An Analysis of the Nutrition Support Process in Rugby Union Athletes in New Zealand: Practical Considerations and Applications within Rugby Developmental Environments

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Doctor of Philosophy in Health, Sport & Human Performance

at

The University of Waikato

by

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2022

Abstract

Nutrition has long been an important consideration for optimal sporting performance and recovery, athlete well-being and the modulation of injury risk. Ensuring that athletes follow dietary patterns that are nutrient-dense and facilitate the meeting of energy and macronutrient requirements is a crucial part of the sports nutrition practitioners' role. Furthermore, the practitioner should facilitate athletes understanding of meal timing and its potential benefit towards optimising performance and recovery. The accurate collection and interpretation of dietary intake data and provision of appropriate support towards athletes meeting overall nutrient requirements, promoting adherence to macro and micronutrient-dense dietary patterns and manipulation of meal timing may thus facilitate optimal performance and recovery.

The emergence of the SARS-CoV-2 virus in December 2019 and subsequent global spread saw the World Health Organisation declare a pandemic. As a result, governments and local authorities implemented a variety of restrictions to minimise the spread of the virus. In March 2020, New Zealand enforced strict lockdown restrictions that saw the forced closure of shops, restaurants, gyms and training facilities alongside mask requirements, social distancing, and the encouragement of more intensive hygiene procedures. As such, the purpose of Chapter 3 was to report the perceived influence of such restrictions on nutrition and training habits in rugby players. Changes in living situations were reported in response to lockdown restrictions, and diet quality may have improved, with limited respondents reporting reduced fruit and vegetable intake and increased packaged and convenience food intake. Furthermore, participants reported a reduction in motivation to exercise and train during lockdown, with follow-up survey responses indicating positive changes once restrictions were lifted. A variety of sources of nutrition information aside from dieticians or

nutritionists were reported by participants including coaching staff, team-mates, family, social media, and the internet. Collectively, the data indicate that unexpected events such as the emergence and global spread of the SARS-CoV-2 virus can influence athletes' dietary choices and nutrition practitioner support may be valuable for ensuring athletes make appropriate dietary choices during times of reduced training volume to maintain lean mass, adaptations, health and mitigate injury risk upon the return to play.

The use of technology to assist and facilitate the monitoring and analysis of dietary intake has gained popularity in both research and practice due to less participant burden and the potential for more accurate information. Despite this, the practical validity of such tools is unknown. The findings of Chapter 4 indicate that the remote food photography method application utilised in this thesis demonstrates ecological validity on a group level in athletic individuals. Despite this, significant individual variability is present, with inter-individual discrepancy in the % difference in calculated energy and macronutrient values. As such, the findings of this data suggest the remote food photography method may be beneficial for providing group level recommendations; however, individual intakes must be interpreted with caution.

In Chapter 5, the daily distribution patterns of professional and semi-professional rugby players were investigated. Rugby players may benefit from consideration of protein distribution, with mechanistic research suggesting an even spread of 0.4g·kg·d across 4 – 6 meals may result in a more optimal anabolic response; as such, adherence to such a pattern may optimise recovery, physiological adaptations, and performance. The data in Chapter 5 are in alignment with patterns presented in other athletic disciplines, whereby sub-optimal consumption is reported at snacks and only two eating occasions meeting the proposed 0.4g·kg threshold for eliciting an optimal anabolic response.

The manipulation of daily protein distribution was to be applied as an intervention in response to the findings in Chapter 5 to investigate the influence of optimised patterns on body composition, performance variables and well-being; however, it was determined following initial monitoring of the participants' dietary intake that requirements based on best- practice literature and recommendations were not being met. As such, the intervention reported in Chapter 6 was adapted to investigate how the implementation of full-time nutrition practitioner support delivered over a four-week period in an environment where prior support was minimal influenced total and per-meal nutrient intake, nutrition knowledge, body composition and well-being in provincial academy rugby players. Significant increases following intervention delivery were observed for total energy and protein intake. Additionally, consumption of protein at the breakfast, post-gym and snack eating occasions was greater. Carbohydrate intake pre-gym significantly increased in response to the intervention whilst consumption at PM snack and dinner was reduced.

