 ± 11^{c}
	Backs	55 ± 9^{a}	60 ± 21^{b}	107 ± 19^{abc}	84 ± 8^{c}
TD (km)	Forwards	-	$1.8 \pm 0.4^{ab*}$	$5.2 \pm 0.7^{ac*}$	$4.2 \pm 1.1^{bc*}$
	Backs	-	2.4 ± 0.4^{ab}	6.7 ± 0.6^{a}	5.7 ± 1.8^{b}
HMLD (m)	Forwards	-	$107 \pm 63^{ab*}$	$585 \pm 202^{a*}$	$663 \pm 277^{b*}$
	Backs	-	225 ± 85^{ab}	1031 ± 164^{a}	1100 ± 397^{b}
AvgHR (bpm)	Forwards	140 ± 3^{ad}	107 ± 7^{abc}	136 ± 10^{be}	174 ± 4^{cde}
	Backs	142 ± 3^{ad}	110 ± 8^{abc}	140 ± 9^{be}	170 ± 4^{cde}
MaxHR (bpm)	Forwards	181 ± 3^{ab}	173 ± 15^{cd}	191 ± 6^{ac}	192 ± 5^{bd}
	Backs	182 ± 3^{ab}	179 ± 13^{d}	191 ± 9^{a}	194 ± 4^{bd}
EEE ($kcal \cdot day^{-1}$)	Forwards	583 ± 86^{ab}	521 ± 66^{cd}	1477 ± 159^{ac}	1441 ± 244^{bd}
	Backs	520 ± 63^{ab}	539 ± 60^{cd}	1473 ± 116^{ac}	1525 ± 151^{bd}
KPM ($kcal \cdot kg \cdot min^{-1}$)	Forwards	0.090 ± 0.013^{a}	$0.074 \pm 0.010^{a*}$	$0.118 \pm 0.013^{a*}$	$0.170 \pm 0.014^{a*}$
	Backs	0.104 ± 0.018^{ab}	0.098 ± 0.011^{cd}	0.150 ± 0.011^{ace}	0.198 ± 0.014^{bde}

Mean ± standard deviation. GD = game-day, TD = total distance, HMLD = high-metabolic load distance, AvgHR = average heart rate, MaxHR = maximum heart rate, bpm = beats per minute, EEE = exercise energy expenditure, KPM = kilocalories per kilogram per minute. * Significant difference between forwards and backs. The letters *a,b,c,d,e* denote a significant difference ($p < 0.05$) from the other. KPM can be calculated as (KPM [factor] x body mass [kg] x duration [mins] = session kcal).

Player Characteristics and Mean Seven-Day Energy and Macronutrient Measures

Demographics, body composition, and mean seven-day energy and macronutrient measures can be observed in Table 29. Forwards demonstrated significantly ($p < 0.01$) greater BM, Sum8SF, FFM, FM, and BF% compared to backs. Mean EA was significantly ($p < 0.01$) lower for forwards compared to backs. Forwards demonstrated significantly ($p < 0.01$) lower relative macronutrient intakes compared to backs.

Table 29. Player characteristics and mean seven-day energy and macronutrient measures.

Variables	All (*n* = 24)	Forwards (*n* = 14)	Backs (*n* = 10)	Effect Size (Cohens *d*)
Demographics				
Age (yrs)	26.9 ± 3.2	27.2 ± 3.5	26.4 ± 2.8	0.26
Height (cm)	187.6 ± 8.2	189.7 ± 8.3	184.7 ± 7.4	0.63
Body Mass (kg)	107.1 ± 15.6	117.6 ± 9.6*	92.3 ± 8.9	2.70
Body Composition				
Sum8SF (mm)	67.5 ± 21.4	80.3 ± 19.0*	49.6 ± 6.3	2.03
Fat-Free Mass (kg)	89.8 ± 10.4	96.7 ± 5.5*	80.1 ± 7.5	2.60
Fat Mass (kg)	17.3 ± 6.0	20.8 ± 5.4*	12.3 ± 1.9	2.00
BF% (%)	15.8 ± 3.3	17.5 ± 3.2*	13.2 ± 1.2	1.66
Energy				
TEI ($kcal \cdot day^{-1}$)	4023 ± 666	3924 ± 810	4163 ± 387	-0.36
EEE ($kcal \cdot day^{-1}$)	1095 ± 94	1093 ± 112	1098 ± 66	-0.06
EA ($kcal \cdot kg^{FFM} \cdot day^{-1}$)	33.2 ± 8.7	29.4 ± 8.2 *	38.6 ± 6.3	-1.23
HEA >40 $kcal \cdot kg^{FFM} \cdot day^{-1}$	7	2	5	-
MEA 30-40 $kcal \cdot kg^{FFM} \cdot day^{-1}$	9	5	4	-
LEA <30 $kcal \cdot kg^{FFM} \cdot day^{-1}$	8	7	1	-
Macronutrient Intake				
Carbohydrate Absolute (g)	379 ± 80	370 ± 102	393 ± 31	-0.28
Protein Absolute (g)	249 ± 36	248 ± 41	251 ± 29	-0.10
Fat Absolute (g)	160 ± 25	155 ± 29	166 ± 17	-0.44
Carbohydrate Relative ($g \cdot kg^{BM}$)	3.7 ± 1.0	3.2 ± 1.0*	4.3 ± 0.5	-1.30
Protein Relative ($g \cdot kg^{BM}$)	2.4 ± 0.5	2.1 ± 0.4*	2.7 ± 0.4	-1.46
Fat Relative ($g \cdot kg^{BM}$)	1.5 ± 0.4	1.3 ± 0.3*	1.8 ± 0.3	-1.68

Mean ± standard deviation. Sum8SF = Sum of eight site skinfolds, BF% = body fat percentage, TEI = total energy intake, EEE = exercise energy expenditure, EA = energy availability, HEA = high energy availability, MEA = moderate energy availability, LEA = low energy availability.
* Significant difference between Forwards and Backs ($p < 0.01$).

Energy Availability Group Characteristics and In-Season Body Mass and Skinfold Changes

Demographics, mean seven-day dietary intake, and four-week in-season BM and Sum8SF changes for each EA group are presented in Table 30. The LEA group possessed significantly ($p < 0.05$) greater FM ($d = 1.28$, 1.96), $RMR^{GD\text{-}3}$ ($d = 2.14$, 2.25), and BM ($d = 2.68$, 2.10) compared to the MEA and HEA groups. Significantly ($p < 0.01$) greater FFM ($d = 1.87$), BF % ($d = 1.76$), BMC ($d = 1.57$), and Sum8SF ($d = 2.17$) were observed in the LEA compared to the HEA group. All EA groups were significantly ($p < 0.05$; $d = 2.05$-5.65) different to one another for EA, EB, and relative macronutrient intakes. Both LEA ($p < 0.01$; $d = 0.144$) and HEA ($p < 0.01$; $d = 1.77$) groups demonstrated significant decreases in Sum8SF following the observed 4-week in-season period. On an individual level, the percentage of players that increased BM in the HEA, MEA, and LEA groups were; 86, 78, and 38%, respectively. The greatest increase in BM for the HEA, MEA, and LEA groups were; 3.0, 4.0, and 0.5 kg, respectively. Meanwhile, the greatest decrease in BM for the HEA, MEA, and LEA groups were; -0.5, -1.7, and -3.1 kg, respectively.

Table 30. Energy availability group characteristics and changes in body mass and skinfolds over a four-week in-season period among all players (n = 24).

	Variables	LEA (n = 8)	MEA (n = 9)	HEA (n = 7)
Demographics	Forwards (n =)	7	5	2
	Backs (n =)	1	4	5
	Age (y)	25.8 ± 2.9	27.1 ± 3.5	27.9 ± 3.0
	Height (cm)	189.2 ± 8.4	189.5 ± 6.8	183.3 ± 9.0
	FFM (kg)	98.2 ± 5.5^{a}	89.1 ± 6.0	81.0 ± 12.2^{a}
	FM (kg)	22.7 ± 6.6^{ab}	16.2 ± 3.2^{a}	12.5 ± 2.8^{b}
	BF % (%)	18.5 ± 4.0^{a}	15.3 ± 2.1	13.3 ± 1.0^{a}
	BMC (kg)	4.0 ± 0.22^{a}	4.0 ± 0.26^{b}	3.6 ± 0.37^{ab}
	BMD (g/cm^2)	1.38 ± 0.06	1.39 ± 0.07	1.34 ± 0.07
	Clinical Site t-score	3.25 ± 1.41	3.34 ± 1.31	2.77 ± 0.58
	RMR^{GD-3}	2822 ± 97^{ab}	2612 ± 99^{a}	2484 ± 195^{b}
Dietary Intake	EA (kcal.kg^{FFM}·day^{-1})	23.0 ± 4.1^{a}	35.0 ± 3.1^{a}	42.8 ± 2.6^{a}
	Abs CHO (g·day^{-1})	300 ± 55^{ab}	407 ± 35^{a}	435 ± 80^{b}
	Abs Protein (g·day^{-1})	219 ± 30^{a}	254 ± 21	277 ± 33^{a}
	Abs Fat (g·day^{-1})	135 ± 19^{ab}	163 ± 11^{a}	183 ± 20^{b}
	Rel CHO (g·kg^{BM}·day^{-1})	2.5 ± 0.5^{a}	3.9 ± 0.5^{a}	4.7 ± 0.2^{a}
	Rel Protein (g·kg^{BM}·day^{-1})	1.8 ± 0.3^{a}	2.4 ± 0.2^{a}	3.0 ± 0.3^{a}
	Rel Fat (g·kg^{BM}·day^{-1})	1.1 ± 0.2^{a}	1.6 ± 0.2^{a}	2.0 ± 0.2^{a}
4-wk Changes	Pre-BM (kg)	120.9 ± 11.2^{ab}	105.3 ± 8.3^{a}	93.4 ± 14.9^{b}
	Post-BM (kg)	120.4 ± 10.3^{ab}	106.2 ± 8.9^{a}	94.1 ± 14.5^{b}
	Pre-Sum8SF (mm)	85.5 ± 19.8^{a*}	69.8 ± 18.3	51.9 ± 7.8^{a*}
	Post-Sum8SF (mm)	78.9 ± 17.7^{a}	66.2 ± 19.3	46.7 ± 6.4^{a}

Mean ± standard deviation. LEA = low energy availability (<30 kcal·kg^{FFM}·day^{-1}), MEA = moderate energy availability (30-40 kcal·kg^{FFM}·day^{-1}), HEA = high energy availability (>40 kcal·kg^{FFM}·day^{-1}), FFM = fat-free mass, FM = fat mass, BF % = body fat percentage, BMC = bone mineral content, BMD = bone mineral density, RMR = resting metabolic rate on game-day -3, EA = energy availability, Abs = absolute, Rel = relative, CHO = carbohydrate, BM = body mass, Sum8SF = sum of eight-site skinfolds. t-score > -1.0 = normal; t-score -1.1 to -2.4 = osteopenia; t-score < -2.5 = osteoporosis. The letters *a,b,c,d,e* denote a significant difference (p < 0.05) from the other.

Daily Total Energy Intake and Energy Availability

Mean daily TEI and EA for forwards can be observed in Figure 14a. Significant differences between days for TEI ($F(6, 78) = 22.52$, $p < 0.01$) and EA ($F(6, 78) = 6.09$, $p < 0.01$) among forwards were observed. Compared to GD, significantly lower TEI was observed on GD-3 ($p < 0.01$; $d = 1.50$) and GD+1 ($p < 0.01$; $d = 2.18$). Significantly lower EA was observed on GD-4 ($p = 0.01$; $d = 1.28$) compared to GD.

Mean daily TEI and EA for backs can be observed in Figure 14b. Significant differences between days for TEI, ($F(2, 20) = 24.23$, $p < 0.01$) were observed among backs. Significant ($p < 0.05$) differences were present for TEI on GD-3 ($p < 0.01$; $d = 1.11$), GD-2 ($p = 0.02$; $d = 0.89$), and GD+1 ($p < 0.01$; $d = 1.22$) compared to GD.

Daily Relative Macronutrient Intake

Mean daily relative carbohydrate, protein, and fat intakes for forwards can be observed in Figure 14c. Significant differences between days for relative carbohydrate ($F(6, 78) = 18.36$, $p < 0.01$) and relative protein ($F(6, 78) = 29.14$, $p < 0.01$) intakes were observed for forwards. Relative carbohydrate and protein intakes were significantly lower on GD-3 ($p < 0.01$; $d = 1.72$), GD-1 ($p < 0.01$; $d = 1.46$), and GD+1 ($p < 0.01$; $d = 2.26$) compared to GD for forwards. Mean daily relative carbohydrate, protein, and fat intakes for backs can be observed in Figure 14d. Significant differences between days for relative carbohydrate ($F(6, 54) = 22.66$, $p < 0.01$) intake was observed for backs. Relative carbohydrate intake was significantly lower on GD-3 ($p = 0.04$; $d = 1.05$) and GD+1 ($p = 0.02$; $d = 1.50$) compared to GD for backs.

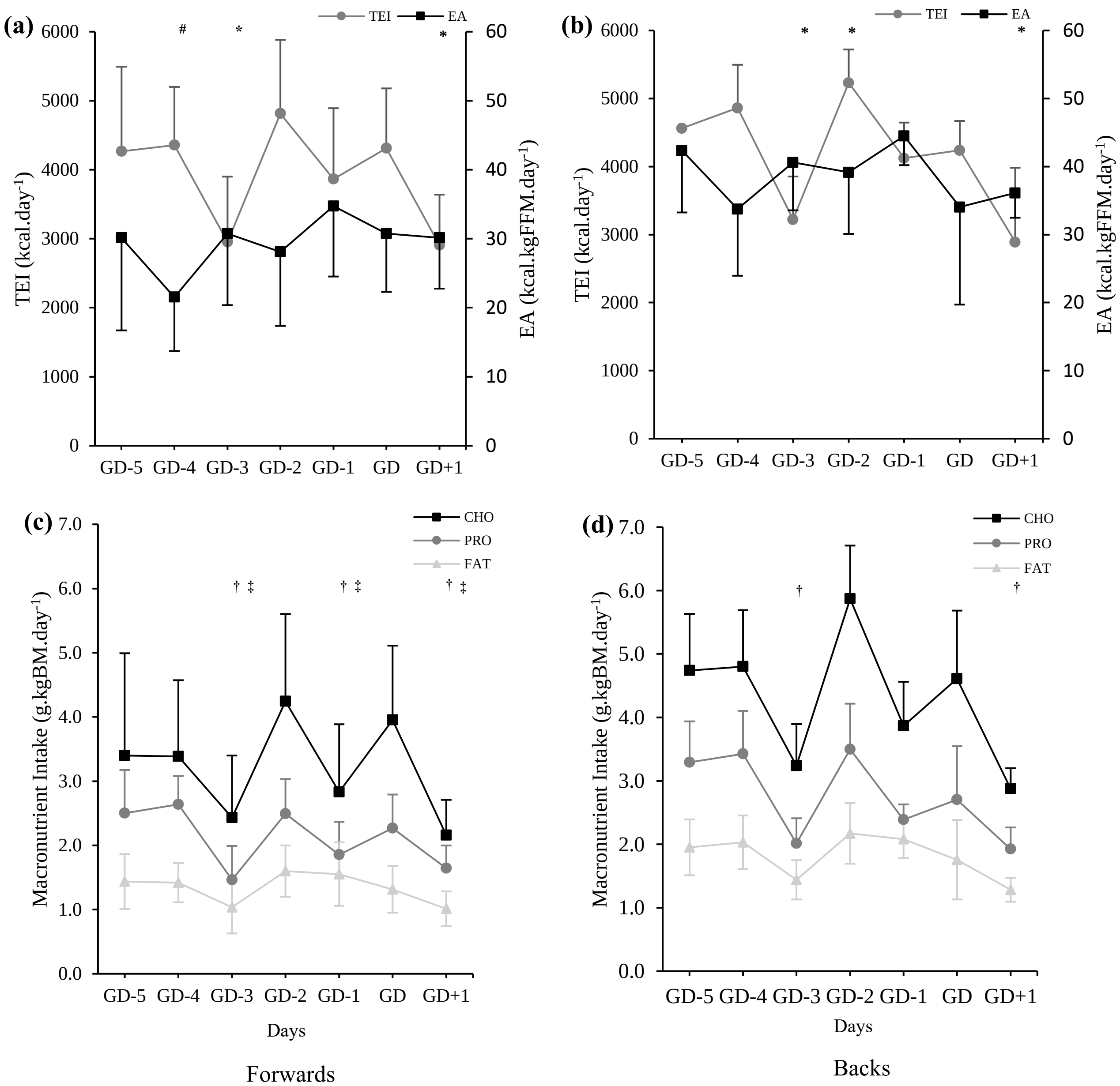


Figure 14. Differences between days for total energy intake (TEI), energy availability (EA), and macronutrient intake among forwards (a) and (c), respectively, and backs (b) and (d), respectively. *Significantly different TEI to game-day (GD) for forwards and backs. # Significantly different EA to GD for forwards. † Significantly different relative carbohydrate intake to GD for forwards and backs. ‡ Significantly different relative protein intake to GD for forwards. Error bars represent standard deviation. Significance was set at $p < 0.05$.

Discussion

This study was the first to assess the EEE of different training sessions and game-play during a competition week in elite male professional RU players. Furthermore, this is the first study to examine in-season EA among this population group and compare changes in BM and Sum8SF over a 4-week in-season period based on each players observed state of EA. The results of our study support our hypotheses whereby significant differences were present between sessions and positions for EEE, EA, and RMR. The heart rate, energy, and movement demands were significantly different between gym, low-field, high-field, and game-play. All EA groups demonstrated favourable changes in BM and Sum8SF over the 4-week in-season period. Significantly greater RMR was observed on GD+1 compared to GD-3 among both forwards and backs.