The development and execution of the research contained in this thesis demonstrates the unpredictable and volatile nature of working in performance environments. Furthermore, major challenges during the nutrition support process, as would be delivered by sports nutrition practitioners, may influence the quality-of-service provision. As summarized in Chapter 7, the research in this thesis provides novel insight into the influence of full-time nutrition support when delivered by practitioners over a four-week period; as such, future research should further bridge the gap between research and practice by analysing the impact of nutrition support over prolonged periods. Additionally, incorporating qualitative data collection will allow for the better understanding of athletes' perceptions of current and desired nutrition support, how the inclusion of nutrition support benefits their perceptions of performance and well-being, and how well- received the inclusion of nutrition support would be. Additionally, future research should aim to build upon the themes introduced in this thesis and explore how the manipulation of dietary protein intake influences athlete-specific performance and adaptation, allowing for the creation of sport-specific, evidence-informed recommendations.

Acknowledgements

Becoming an independent researcher is a monumental group effort. The last three years have truly been an international effort consisting of many people without whom I would not have been able to reach this point.

First, I would not have succeeded on this journey if not for Dr. Stacy Sims being my primary supervisor. Your mentorship, guidance and advice not only got me through some of the hardest times of my life but allowed me to flourish and succeed in achieving my dream job. You always provided a perspective to keep me grounded when things in my head were uncertain. Whilst the academic perspective would be enough for many students, your personal friendship is more important and your ability to draw the perfect balance between supervisor and friend is admirable. Forming relationships with your family Steve, Jera and Tama allowed me to feel at home in an environment where this would not have been the case otherwise and has provided countless memories. For all that, I am truly grateful.

Dr. Tracey Clissold, your wisdom, kindness, and presence as a sounding board during our many long rides to Hamilton was imperative to me developing as a researcher, as an educator, and as a person. You helped me through some tough times and again, I would not be where I am now if not for you. Another person with whom a working relationship turned into a close personal friendship, I felt at home with Deb, Daisy, Teddy and your wider family. Even marking assignments in your living room was enjoyable and I will always look fondly on those summer evenings enjoying a beer in the garden!

To Gilly, thank you for believing in me back in 2018 when I initially reached out at the end of my MSc. Without your support I would not have embarked on this fantastic journey. Marty, you were a rock at the Adams Centre during some very tough times. Our kickarounds provided some much-needed relief from the office and being able to walk down the corridor or invite you to the computer to bounce ideas off was instrumental during those final intervention slogs! Thomas and Logan, your support, assistance, and friendship allowed me to develop as a researcher and practitioner and much of my ability to succeed in collecting data is thanks to you both.

Christian and Cath, I am forever grateful for your friendship, for opening your home to me and being truly awesome people! Koen, we had some (often too prolonged) sounding-board sessions which I know helped me! Jen and Joel, we enjoyed some great evenings of great conversation and complaining! To all the Adams Centre folks Shaun, Tom, Scott, Loretta, Trav, Kim, Andrew, Conor, Steve Finlayson & Fenemor, Roxanne, Ivana, Frank, Tim, Courtney, thank you for friendship, academic and professional support during this time.

To my new friends and colleagues at the University of Northampton who have made the transition from PhD to independent academic not only seamless, but extremely enjoyable, I thank you for welcoming me into the faculty. A special shout-out to Jack, Brett, Ben, Luke & Dec as I couldn't have been luckier to work with a group of people that I have such strong personal and professional relationships with.

To my mum, sister, AJ, grandma, Dave, uncle Ginge, Kimberly and all those who were instrumental in my upbringing and provided emotional support despite not being able to visit for nearly three years, without whom the completion of this PhD would not be possible. To Stu, who unfortunately passed early into the PhD journey but without his fatherly input growing up I would not be where I am today.

To the MacMillan family for all the support in getting me to the point I am at now. The staff and fellow students at the University of Glasgow were instrumental in me getting to this point. Without your specialist knowledge and guidance from a nutrition knowledge, research and critical thinking perspective I would not only have not considered a PhD but fallen at the first hurdle. A special mention to Dr. Dalia Malkova whos' dissertation project enforced my love of science. Most people would find taking bloods every 30 minutes, standing over a 96-well ELISA plate for 8 hours a day repeatedly but it was the catalyst for me embarking on a PhD. Everybody who I have met on this journey to NZ and back, during the amazing travelling experiences, the side jobs I took over the three years, and the other random interactions, it has been a pleasure!