Previous research during the in-season among male professional RU players has demonstrated mean daily TEI of ~3965 and ~3343 kcal·day^{-1} for both forwards and backs, respectively [12]. Our study demonstrated a similar TEI (~3924 kcal·day^{-1}) among forwards, but, substantially greater TEI (~4163 kcal·day^{-1}) among backs. Backs within our study consumed a dietary intake that provided a higher TEI and a significantly greater relative carbohydrate, protein and fat intake compared to forwards, whereas other studies have generally reported greater intakes among forwards [12, 163, 197]. Evidently, forwards consumed a similar dietary intake to backs with energy and absolute carbohydrate, protein, and fat intakes being alike, but with greater variance observed among forwards. Because forwards possess significantly greater FFM compared to backs, this similar TEI puts them in a state of LEA. The same holds true for the lower relative macronutrient intakes compared to backs, given the significantly greater BM observed among forwards.

As a result, only two forwards were in a state of HEA and only five were in a MEA state with the remaining seven being in a state of LEA. Backs on the other hand, had five players in a HEA state, four in a MEA state, and only one player in a state of LEA. This resulted in ~40% of forwards and backs achieving a MEA state that is only recommended for short periods of time [22, 232]. The three lowest EA days during the competition week for both forwards and backs were GD-4, GD-2, and GD, all of which were the highest EEE days. As a group, forwards fell into LEA twice during the week (GD-4 and GD-2), whereas backs did not fall into LEA on any day. Interestingly, carbohydrate intake was higher on these lower EA days among both forwards and backs. It was evident that players were increasing carbohydrate intake on these days given the higher training load and intensity, however both positions still fell short of team-sport recommendations [126]. Higher carbohydrate intakes on the lowest EA days may alleviate some of the negative effects associated with LEA or MEA, given short-term periods of low carbohydrate intake may have greater negative effects on the body compared to or independent of LEA [229, 230].

Our previous research [163] suggested some players during the in-season may have lower than optimal levels of EA given the low energy observed (Forwards = 49.7 ± 7.9 $kcal \cdot kg^{FFM} \cdot day^{-1}$; Backs = 46.4 ± 8.3 $kcal \cdot kg^{FFM} \cdot day^{-1}$) relative to FFM without taking into account EEE. Elite male RU players have reported LEA (19.6 ± 11.4 $kcal \cdot kg^{FFM} \cdot day^{-1}$) during the pre-season period, where body composition changes are prevalent and generally prioritised [185]. Black et al. [185] reported a mean decrease in Sum8SF (7.5 ± 13.6 mm) for the whole group, with the weight loss group reducing Sum8SF (10.5 ± 5.9 mm) more than the weight maintenance (4.2 ± 4.9 mm), and weight gain (8.5 ± 4.9 mm) groups following their pre-season period.

Mean EA was considerably higher among our group (33.2 ± 8.7 $kcal \cdot kg^{FFM} \cdot day^{-1}$) compared to Black et al. [185]. Over the four-week in-season period, we observed increases in BM among both the MEA and HEA groups (+0.7 ± 1.1 and +0.9 ± 1.5 kg, respectively). As expected, the LEA group demonstrated a decrease in BM (-0.5 ± 1.2 kg). Similar to the weight loss, gain, and maintenance groups reported by Black et al. [185], all of our EA groups decreased Sum8SF, with the LEA group demonstrating the greatest loss (-6.6 ± 4.6 mm), followed by the HEA (-5.1 ± 2.9 mm) and MEA (-3.6 ± 4.9 mm) groups. Interestingly, the weight gain group from Black et al. [185] and the High EA group from our study, both demonstrated similar reductions in Sum8SF when compared to the weight loss and LEA groups, respectively. Future research may want to explore if this is associated with higher quality training and/or recovery due to greater EA and therefore, more optimal physiological function [22, 228, 232, 233].

Indeed, the LEA group predominantly comprised forwards (7 out of 8) with only one back in the group. Forwards are more likely to undergo body composition changes than backs given their greater BM and Sum8SF, where too higher measures may negatively affect fitness characteristics [160]. The weight loss group observed during the pre-season by Black et al. [185] consisted of five forwards and only one back, with this group being heavier and possessing significantly greater Sum8SF compared to the weight gain and weight maintenance groups [185]. In comparison, five out of the eight players in our study that were in the LEA group were aiming to achieve lower Sum8SF, all of which were forwards. The remaining three players in the LEA group were encouraged to meet energy requirements.

Taken together, these results demonstrate that players in a MEA to HEA state predominantly achieve increases in BM and a reduction in Sum8SF, while players in a state of LEA achieve considerable decreases in both BM and Sum8SF. Furthermore, when bone measures were compared between EA groups, no significant differences in BMD and clinical site t-scores were observed. However, greater BMC was observed for LEA and MEA groups compared to HEA, but this is due to the HEA group being made up of predominantly backs who typically possess lower BMC [160]. The LEA group also appeared to possess a relatively normal RMR [164], which was significantly higher than the MEA and HEA groups. Indeed, this appears due to the LEA group comprising mainly large forwards who have previously shown higher RMR [164].

When determining energy requirements, it is important to quantify EEE for each type of session, given the significant differences observed between different training sessions and game. Our daily EEE on (GD-4 and GD-2) were 2246 ± 178 and 2125 ± 217 kcal, respectively which was lower than a pre-season study (3015 ± 918 kcal.day-1) in NZ [185]. Higher EEE and training loads are expected during pre-season periods [13], which may explain the greater outputs observed by Black et al. [185]. However, it is difficult to compare session EEE given specific session duration and EEE were not reported. Given significant increases in RMR were observed on GD+1 compared to GD-3 among forwards and backs, similar to previous works [100, 184], factoring these additional energy requirements are important for enhancing recovery.

During game-play, a previous study reported a TD (6.7 km and 7.2 km) and EEE (8.2 MJ [1959 kcal] and 6.9 MJ [1648 kcal]) for each forward (n = 1) and back (n = 1), respectively [7]. This was greater than the mean TD and EEE we observed among our group of forwards (n = 14) and backs (n = 10), even though near identical average heart rates (~172 bpm) were observed during the game between studies. One of our forwards from a similar position (blind-side flanker [no. 6]) who weighed 118 kg and played the entire game (89-min total time on field) achieving 1141 m of HMLD, demonstrated lower EEE (1729 kcal) and TD (6.2 km) compared to Cunniffe et al. [7]. More similar results were observed when comparing one of our backs from a similar position (first-five-eighth [no.10]) who weighed 85 kg and played the entire game (89-min total time on field) achieving 1536 m of HMLD, demonstrated a marginally lower EEE (1581 kcal) and TD (6.9 km) compared to Cunniffe et al. [24].

During semi-professional rugby league game-play, players (*n* = 17) with a mean BM of 90.2 ± 9.6 kg have also reported greater mean EEE (7.9 MJ [1887 kcal]) [108] compared to our results. Relative to BM and minutes played, both Cunniffe et al. [7] and Coutts et al. [108] demonstrated 0.206 (0.862 kj·kg·min^{-1}) and 0.226 (0.946 kj·kg·min^{-1}) kcal·kg·min^{-1} during game-play. These are higher than our findings among both forwards (0.170 kcal·kg·min^{-1} [0.71 kj·kg·min^{-1}]) and backs (0.198 kcal·kg·min^{-1} [0.83 kj·kg·min^{-1}]). All of these expenditures are substantially higher than what has been reported in football (0.146 kcal·kg·min^{-1} [0.61 kj·kg·min^{-1}]) [234] and Australian football (0.136-0.158 kcal·kg·min^{-1} [0.57-0.66 kj·kg·min^{-1}]) [110, 235] game-play.

When comparing high-field training sessions, we observed expenditures of 0.118 ± 0.013 kcal·kg·min^{-1} (0.49 kj·kg·min^{-1}) for forwards, and 0.150 ± 0.011 kcal·kg·min^{-1} (0.63 kj·kg·min^{-1}) for backs. Whereas, AFL players have reported expenditures of 0.100 ± 0.019 kcal·kg·min^{-1} (0.42 ± 0.08 kj·kg·min^{-1}) during team training [110]. The main training session duration among AFL players was 66-83 mins compared to our two main high-field sessions, which were 107 ± 19 mins. Although AFL and RU backs have a greater running profile than RU forwards, a lot of energy is expended by forwards during relatively stationary high-effort exertions which include; scrummaging, tackling/wrestling, explosive line-out manoeuvres with jumping, lifting, mauling, interspersed with intermittent-running. This is how forwards achieve similar average and maximum heart rate measures and in turn, EEE compared to backs, despite the significant difference in TD and HMLD across all sessions. Previous research has suggested that HR-based EEE is over-estimated in team-sports compared to metabolic power calculations [110], however it has also been suggested that metabolic power under-estimates EEE [111].

A limitation within our study was not being able to validate EEE with a gold standard method to determine how much under- or over-estimation was present. However, because the players' changes in BM and Sum8SF generally changed based on the players state of EA, we can assume that these energy requirements were acceptable for this group. However, not being able to measure hormonal markers of EA was another limitation as this would have provided additional factors to help determine EA. Given that each players dietary intake, EEE, and EA was only assessed during the first two weeks of the four-week observational period for BM and Sum8SF changes, the players state of EA also present limitations as fuelling habits may have fluctuated during this time. However, each player was monitored and supported during the entire period to ensure similar fuelling habits were being achieved based on training outputs. Additionally, players were in a hotel environment, with the same training schedule, training load, and catered food environment across the four-week period so each athlete could achieve consistent habitual practices. Although error will be present among our EEE data, being able to estimate EEE from each session may provide better estimates than daily estimations of TEE based on physical activity level factors alone. This is because daily EEE can fluctuate largely based on the number of sessions (including type and duration) scheduled, and the players position and BM.

Conclusion

In conclusion, forwards were more likely than backs to have inadequate EA during the competition week, particularly on GD-4 and GD-2. Despite efforts to increase carbohydrate intake on these higher training load days (GD-4 and GD-2), forwards still consumed less carbohydrate than backs and below quantities recommended for high training load days in team-sport athletes. All EA groups showed favourable reductions in Sum8SF over the four-week observation period. Both the MEA and HEA group gained BM, while the LEA group had the largest reductions in both Sum8SF and BM. Considering the type, duration, and intensity of training and game-play is essential for determining energy demands, given the significant differences observed across different sessions and days during the competition week. This aids the practitioner with average energy demands for different sessions types, particularly if EEE is unable to be measured, enhancing individual/positional programming. Further support for GD+1 RMR assessments and/or increased fuelling above baseline to optimise recovery after game-play are recommended.

CHAPTER TEN

General Summary

Body composition and nutrition play a vital role in both health and sporting performance. Optimising energy and macronutrient requirements can enhance an athlete's preparation, performance, and recovery from training and competition. However, the body composition and nutrition requirements of New Zealand (NZ) professional rugby union (RU) players is limited. Professional RU is unique given the considerable position specific differences and the varied styles of game-play different teams and/or regions express. This thesis carried out seven studies which have enhanced the understanding of the physical characteristics and fuelling requirements of professional male RU players from NZ and have enhanced strategies commonly used to optimise body composition and nutrition prescription among this group of athletes. This study also has provided further understanding regarding the physical characteristics of elite female RU players from NZ. This chapter presents a summary of the main findings for each study presented in the thesis. The practical applications and limitations of the thesis are considered and suggestions for future research are presented.

Study One: Physical and Fitness Characteristics of Elite Male Professional Rugby Union Players

To the best of our knowledge, this was the first study to examine the relationships between the physical (body composition measures) and fitness characteristics (strength, power, speed, and aerobic fitness tests) among elite male professional RU players.

- Forwards were substantially bigger and stronger in all areas and possessed greater absolute power compared to backs. In contrast, backs were leaner, faster, aerobically fitter, and possessed greater relative power and broad jump distance.
- Both forwards and backs within this study were taller, heavier, and leaner than players from previous studies in the northern hemisphere.
- Among forwards, Sum8SF demonstrated *very large* correlations with relative power and sprint measures. Fat mass and BF% demonstrated *very large* correlations with sprint and aerobic fitness measures among forwards.

- Backs demonstrated *large* correlations between Sum8SF and aerobic fitness. For BM, lean mass, and fat mass, *large* to *very large* correlations were observed with strength and relative power measures.
- Leaner forwards possess more favourable fitness characteristics, however, too much BM, regardless of composition may lead to decreased power, slower sprint times, and lower aerobic fitness.
- Greater Sum8SF relate to slower sprint times and less Yo-Yo distance and therefore lower aerobic fitness.

This study demonstrated that Sum8SF, fat mass, and BF% relate strongly with key fitness characteristics required for elite male professional RU performance. It also provides primary position benchmarks for developing RU players from NZ.

Study Two: The Physical Characteristics of Elite Female Rugby Union Players

To the best of our knowledge this was the first study to assess the body composition characteristics of elite female RU players using Dual-energy X-ray Absorptiometry (DXA), and the first to explore differences between forward and back positional groups (Tight-Five, Loose-Forwards, Inside-Backs, Outside-Backs).

- Forwards were significantly taller, heavier, and possessed greater Sum8SF than backs.
- Forwards possessed significantly greater total and regional body composition measures compared to backs.
- Forwards presented greater bone mineral density across all sites with significant differences observed at the arms and femoral-neck compared to backs.
- Only forward positional groups demonstrated significant differences, with Tight-Five possessing significantly greater anthropometric, total, and regional body composition measures compared to Loose-Forwards. These findings suggest that positional groups among backs are more homogeneous than among forward positional groups. Therefore, more individualised training and nutrition programming may be required for forwards compared to backs.
- The percentage difference for anthropometric and total body composition measures between forwards and backs within elite females were very similar to elite males. These

findings suggest that regardless of sex, RU may produce similar positional differences in relation to anthropometrics and body composition.

- Bone mineral density values were all in normal range and does not appear to be a concern within this group of elite female athletes. However, further longitudinal tracking is required to monitor changes.

This study demonstrated that specific programming and monitoring for forwards and backs, particularly within forward positional groups, appear important due to such physical characteristic differences.

Study Three: Position Specific Anthropometrics and Body Composition Among Professional Male and Female Rugby Union Players

The anthropometric and body composition characteristics among professional RU forwards and backs is well documented. However, position specific characteristics and practical measures to predict BF% require further investigation. The aims of this study were to; assess the position specific anthropometric and body composition characteristics of elite and sub-elite male and female RU players and to develop a BF% prediction equation for both groups using Sum8SF. To the best of our knowledge, this was the first study to assess the differences in body composition between specific playing positions and between playing levels among professional male and female RU players using DXA and Sum8SF.

- Elite players demonstrated significantly higher levels of lean mass than sub-elite players.
- Props and Locks were the heaviest and tallest of the forwards, respectively.
- Midfielders were generally taller, heavier, and possessed the greatest lean mass, fat mass, and bone mineral content compared to all other back positions.
- Although Hookers are positioned in the Front-Row, they demonstrate significantly lower Sum8SF and BM than Props among males.
- Among females, Hookers were not significantly different to Props even though they were significantly lighter.
- Among both male and female backs, although significant differences were present between for BM, no significant were present for Sum8SF, suggesting both male and female back positions are more homogenous than forward positions regarding Sum8SF.

- Relationships between BF% and Sum8SF were *large* among female backs and *very large* among male and female forwards and backs.
- The development of a BF% prediction equation using Sum8SF for male forwards and backs, and female forwards and backs was created.
- The mean accuracy percentage for male forwards and backs was 93 and 94%, respectively.
- The mean accuracy percentage for female forwards and backs was 94 and 91%, respectively.
- Of the 56 male forwards, 45 (80%) were predicted within 10% of measured values and of the 48 male backs, 40 (83%) were predicted within 10% of measured values.
- For female forwards, 32 out of 37 (87%) were predicted within 10% of measured values and 27 out of 38 female backs (71%) were predicted within 10% of measured values.
- Female backs appear to demonstrate less accuracy when using Sum8SF to predict BF%.

This study provided position specific physical characteristics for male and female RU players and the newly developed BF% prediction equations and conversion (Table 16, Chapter Five) can help practitioners more easily and conveniently predict BF% from Sum8SF measures.

Study Four: Competition Nutrition Practices of Elite Male Professional Rugby Union Players

This study was the first to report the dietary intakes of elite male professional RU players on game-day, including food intake prior to kick-off, pre-game meal, and post-game dietary intakes and how game-day compares to other days during the competition week.

- Mean seven-day absolute energy intake was significantly higher for forwards (4606 ± 719 kcal·day^{-1}) compared to backs (3761 ± 618 kcal·day^{-1}).
- Forwards demonstrated significantly higher mean seven-day absolute macronutrient intakes compared to backs, but no significant differences were observed for mean seven-day carbohydrate, protein, and fat intakes.
- Mean seven-day relative carbohydrate intake for forwards and backs were ~3.6 ± 0.8 g·kg·day^{-1}.
- Mean seven-day relative protein intake for forwards and backs were ~2.5 ± 0.5 g·kg·day^{-1}.