Table of Contents

Thesis outputs

Roberts, C. J., Gill, N., & Sims, S. (2020). The Influence of COVID-19 Lockdown Restrictions on Perceived Nutrition Habits in Rugby Union Players. Frontiers in Nutrition. https://doi.org/10.3389/fnut.2020.589737

Roberts, C., Gill, N., & Sims, S. The Influence of COVID-19 Lockdown Restrictions on Perceived Nutrition Habits in Rugby Union Players, oral presentation at conference, Sport and Exercise Science New Zealand conference, Christchurch, New Zealand (November 2020)

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. https://doi.org/10.36905/jses.2022.01.05

Roberts, C., Gill, N., Beaven, C., Posthumus , L., & Sims , S. 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. *Accepted for publication in the International Journal of Sport Science and Coaching*

Roberts, C., Gill, N., Beaven, C., Posthumus , L., & Sims ,S. Semi-Professional rugby union players may be at risk of low-energy availability, oral presentation at conference, European College of Sport Science conference, Seville, Spain (August 2022)

Roberts, C., Gill, N., Beaven, C., Posthumus , L., & Sims , S. Nutrition knowledge in New Zealand rugby union athletes, poster presentation at conference, International Society of Sports Nutrition conference, Fort Lauderdale, USA (June 2022)

List of figures

List of tables

List of abbreviations

ADP – Adenosine diphosphate

AMPK – AMP-activated protein kinase

ANOVA – Analysis of variance

ATP – adenosine triphosphate

ANSKQ - Abridged Nutrition for Sports Knowledge Questionnaire

BMR – basal metabolic rate

CI – confidence intervals

CK – creatine kinase

Co2 – carbon dioxide

CV – coefficient of variation

CVD – cardiovascular disease

d – day

DLW – doubly-labelled water

DNA – deoxyribonucleic acid

EAA – essential amino acid

FFM – fat free mass

FFQ – food frequency questionnaire

g – gram

h – hour

HFLC – high fat, low carbohydrate

IAAO – indicator amino acid oxidation

IL – interleukin

kcal - kilocalorie

kg – kilogram

KHFLC – ketogenic high fat, low carbohydrate

LDH – lactate dehydrogenase

LOA – limit of agreement

m – metre

MPB – muscle protein breakdown

MPS – muscle protein synthesis

mRNA – messenger ribonucleic acid

mTORC – mammalian target of rapamycin complex

o2 - oxygen

PUFA – polyunsaturated fatty acid

RCT – randomised controlled trial

RDA – recommended dietary allowance

RER – respiratory exchange ratio

RFPM – remote food photography method

RMR – resting metabolic rate

RPE – rate of perceived exertion

Vo2 – oxygen uptake

Chapter 1: Introduction

Rugby union ("rugby") is an intermittent team sport comprised of concurrent anaerobic and aerobic movement patterns. A rugby athlete is expected to maintain sufficient aerobic capacity, strength, power, speed, and agility for the successful execution of plays. Furthermore, collision events such as tackles, scrums and rucks lead to significant physiological perturbations and impairments following matches. The development of different characteristics via specific training modalities is likely to lead rugby athletes to engage in high training volumes.

Rugby athletes have heterogenous on-pitch demands and body composition requirements. With twelve distinct positions in a rugby squad separated into forwards (tight head prop, hooker, loose head prop, lock, blind side flanker, open side flanker, number 8) and backs (scrum-half, fly-half, wing, centre and full back) inter-individual match objectives, movement patterns and body composition requirements are observed. Positional differences of demands during match-play are apparent and rugby athletes experience significant physiological and metabolic stress (Hudson et al., 2021) energy expenditure (Bradley et al. 2015; Bradley et al. 2015; Smith et al. 2018) and nutrient requirements (Black et al., 2018).

Broad recommendations for carbohydrate (3.0 – 7.0 g·kg·d) (Burke et al., 2011; Thomas et al., 2016) and protein (1.2 – 2.0 g·kg·d) (Thomas et al., 2016; Jäger et al., 2017) have been described in the literature for team sport athletes. Rugby players require adequate dietary protein consumption to facilitate the repair and re-modelling of damaged tissue and enhance structural and functional adaptations (Black et al., 2018). Dietary carbohydrates are essential as muscle glycogen is depleted in response to consecutive repeated sprints (Williams and Rollo, 2015), which represents the main pattern of play in rugby. Providing specific recommendations to rugby athletes based on best-practice guidelines in the literature is difficult given the heterogenous match-play and training demands, body composition requirements and seasonal variation in training goals (Jenner et al., 2019).