- Mean seven-day relative fat intake for forwards and backs were ~1.8 ± 0.5 $g \cdot kg \cdot day^{-1}$.
- Both forwards and backs reported their highest energy (5223 ± 864 vs 4694 ± 784 $kcal \cdot day^{-1}$) and carbohydrate 4.4 ± 1.2 vs 5.1 ± 1.0 $g \cdot kg \cdot day^{-1}$) intakes on game-day, with ~62% of total kcal being consumed prior to kick-off.
- Mean pre-game meal (3-4-hr prior to kick-off) consumption for all players was 1.4 ± 0.5 $g \cdot kg^{-1}$ carbohydrate, 0.8 ± 0.2 $g \cdot kg^{-1}$ protein, and 0.5 ± 0.2 $g \cdot kg^{-1}$ fat.
- On game-day, from the players first meal until kick-off, ~3363 ± 759 kcal was consumed by forwards and ~1860 ± 601 kcal was consumed post-game. For backs, 2786 ± 496 kcal was consumed prior to kick-off and 1908 ± 661 kcal was consumed post-game.
- Within the ~3-hr eating window post-game, players were near suggested refuelling requirements with ~1-1.2 $g \cdot kg^{-1}$ of carbohydrate consumed immediately after the game followed by another ~0.5-1 $g \cdot kg^{-1}$ of carbohydrate an hour later, accompanied by ~1.1 $g \cdot kg^{-1}$ of protein.
- Energy intake on was higher the day after the game (GD+1) compared to the day off during the week (GD-3).
- Players fell short of daily sports nutrition guidelines for carbohydrate and appeared to "eat to intensity" by increasing or decreasing energy and carbohydrate intake based on the training load they were being exposed to.
- Despite recommendations and continued education, many rugby players select what would be considered a "lower" carbohydrate intake.
- During the seven-day competition week, forwards covered a total distance of 20.2 ± 3.4 km and backs covered a total distance of 25.7 ± 3.9 km, which was substantially higher than previous studies in professional RU.
- During the seven-day competition week, session rate of perceived exertion was 4357 ± 469 arbitrary units for forwards and 4416 ± 449 arbitrary units for backs.

Study Five: Dietary Intakes of Elite Male Professional Rugby Union Players in Catered and Non-Catered Environments

In professional RU, it is common for players to switch between catered and non-catered dietary environments throughout a season. This was the first study to compare the dietary intake of elite male professional RU players during the competition weeks in both catered and non-catered environments.

- No significant differences were observed in relative carbohydrate intake between catered and non-catered environments among forwards and backs ~3.5 $g{\cdot}kg{\cdot}day^{-1}$.
- Forwards reported significantly greater mean seven-day absolute energy intake in a catered (5210 ± 674 $kcal{\cdot}day^{-1}$) compared to non-catered environment (4341 ± 654 $kcal{\cdot}day^{-1}$).
- Forwards demonstrated significantly greater relative protein (2.8 ± 0.3 vs 2.3 ± 0.3 $g{\cdot}kg{\cdot}day^{-1}$) and relative fat (2.1 ± 0.3 vs 1.5 ± 0.3 $g{\cdot}kg{\cdot}day^{-1}$) intakes in a catered compared to a non-catered environment, respectively.
- Backs demonstrated higher energy and macronutrient intakes within a catered compared to a non-catered environment, however, no significant differences were present.
- When energy intake was expressed relative to fat-free mass (FFM), our results suggested that some players may be at risk of low energy availability (LEA). This is due to players in a catered environment only achieving ~50-55 $kcal{\cdot}kg^{FFM}{\cdot}day^{-1}$ and ~40-45 $kcal{\cdot}kg^{FFM}{\cdot}day^{-1}$ in a non-catered environment, prior to factoring in exercise energy expenditure (EEE).
- Number of meals per day were 5.2 ± 0.6 and 5.1 ± 0.8 among forwards in a catered compared non-catered environment, respectively. For backs, number of meals per day were 4.9 ± 0.3 and 4.6 ± 0.7 in a catered compared to non-catered environment.
- Fibre intakes were considerably higher in a catered environment compared to a non-catered environment among both forwards and backs.

Forwards and backs within a non-catered environment may be at greater risk of being in a state of LEA, however, those in a catered environment still need to be diligent with their dietary intake strategies. More similar dietary intakes were observed among backs regardless of the catering environments. Forwards may require more support and/or attention when transitioning between catered and non-catered environments to ensure that recommended dietary intakes are being achieved. For teams, that have players subject to both catered and non-catered environments during the season, it may be beneficial to compare dietary intakes within each environment to optimise and align nutritional habits to meet appropriate nutritional needs.

Study Six: The Development of a Resting Metabolic Rate Prediction Equation for Professional Male Rugby Union Players

Determining resting metabolic rate (RMR) is an important aspect when calculating energy requirements for professional RU players. Prediction equations are often used for convenience to estimate RMR. However, the accuracy of current prediction equations for professional RU players was unclear. This study compared nine commonly used prediction equations to measured values, then developed and validated an FFM- and BM-based prediction equation specific to professional RU players.

- Mean RMR values of 2585 ± 176 kcal·day^{-1} were observed among the group.
- Forwards demonstrated significantly higher (2706 ± 94 kcal·day^{-1}) RMR compared to backs (2465 ± 156 kcal·day^{-1}).
- Compared to measured RMR for the group, seven of the nine commonly used prediction equations significantly under-estimated RMR (-104-346 kcal·day^{-1}) and one equation significantly over-estimated RMR (192 kcal·day^{-1}).
- The strongest predictor of RMR for this group was FFM alone (R^2 = 0.70; SEE = 96.65), followed by BM alone (R^2 = 0.65; SEE = 104.97).
- We observed *very large* correlations between FFM and RMR, and a nearly perfect relationship between FFM and BM.
- As BM increased within our group, RMR did not necessarily increase unless FFM was associated with the increase in BM.
- Newly developed FFM RMR Prediction Equation (kcal·day^{-1}) = 1351.74 + (14.53 x FFM in kg).
- Newly developed BM RMR Prediction Equation (kcal·day^{-1}) = 1489.93 + (10.63 x BM in kg).
- Following *k*-fold (*k* = 10) cross-validation, no significant differences were present between measured RMR and the newly developed prediction equations.
- Very *large* relationships were observed between measured RMR and the newly developed FFM- and BM-based prediction equations.
- The newly developed FFM-based prediction equation demonstrated marginally better mean absolute percentage error (3.2 ± 2.4% vs 3.4 ± 2.7%), R^2 = 0.69 vs 0.68), and root-mean squared error (98 vs 105 kcal·day^{-1}) than the BM prediction equation when compared to measured RMR.

Measuring RMR within a group of professional male RU players is important, as current prediction equations may under- or over-estimate RMR. If direct measures of RMR cannot be obtained, we propose the newly developed prediction equations be used to estimate RMR within professional male RU players. Otherwise, developing team- and/or group-specific prediction equations is encouraged.

Study Seven: **In-Season Energy Demands of Elite Male Professional Rugby Union Players**

To optimise the health and performance of elite male professional RU players, understanding the energy demands for specific days and exercise sessions over a competition week is critical. While earlier studies explored mean daily total energy expenditure, session specific EEE required further investigation. This study was the first to assess the EEE of different training sessions and game-play during a competition week in elite male professional RU players. This was also the first study to examine in-season EA among this population group and compare changes in BM and Sum8SF over a four-week in-season period based on each players observed state of EA.

- Mean seven-day energy availability was significantly lower for forwards (29.4 ± 8.2 $kcal \cdot kg^{FFM} \cdot day^{-1}$) compared to backs (38.6 ± 6.3 $kcal \cdot kg^{FFM} \cdot day^{-1}$).
- Mean total energy intake was highest on GD-2 compared to all other days among both forwards and backs.
- Mean relative carbohydrate intake was also highest on GD-2 compared to all other days among both forwards and backs.
- The LEA group demonstrated decrease in BM of -0.5 kg and a decrease of 6.6 mm for Sum8SF following the four-week in-season period.
- The moderate energy availability (MEA) group gained 0.9 kg of BM and decreased 3.6 mm of Sum8SF over the four-week in-season period.
- The high energy availability (HEA) group demonstrated an increase in BM of 0.7 kg and a decrease of 5.2 mm for Sum8SF) following the four-week in-season period.
- The LEA group contained seven forwards and only one back, the MEA group contained five forwards and four backs, and the HEA group contained two forwards and five backs.

- No significant difference existed between energy availability groups for bone mineral density.
- The LEA and MEA groups demonstrated significantly greater bone mineral content compared to the HEA group. However, this seems to be due to the LEA and MEA groups containing more forwards, who are larger than backs, and therefore possess greater bone mineral content.
- Mean RMR among the LEA group appeared normal. The LEA group demonstrated significantly higher RMR compared to both the MEA and HEA groups, however similar to bone mineral content, this is most likely due to the LEA group comprising mainly large forwards who have previously shown significantly higher RMR than backs (Study Six, Chapter Eight).
- All EA groups had significantly different mean seven-day EA from one another, with LEA, MEA, and HEA groups reporting; 23.0 ± 4.1, 35.0 ± 3.1, 42.8 ± 2.6 $kcal \cdot kg^{FFM} \cdot day^{-1}$, respectively.
- All EA groups demonstrated significantly different mean seven-day relative macronutrient intakes to one another.
- The LEA (98.2 ± 5.5 kg) group possessed significantly greater FFM compared to the HEA group (81.0 ± 12.2 kg).
- The LEA group also possessed significantly greater BF% compared to the HEA group.
- On GD-4 and GD-2 forwards were in a state of LEA (<30 $kcal \cdot kg^{FFM} \cdot day^{-1}$). Interestingly, relative carbohydrate intake was highest on these days and GD.
- Mean EA for backs did not fall below 30 $kcal \cdot kg^{FFM} \cdot day^{-1}$ on any day during the competition week. Similar to forwards, backs reported their highest relative carbohydrate intakes on GD-4 and GD-2.
- Among forwards, RMR the day after the game (GD+1 = 2946 ± 176 $kcal \cdot day^{-1}$) was significantly higher than on a rest/recovery day three-days prior to the game (GD-3 = 2767 ± 114 $kcal \cdot day^{-1}$).
- For backs, RMR on GD+1 (2659 ± 158 $kcal \cdot day^{-1}$) was significantly higher than on GD-3 (2473 ± 124 $kcal \cdot day^{-1}$).
- Total distance for Low-Field (1.8 ± 0.4 & 2.4 ± 0.4 km), High-Field (5.2 ± 0.7 & 6.7 ± 0.6 km), and Game-Play (4.2 ± 1.1 & 5.7 ± 1.8 km) were significantly lower among forwards compared to backs, respectively.