Mechanistic research suggests that the per-meal dose and timing of dietary protein is an important modulator of the anabolic response due to the short-lived stimulation of MPS to amino acid provision (Bohé et al., 2001). An even distribution of 0.4 g·kg dietary protein across 4-6 feeding occasions throughout the day may optimally enhance the anabolic response to amino acids (Morton et al., 2015; Schoenfeld and Aragon, 2018). As such, subsequent structural and functional adaptation may be amplified, and amino acid oxidation minimised (Moore, 2019) however the translation of mechanistic observations into a practical setting in athletes is currently inconclusive. Whilst rugby athletes' dietary protein distribution (≥20g per serving) has been explored (MacKenzie et al., 2015) the values have not been presented relative to body mass (Moore, 2019) and as such, further investigation to explore whether such athletes meet the best-practice guidelines (Schoenfeld and Aragon, 2018; Morton et al., 2015) is warranted.

Provincial academies represent an important gap for the development of an elite-level athlete. Engagement in an academy will see the athlete training and competing with semi-professional athletes and coaching staff, whilst also participating at the amateur club level. Academies will provide the athlete with elite-level coaching support and facilities to develop the skills required for transitioning into provincial rugby. Engagement in a rugby academy therefore provides a direct pathway into professional rugby. To our knowledge, no data detailing nutrient intake in provincial academy rugby players in New Zealand has been published.

Provincial academy rugby athletes are a unique population in that they compete and train at both semi-professional academies and amateur level clubs. This not only increases training volume but may result in contradictory training goals, as both the competition season for amateur teams the pre-season for semi-professional development run simultaneously. Despite training at semi-professional academies, many are not yet contracted and as such receive little to no financial support for their participation in rugby. Alongside training schedules, the athletes are likely to be working or studying which adds further time constraint (Heaney et al., 2008). Athletes will need to manage social and leisure time and may need to travel for matches. Collectively, working full-time and training may account for over 50 hours per week alone.

Due to the congested schedules, high energy and nutrient requirements and variable performance and body composition goals, meal timing and nutrient periodisation (Jeukendrup, 2017; Mujika et al., 2018) are important considerations for this population. Ensuring athletes are nutrient sufficient is challenging as multiple obligations can interrupt potential feeding occasions. Additionally, due to the developmental and competitive level of the athletes' specific nutrient timings may be beneficial to optimise performance and adaptation. Large training volumes may increase energy and nutrient requirements. Ensuring athletes consume an energy-sufficient and nutrient-dense diet is of the utmost importance and a vital component of the sports practitioner role.

Access to nutrition support for developing athletes is likely to be beneficial for their personal and athletic development however such individuals may have little to no contact with practitioners (Sharples et al., 2021). Due to the heterogenous nature of rugby match play, variability in body composition and congested schedules that transcend different seasons, limited access to nutrition practitioner support is likely to be detrimental to the nutrient intake, body composition, performance, recovery, and well-being of the developing rugby athlete. Despite this, no research has sought to implement a nutrition support protocol, of which might be expected at a club with greater accessibility to resources, and evaluated the impact on nutrient intake, body composition, nutrition knowledge and well-being in this population. As the athletes have little prior access to appropriate nutrition support, implementing full-time practitioner support may be of significant benefit.

Collectively, consideration of nutrient intake in rugby athletes present a significant gap in the literature. Specifically, the distribution of dietary protein intake expressed relative to body weight requires quantification based on the mechanistic research indicating 0.4 g·kg spread across 4-6 meals may be beneficial for eliciting an optimal anabolic response (Schoenfeld and Aragon, 2018). Furthermore, the implementation of nutrition support protocols can further our understanding of the influence of such services, particularly in a cohort that receives little prior support, receive little to no financial support for participation and must navigate multiple sporting and life obligations.

Dietary analysis involves the evaluation of an individuals' or groups' food, beverage, and supplement intake. Analysis is conducted over undefined periods, the objectives being to quantify energy, macronutrient and/or micronutrient intake or observation of dietary trends such as the number and timing of meals consumed, generic components of meals and consumption of fruit and vegetables (Larson-Meyer, 2019). This information is used to monitor whether the athlete is meeting specific health, performance, and development goals (Capling et al., 2017). A vital component of the sports nutrition practitioners' role is the ability to accurately collect and interpret dietary intake data. Failure to do so may lead to poor quality information and advice being provided to the athlete that could impair performance and recovery. Furthermore, the practitioner may fail to notice deficiencies in the athletes' diet that may negatively influence health, growth, and development, increase injury risk (Thomas et al., 2016) and may require clinical intervention. Despite this, dietary analysis in research and practice is prone to considerable error, as seen when data is compared to biological markers (Hill and Davies, 2001). Dietary analysis conducted over more days is likely to produce a better understanding of the athletes' actual food and nutrient consumption, however increases the likelihood of recording fatigue (Larson-Meyer et al., 2018) particularly when the methodologies utilised require greater input and literacy from the individual. All dietary analysis methods require some degree of self-reporting, increasing the likelihood of the misreporting of true intake (Capling et al., 2017). Additionally, practitioner variability in the interpretation of meals and coding of data (Braakhuis et al., 2003; Stables et al., 2021) can contribute to potential error in collected data. Recently, research has suggested that image-based nutrition assessment which utilise mobile phone cameras are both valid (Costello et al., 2017) and better accepted by athletes (Simpson et al., 2017), however the practical validity of such tools is yet to be determined.

The global spread of the SARS-CoV-2 virus, referred to from here as COVID-19, presented significant challenges to daily life. Lockdown restrictions were imposed as a means of mitigating the spread of the virus and as such, rugby players were unable to train, eat and socialise as normal. Players were forced to train without access to typical environments such as clubhouses and gyms and were only able to purchase food from supermarkets. Due to the novelty of the COVID-19 pandemic, no literature existed concerning the impact of such lockdown restrictions on the perception of nutrition and training habits in rugby players.

Thesis aims

The aims of this thesis were to:

- Explore the implementation of a nutrition support protocol in a provincial New Zealand rugby academy team and assess how the protocol influences nutrient intake, meal distribution, nutrition knowledge, body composition and subjective well-being.
- Identify and describe the practical considerations required for the analysis of dietary intake and delivery of nutrition support in athletes.
- Observe and describe overall and per-meal dietary protein intake in semi-professional and professional rugby athletes in New Zealand, with consideration to both total and body mass-relative values, to account for large inter-individual body composition values which may dictate specific requirements.
- Assess the practical validity of a mobile phone application based dietary assessment method in athletic individuals for the collection and interpretation of energy and macronutrient intake.
- As a secondary situational aim, this thesis sought to describe the impact of COVID-19 lockdown restrictions on nutrition and training habits as perceived by rugby players.
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- **Hypotheses**
-
- The implementation of a nutrition support protocol, designed around behaviour change techniques would facilitate improvement in total and per- meal energy and macronutrient intake, body composition, nutrition knowledge, and subjective well-being in provincial academy rugby athletes in New Zealand (H_1). For H_0, the implementation

of a nutrition support protocol would not facilitate improvement in the aforementioned variables.

- Daily dietary protein intake in athletes across various levels of professionalism of rugby union would exceed recommendations set by various academic organisations similarly to previous research.
- In accordance with previous research in other athletic disciplines, rugby athletes in New Zealand would not consume dietary protein in line with updated recommendations for the development or maintenance of lean mass on a per-meal basis (0.4 g·kg per meal across 4-6 eating occasions).
- A mobile phone application would be a valid tool for the collection and accurate estimation of energy and macronutrient intake in a practical setting in athletic individuals when compared to the weighed food diary (H_1). For H_0, a mobile phone application would not be valid for the collection and accurate estimation of energy and macronutrient intake in a practical setting in athletic individuals when compared to the weighed food diary.
- The introduction of COVID-19 lockdowns and restrictions would influence the perceived nutrition and training habits of rugby players.

Chapter 2: Literature review

Demands of the rugby athlete

Rugby is a popular collision sport with over eight million individuals from over 120 countries playing globally (Griffin et al., 2021). Rugby can be classified as an intermittent team sport, with high-intensity intervals of activity interspersed with low intensity periods of walking played over an 80-minute period (Black et al., 2018). The low intensity periods are further compounded by periods in which the ball is out of play. Read et al (2018) demonstrated that out-of-play periods totaled 63% during matches and thus outweighed the ball being in-play. Alongside the intermittent nature of play, rugby can be characterized as a collision sport due to contact being “necessary and integral to play” (Keeler, 2007). Contact is common in rugby match-play in the form of tackles, scrums, mauls, rucks, lineouts, and other miscellaneous collisions (Fuller et al., 2007). Despite widespread popularity, rugby remained an amateur sport until 1995 (O’Brien and Slack, 2003) and the advent of professionalism brought dramatic changes to players physical characteristics and match events (Quarrie and Hopkins, 2007). A successful rugby player will possess and develop appropriate endurance, speed, and power capacity (Naughton et al., 2021) and may require significant training volumes alongside playing time.