- High metabolic load distance for Low-Field (107 ± 63 & 225 ± 85 m), High-Field (585 ± 202 & 1031 ± 164 m), and Game-Play (663 ± 277 & 1100 ± 397 m) was significantly lower among forwards compared to backs, respectively.
- Average Heart Rate for Gym (140 ± 3 & 142 ± 3 bpm), Low-Field (107 ± 7 & 110 ± 8 bpm), High-Field (136 ± 10 & 140 ± 9 bpm), and Game-Play (174 ± 4 & 170 ± 4 bpm) were reported among forwards and backs, respectively.
- No significant differences between forwards and backs, were observed regarding mean EEE for Gym (583 ± 86 & 520 ± 63 kcal·day^{-1}), Low-Field (521 ± 66 & 539 ± 60 kcal·day^{-1}), High-Field (1477 ± 159 & 1473 ± 116 kcal·day^{-1}), and Game-Play (1441 ± 244 & 1525 ± 151 kcal·day^{-1}), respectively.
- KPM for Gym (0.090 ± 0.013 & 0.104 ± 0.018 kcal·kg·min^{-1}), Low-Field (0.074 ± 0.010 & 0.098 ± 0.011 kcal·kg·min^{-1}), High-Field (0.118 ± 0.013 & 0.150 ± 0.011 kcal·kg·min^{-1}), and Game-Play (0.170 ± 0.014 & 0.198 ± 0.014 kcal·kg·min^{-1}) were reported among forwards and backs, respectively. Backs demonstrated significantly higher KPM for Low-Field, High-Field, and Game-Play compared to forwards.

The results of this study reported that forwards were more likely than backs to have inadequate EA during the competition week, particularly on GD-4 and GD-2. Despite efforts to increase carbohydrate intake on these higher training load days, forwards still consumed less than backs and were below recommended levels for team-sport athletes. All EA groups showed favourable reduction in Sum8SF over the four-week observation period. Both the MEA and HEA groups gained BM, while the LEA group had the largest reductions in both Sum8SF and BM. The findings from this study demonstrate that; considering the type, duration, and intensity of training, and game-play is essential for determining energy demands, given the significant differences observed across different sessions and days during the competition week. This aids the practitioner with average energy demands (AED) for the different session types, which is particularly useful if EEE is unable to be measured, enhancing individual/positional programming. When determining energy requirements on GD+1, extra fuel may be required given the increased RMR levels on GD+1 compared to GD-3, which previous research has suggested is most likely due to the collision demands of game-play.

Practical Applications

The following recommendations have been developed from the research in this thesis:

- The promotion of FFM and minimisation of fat mass among professional RU players is critical given the significant differences observed between playing levels.
- Both the assessment and monitoring of fat mass, BF%, and Sum8SF are important among professional RU players given the *large* and *very large* relationships these measures have with fitness characteristics.
- Reducing fat mass, BF%, and Sum8SF may improve speed, power, and aerobic fitness measures among professional RU players, given the strong correlations observed between physical and fitness characteristics.
- Examining body composition by specific playing position is important due to the considerable differences between positions. Particularly, forwards are more heterogenous than backs among both professional male and female players. Therefore, forwards may require more individual/specific programming.
- Skinfold measures relate strongly with DXA and are therefore still an affordable, convenient, and time-efficient tool for assessing body composition among professional RU players if DXA is not required or difficult to obtain.
- Skinfold prediction equations to develop BF% and in turn, FFM, should be implemented in the specific groups of interest with the same laboratory- and field-based machines/measures to ensure the most accuracy and practicality. Practitioners can then establish position norms and or refence tables to determine FFM and/or Sum8SF from one another.
- Professional RU players can "eat to intensity" or better known in the literature as "fuel for the work required', whereby more energy and carbohydrate intake is increased on more intense training days, less on lower intensity days and rest/recovery days, and perform at a high-level whilst establishing relatively high FFM and low BF%.
- Establishing RMR among the specific population group of interest is important given the significant differences that can exist between measured RMR and predicted RMR when using equations that were developed in cohorts that do not reflect the group being assessed.
- Professional RU players should aim to enhance fuelling on GD and may consume ~62% of their days intake prior to kick-off to ensure fuel stores are appropriately topped up.

- Although below team-sport recommendations, professional RU players appear to achieve mean relative carbohydrate intakes of ~4-6 $g \cdot kg \cdot day^{-1}$ on intense-training days and GD, and still perform at the highest levels. However, as our findings show, these are mean intakes, some individuals achieve much higher outputs than others and therefore, individual requirements are important to promote.
- Professional RU players may need to fuel better in non-catered environments to better meet the energy demands of the sport. Some players in catered environments also need to be diligent with their fuelling strategies and may require further nutrition education.

This study provides enhanced strategies to optimise body composition and fuelling requirements among professional RU players if the use of laboratory-based equipment or assessment is not available or feasible. It provides a BF% prediction equation based off total Sum8SF, which can be used to determine BF%, and ultimately FFM with an additional calculation based on the players BM. It also provides FFM- and BM-based prediction equations to estimate RMR among professional RU players, with the FFM-based equation being the preferred method as it was the most accurate during development. However, if FFM cannot be obtained due to limited access to a device like DXA or a practitioner who can accurately assess Sum8SF, then the BM-based equation can be used. Lastly, average energy demands are provided through a kcal per minute (KPM ($kcal \cdot kg \cdot min^{-1}$)) factor among forwards and backs for Gym, Low-Field, High-Field, and Game-Play. This can assist in the profiling of energy requirements based on the type and duration of training sessions, as well as the players position and BM. A schematic outlining an example case study for a professional RU forward and back is presented in Figures 15 and 16, respectively, demonstrating how these methods can be practically applied.

Example of Male Professional RU Forward

Bodyweight = 107 kg
Sum8SF = 70 mm
Gym Session = 1x 60 min
Low-Field Session = 1x 45 min
High-Field Session = 1x 90 min
Energy Intake = 5500 kcal·day^{-1}