Rugby players experience inter-individual differences in anthropometrics and physical characteristics, with such observations being made prior to the professionalism of the game (Bell, 1979). A players’ position determines the demands experienced during a match (Lindsay et al., 2015). Despite all players completing common movements such as tackles, ball handling and running, tactical differences between forwards and backs are apparent. During match-play, forwards aim to gain possession of the ball and gain territory by engaging in scrums, rucks, mauls, and lineouts. Male and female forwards possess greater total body mass, lean body mass and fat mass (Harty et al., 2019; Zemski et al., 2015; Posthumus et al., 2020; Donkin et al., 2020) and engage in greater high-intensity activity due to the involvement in events of static exertion (Roberts et al., 2008). Backs tend to be involved in more periods of intense running (Cunniffe et al., 2009; Duthie et al., 2003), possess greater high-intensity running ability and sprint velocities (Nakamura et al., 2017; Darrall-Jones et al., 2016) and appear to cover greater distances during a match than forwards (Cahill et al., 2013; Roberts et al., 2008). Ten-metre sprint speed, line breaks and tries scored and strength markers correlate weakly with turnover rate (Smart et al., 2014) indicating specific attributes may be better suited to different positions and successful game outcomes.

In international level match play, flankers may engage in 13 ± 5.7 successful tackles whereas fullbacks only 3.8 ± 2.5. In comparison, flankers perform 2.7 ± 2.2 runs with the ball > 5 metres as opposed to fullbacks who perform 8 ± 3.9 (Quarrie et al., 2013). Total collisions during a match vary between positions, with open-side flank engaging in 50.9 compared to 16.3 involving the scrum-half (Schoeman et al., 2015). Despite different positional demands during match-play (Dubois et al., 2017) rugby union players in all positions experience large physiological and metabolic stress (Hudson et al., 2021; Lindsay et al., 2015).

Rugby player characteristics and performance measures also differ based on level of play beginning in adolescence, with Jones et al (2018) comparing physical characteristics between U18 regional academy and school rugby players. The authors observed a greater body mass, three repetition max bench press and 20m and 40m sprint time in the regional academy players, likely contributing to more sprinting, greater total distance covered and a greater involvement in static exertions during match-play (Jones et al., 2018). Professional players playing in international matches demonstrate faster sprint times, have lower body fat and greater fat-free mass (Smart et al., 2013), higher body mass and increased strength and power than semi-professionals and academy players (Argus et al., 2012). Despite this, rugby players transitioning from Super Rugby to provincial competition demonstrate small positive changes in lower body strength, upper body strength and sprint times, possibly due to a reduction in training volume and international travel (Smart et al., 2013).

The intermittent nature of play and frequent collisions may cause rugby players to be at an increased risk of injury when compared to non-collision sports, with many injuries sustained during tackling events (Brooks and Kemp, 2008; Fuller et al., 2010). Questionnaire data suggests that rugby players have a greater risk of a substantial injury (one that has the potential to be serious and restricts participants from their usual activities) and that collisions were a major contributor (Nicholl et al., 1995). In New Zealand, soft-tissue injuries are extremely prevalent in rugby union (76% of injuries), however fractures, dislocations, concussions, and dental injuries are also common (Quarrie et al., 2020).

An important adaptive consideration for rugby players is the development of lean mass; the development of contractile skeletal tissue can result in increased strength, power (Schoenfeld et al., 2021; Rodríguez-Rosell et al., 2018) and speed (Cronin and Hansen, 2005). Indeed, grater mass in players may be predictive of overall competition success in international rugby (Barr et al., 2014; Sedeaud et al., 2012). A common outcome of an athletes' pre-season is the development of skeletal muscle tissue, with multiple authors observing significant lean mass gains across 11 – 14-week pre-seasons (Zemski et al., 2019b; MacKenzie-Shalders et al., 2019). Academy players particularly exhibit significant increases in lean mass during the early tenure as senior players (McHugh et al., 2021). Despite this, lean mass may reduce during the competitive season (Lees et al., 2017; Georgeson et al., 2012) due to a greater focus on competitive outcomes, a reduction in hypertrophy-focused training volume and a change in nutritional habits in response to training requirements.