Determine RMR

If **NO** Indirect-Calorimetry, use Posthumus^{FFM} RMR Prediction Equation

If **NO** DXA, use Sum8SF Prediction Equation for BF%, then FFM

If **NO** DXA / Sum8SF, use Posthumus^{BM} RMR

Determine FFM

Enter Sum8SF into **Forwards BF%** Prediction Equation

BF% Equation = 10.374 + (0.101 x ***Sum8SF (mm)****)*

Example = 10.374 + (0.101 x **70**) = **17.4 %**

FFM = (0.174 x 107 kg) – 107kg = 88.4 kg·FFM

Determine BM

Calibrated Measuring Scales **(kg)**

Determine RMR using FFM-Prediction Equation

Posthumus^{FFM} Equation = 1351 + (14.53 x ***FFM (kg)****)*

Example = 1352 + (14.53 x **88.4 (kg)**) = **2637 kcal·day^{-1}**

Determine RMR using BM-Prediction Equation

Posthumus^{BM} Equation = 1490 + (10.63 x ***BM in kg****)*

Example = 1490 + (10.63 x **107 (kg)**) = **2627 kcal·day^{-1}**

Determine EEE

If **NO** measure of EEE, use KPM Factor = Kcal·kg·min^{-1}

Gym Session

Backs KPM = 0.090 x ***BM (kg)*** *x* ***mins***

Example = 0.090 x **107 kg** x **60 mins** = **579 kcal**

Low-Field Session

Backs KPM = 0.074 x ***BM (kg)*** *x* ***mins***

Example = 0.074 x **107 kg** x **45 mins** = **356 kcal**

High-Field Session

Backs KPM = 0.118 x ***BM (kg)*** *x* ***mins***

Example = 0.118 x **107 kg** x **90 mins** = **1136 kcal**

Determine EEE and EA

EEE from Gym, Low- and High-Field = **2071 kcal**

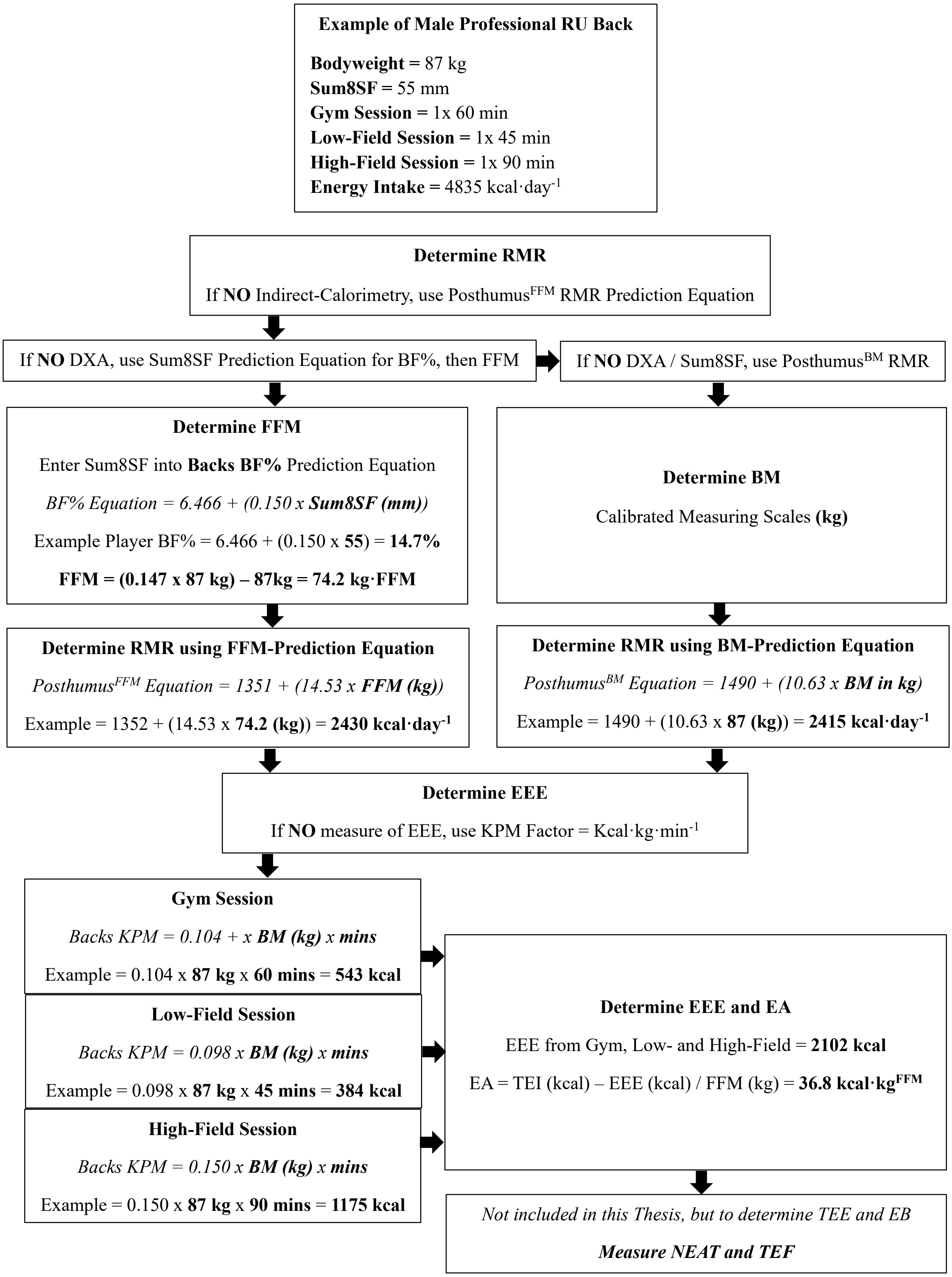
EA = TEI (kcal) – EEE (kcal) / FFM (kg) = **38.8 kcal·kg^{FFM}**

Not included in this Thesis, but to determine TEE and EB

Measure NEAT and TEF

Abbreviations: RU = rugby union, RMR = resting metabolic rate, FFM = fat-free mass, DXA = dual-energy x-ray absorptiometry, BF% = body fat percentage, Sum8SF = sum of eight-site skinfolds, BM = body mass, EEE = exercise energy expenditure, KPM = kcal·min·kg, EA = energy availability, TEE = total energy expenditure, NEAT, non-exercise activity thermogenesis, TEF = thermic effect of food.

Figure 15. Determining energy requirements for a male professional rugby union forward using prediction equations and average energy demands developed from the thesis.



Abbreviations: RU = rugby union, RMR = resting metabolic rate, FFM = fat-free mass, DXA = dual-energy x-ray absorptiometry, BF% = body fat percentage, Sum8SF = sum of eight-site skinfolds, BM = body mass, EEE = exercise energy expenditure, KPM = kcal·min·kg, EA = energy availability, TEE = total energy expenditure, NEAT, non-exercise activity thermogenesis, TEF = thermic effect of food.

Figure 16. Determining energy requirements for a male professional rugby union back using prediction equations and average energy demands developed from the thesis.

Limitations

The findings and outcomes presented in the thesis have direct and practical outcomes for; understanding the physical characteristics and fuelling requirements of professional male RU players, and enhancing strategies used to optimise body composition and nutrition prescription among these athletes. Within the thesis, each study has attempted to acknowledged its own specific limitations (Chapters Three to Nine), however some limitations across the thesis are evident and will be addressed below.

The research within this thesis was conducted in elite and sub-elite rugby environments, which in some cases impacted the sample size for some of the studies. While each study was carefully designed and the highest number of players were recruited as possible, the elite sporting environment can halt or change direction on research in an instant. In some instances, sample sizes were projected to be higher, however due to selection changes, injuries, schedule changes, and attempting to limit time burden on a certain number of players at a time, had to be navigated carefully within the thesis. Furthermore, the effects of the COVID-19 Pandemic had detrimental effects on the planned studies, their designs, and the number of participants recruited. Regardless, the level of athletes this thesis was able to recruit and examine makes up a considerable amount of the professional RU players in NZ, and is similar to sample sizes used in similar high-performance cohorts and study designs. However, we acknowledge that the studies could be more robust with larger sample sizes.

When examining DXA within Studies One to Three, players were not able to be in a completely overnight fasted state for DXA scans due to being in the middle of an important training week and some players having to train the same afternoon following the scan. Therefore, in an attempt to not compromise athletic preparation and performance, food and fluid intakes were prescribed and remained below 500 g for each player, which although not ideal, this method has been shown to minimise error when using DXA [53]. However, we acknowledge that this may cause limitations when comparing these results with other studies that have not consumed anything prior to scanning. Another limitation present among the DXA studies (Studies One to Three) in this thesis, is the small number of players who were marginally longer than the bed of the DXA scanner. Players too tall for the scanning bed were scanned with the overhanging portion of their feet removed from the scan. We acknowledge that this may be prone to some error, however it was not feasible to perform multiple scans.

It is important to note that when assessing dietary intakes among any participants let alone elite athletes, error may exist due to players mis- or under-reporting what they actually consume. This may occur intentionally or unintentionally and is an area that cannot be completely accounted for and relies on a trust model with the players. However, every attempt was made to connect with each player to ensure no meals/foods were missed and constant reminders were sent out at different stages of the day to keep the process at front of mind so players did not forget to capture food they consumed. However, we acknowledge that a considerable limitation within dietary assessment research is the fact that players can simply not capture additional food they consume and/or capture food that is not theirs or that they have not consumed.

Not being able to assess total energy expenditure and validate our EEE measures is another limitation within this thesis. Although our aim was to assess total energy expenditure using doubly labelled water, this study was significantly impacted by COVID-19 and had to be abandoned. This is unfortunately a gap in the literature where determining the total energy expenditure of elite professional RU players would be of great value. Therefore, we sought to explore the EEE and EA of elite male professional RU players. Although limitations exist regarding the use of heart rate to determine EEE, it has been used previously among professional rugby players to determine EEE. However, we accept that this is method is not the most accurate method for assessing EEE and that in a collision-based sport such as RU, the energy expenditure from the contact and collision demands is unable to be accurately quantified using wearable technology. Therefore, these findings should be carefully considered by readers and such methods, if possible, should be implemented in their own environment to confirm if similar results exist.

Another limitation within this thesis was not being able to carry out an intervention to quantify whether the dietary intakes reported by these elite male RU players were of benefit or detrimental to performance. However, interventions in elite sporting environments are often difficult. Therefore, we can only assume that these intakes are appropriate given the experience level of the players and provided they continue to perform at the highest levels. However, we acknowledge that measures of glycogen storage, exercise performance tests, and/or game-play analysis is required to determine what dietary and macronutrient intakes are optimal to influence physical and sporting performance among elite male professional RU players.

Suggestions for Future Research

This thesis has contributed to, and extended the body of knowledge regarding the body composition characteristics and fuelling requirements of professional RU players, particularly from NZ. Based on the findings and limitations presented within this thesis, the following suggestions for future research are presented.

- Understanding the physical and fitness characteristics among elite female RU players similar to Study One (Chapter Three), in order to gain greater insight into the relationships between body composition and fitness tests. This may be beneficial to further enhance training and nutrition programming among elite female RU players.
- Examining the dietary intakes among elite female RU players to further understand the nutrition practices of these athletes during different phases of the season, in catered and non-catered environments, and fuelling strategies on GD.
- Professional RU players do not meet the carbohydrate recommendations for team-sport athletes. It would be valuable to measure glycogen stores alongside different carbohydrate intakes commonly used among professional RU players to better understand whether the relatively 'lower' carbohydrate intakes observed are suitable for performance or if more optimal strategies can be implemented.
- Total energy expenditure using doubly labelled water should be implemented in both male and female professional RU players to accurately determine total energy requirements among this group of athletes. Furthermore, with the emergence of new technology, more wearable devices should be monitored alongside doubly labelled water to better understand the error associated with these devices, and whether they are reliable enough to track energy expenditures.
- Resting metabolic rate should be assessed post-game, and the collection of game-play characteristics should be recorded to determine whether any associations between game-play variables such as; minutes played, number and/or magnitude of collision and impact exposures, and tackle and breakdown involvement, have a scalable effect on RMR and therefore energy and recovery requirements.
- It may be beneficial to assess off-season RMR among professional RU players to further understand if RMR is higher among RU players during the pre- and in-season periods due to training and the demands of rugby.

- Future studies could report nutritional intakes during travel and could compare macronutrient distribution and food product differences across meals throughout the day in a range of environments.
- Fuelling habits of professional RU players at pinnacle events such as the Rugby World Cup would provide interesting insight to whether fuelling habits change when increased/optimal performance is desired and greater outcomes are at stake.
- Future research may also want to explore the EA among both male and female professional RU players and collect further diagnostic measures such as blood and hormonal markers to further understand EA among this population.

Conclusion

This thesis provides original research into the physical characteristics of male and female professional RU players, and the fuelling requirements of professional male RU players which include strategies to optimise body composition and nutrition prescription among this group of athletes. The findings presented in this thesis can be used by strength and conditioning coaches, sports scientists, and sports nutritionists to help guide programming to enhance an athlete's preparation, performance, and recovery/adaptation from training and competition. The major findings in this thesis were; strong relationships exist between body composition and fitness measures, GD is an important and substantial fuelling day for professional RU players during a competition week, relative carbohydrate intakes are low and relative protein intakes are high compared to team-sport recommendations, commonly used RMR prediction equations significantly mis-report RMR among professional male RU players and that some players, particularly forwards may be at risk of being in a state of LEA, and even more so in a non-catered environment, understanding the type, duration, and intensity of training is important given the significant differences observed among different training sessions and game-play during a competition week. Professional RU players require a balance of physical and fitness characteristics to meet the demands of the sport and therefore, determining specific body composition and fuelling requirements should be implemented to try and enhance both player health and performance.

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Appendices

The following appendices include:

Appendix A: Co-authorship forms for studies one to seven (Chapters Three to Nine)

Appendix B: Co-authored peer reviewed journal publications and conferences during the time of this PhD Thesis

Appendix A

Co-Authorship Forms

Study One (Chapter Three)

THE UNIVERSITY OF WAIKATO
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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter Three – Physical and Fitness Characteristics of Elite Professional Rugby Union Players.

Posthumus, L., Macgregor, C., Winwood, P., Darry, K., Driller, M., & Gill, N. (2020). Physical and fitness characteristics of elite professional rugby union players. Sports, 8(6), 85. https://doi.org/10.3390/sports8060085

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	85%

CO-AUTHORS

Name	Nature of Contribution
Campbell Macgregor	Support in data collection, interpretation of data, revision of manuscript.
Paul Winwood	Support in study design, interpretation of data, revision of manuscript.
Katrina Darry	Support in data collection, interpretation of data. revision of manuscript.
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.
Nicholas Gill	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.

Certification by Co-Authors

The undersigned hereby certify that:

❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
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Paul Winwood		17/05/2024
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Study Two (Chapter Four)

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Chapter Four – The Physical Characteristics of Elite Female Rugby Union Players.

Posthumus, L., Macgregor, C., Winwood, P., Tout, J., Morton, L., Driller, M., & Gill, N. (2020). The physical characteristics of elite female rugby union players. International Journal of Environmental Research and Public Health, 17(18), 6457. https://doi.org/10.3390/ijerph17186457

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	85%

CO-AUTHORS

Name	Nature of Contribution
Campbell Macgregor	Support in data collection, interpretation of data, revision of manuscript.
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Lillian Morton	Support in data collection, interpretation of data, revision of manuscript.
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Study Three (Chapter Five)

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Chapter Five – Position Specific Body Composition and Anthropometrics among Professional Male and Elite Female Rugby Union Players.

Posthumus, L., Driller, M., Winwood, P., & Gill, N. (Under Review). Position Specific Body Composition and Anthropometrics Among Professional Male and Elite Female New Zealand Rugby Union Players.

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	90%

CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.
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Chapter Six – Competition Nutrition Practices of Elite Male Professional Rugby Union Players.

Posthumus, L., Fairbairn, K., Darry, K., Driller, M., Winwood, P., & Gill, N. (2021). Competition nutrition practices of elite male professional rugby union players. International Journal of Environmental Research and Public Health, 18(10), 5398. https://doi.org/10.3390/ijerph18105398

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, additional data collection, interpretation of data, follow up analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	80%

CO-AUTHORS

Name	Nature of Contribution
Kirsty Fairbairn	Research conceptualisation, initial data collection, initial analysis, interpretation of data, revision of manuscript.
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Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical review of the manuscript.
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Study Five (Chapter Seven)

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Chapter Seven – Dietary Intakes of Elite Male Professional Rugby Union Players in Catered and Non-Catered Environments.

Posthumus, L., Driller, M., Darry, K., Winwood, P., Rollo, I., & Gill, N. (2022). Dietary Intakes of Elite Male Professional Rugby Union Players in Catered and Non-Catered Environments. International Journal of Environmental Research and Public Health, 19(23), 16242. https://doi.org/10.3390/ijerph192316242

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	85%

CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.
Katrina Darry	Support in data collection, interpretation of data. revision of manuscript.
Paul Winwood	Support in study design, interpretation of data, revision of manuscript.
Ian Rollo	Support with interpretation of data, revision of manuscript.
Nicholas Gill	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.

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Chapter Eight – The Development of a Resting Metabolic Rate Prediction Equation for Professional Male Rugby Union players.

Posthumus, L., Driller, M., Winwood, P., & Gill, N. (2024). The Development of a Resting Metabolic Rate Prediction Equation for Professional Male Rugby Union Players. Nutrients, 16(2), 271. https://doi.org/10.3390/nu16020271

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	90%

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Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.
Paul Winwood	Support in study design, data collection, interpretation of data, revision of manuscript.
Nicholas Gill	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.

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Nicholas Gill		17/05/2024

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Study Seven (Chapter Nine)

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Chapter Nine – In-Season Energy Demands of Elite Male Professional Rugby Union Players.

Posthumus, L., Driller, M., Darry. K., Winwood, P., Rollo, I., & Gill, N. (Under Review). In-Season Energy Demands of Elite Male Professional Rugby Union Players

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation, journal submission and response to reviewers.
Extent of contribution by PhD candidate (%)	80%

CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript.
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Appendix B

Co-Authored Peer Reviewed Journal Publications During Time of PhD Thesis

Roberts, C., Gill, N., Darry, K., **Posthumus, L.,** & Sims, S. (2022). Daily protein distribution patterns in professional and semi-professional male Rugby Union players. The Journal of Sport and Exercise Science, 6(1), 31-41.

Roberts, C. J., Gill, N. D., Beaven, C. M., **Posthumus, L. R.,** & Sims, S. T. (2022). The Influence of Full-Time Holistic Support Delivered by a Sports Nutritionist on Within-Day Macronutrient Distribution in New Zealand Provincial Academy Rugby Union Players. *Nutrients*, *15*(1), 17.

Roberts, C. J., Gill, N. D., Beaven, C. M., **Posthumus, L. R.,** & Sims, S. T. (2023). Application of a nutrition support protocol to encourage optimisation of nutrient intake in provincial academy rugby union athletes in New Zealand: Practical considerations and challenges from a team-based case study. *International Journal of Sports Science & Coaching*, *18*(6), 2263-2276.

Co-Authored Peer Reviewed Conference Presentations During Time of PhD Thesis

Roberts, C., Gill, N., Beaven, C., **Posthumus, L.,** & Sims, S. (2022). *Nutrition knowledge in New Zealand rugby union athletes*. Presented at the International Society of Sports Nutrition Conference, Fort Lauderdale, USA. (Poster Presentation).

Roberts, C., Gill, N., Beaven, C. M., **Posthumus, L.,** & Sims, S. (2022). *Full-time nutrition practitioner support may positively influence meal distribution of dietary protein in provincial academy rugby union athletes*. Sport and Exercise Science New Zealand Conference, Auckland, New Zealand. (Oral Presentation).

Roberts, C., Gill, N., Beaven, C., **Posthumus, L.,** & Sims, S. (2022). *Semi-Professional rugby union players may be at risk of low-energy availability*. Presented at the European College of Sport Science Congress, Seville, Spain. (Oral Presentation).