Due to the high-intensity nature of match-play, intermittent movement patterns, expected collisions, high-training volumes and requirement to promote training adaptation, rugby can exert significant physiological and psychological stress on a player that may manifest as disruptions to muscle structure, endocrine homeostasis, or mood (West et al., 2014; Shearer et al., 2015; Suzuki et al., 2004) Such disruptions to the testosterone/cortisol ratio and subjective mood can be expected to persist for up to 36-hours (West et al., 2014; Shearer et al., 2015). Unsurprisingly, game outcome has been shown to influence mood with winning associated with both increased (Kerr and van Schaik, 1995) and decreased arousal (Wilson and Kerr, 1999) and decreased stress (Kerr and van Schaik, 1995; Wilson and Kerr, 1999); additionally, games played at away venues elicited greater arousal responses (Kerr and van Schaik, 1995) whereas self-confidence was greater and tension, anger, fatigue, confusion and anxiety lower at home games (Terry et al., 1998).

Muscle damage can increase permeability of the cell and thus result in intramuscular protein expression in circulation. Measurement of serum levels of CK (Baird et al., 2012), LDH and myoglobin (Sorichter et al., 1999) are often analysed as indirect markers of skeletal muscle damage. Following rugby match play, muscle damage and inflammatory markers including cortisol (Lindsay et al., 2015; Lindsay et al., 2015; West et al., 2014), myoglobin (Lindsay et al., 2015; Lindsay, Lewis et al., 2015; Takarada, 2003), neopterin (Lindsay et al., 2015; Lindsay et al., 2015), LDH (Gutierrez et al., 2020; Suzuki et al., 2004) and CK (da Silva et al., 2020; Jones et al., 2014; Suzuki et al., 2004) increase post-game which may translate to greater recovery demands between positions, with forwards appearing to demonstrate greater muscle damage (CK, LDH) and inflammatory (IL-10, IL-8, IL-6) markers (Gutierrez et al., 2020). Alongside this, metabolomic analysis following match- play in elite English players suggests significant structural muscle degradation. Methylhistidine, a modified amino acid present in both actin and myosin proteins, was increasingly present in urine for two days following match-play (Hudson et al, 2021). Indirect muscle damage markers have demonstrated significant positive correlation with the number of tackles (Jones et al., 2014; Takarada, 2003; Oxendale et al., 2016) and high-intensity activities (Oxendale et al., 2016; Jones et al., 2014) post-match.

To summarise, rugby players engage in and experience significant physiological and metabolic demands during matches and demonstrate a requirement for greater lean mass growth and the development of characteristics important for match success during a rugby game. The unique demands of the rugby player and major inter-individual variation between positions and level of play demand unique consideration for nutrient intake.

Nutrition for athletes

Energy

General overview

Energy homeostasis is complex and whilst the basic concepts of energy balance (energy intake and energy expenditure) are often discussed, the interaction between genetics, physiology, and cognitive behaviours (Lam & Ravussin, 2016) that can determine energy intake and expenditure are both not fully elucidated and difficult to apply in real-world contexts. Energy production is required to sustain many processes within the body such as muscle contraction, active ion transport and the synthesis of biomolecules such as proteins, DNA, RNA, lipids, and sugars (Bonora et al, 2012). Amino acids, fatty acids and saccharides are metabolised to re-synthesise adenosine triphosphate, the primary source of chemical energy (Guimarães-Ferreira, 2014).

Multiple components determine the energy one expends. BMR represents the minimal energy required to sustain life and preserve vital functions (Henry, 2005). Standardisation of accurate BMR testing is difficult to manage, particularly in athletes, as strict conditions must be adhered to such as prolonged fasting periods and ensuring one is free from emotional stress (McMurray et al, 2014). As such, it may be more appropriate to measure RMR; similar to BMR the measurement is less stringent and can be conducted with minimal rest and in either seated or supine conditions (McMurray et al, 2014).

RMR is often estimated using a variety of prediction equations (Thompson & Manore, 1996). The accuracy of these equations in athletic populations has been questioned (Compher et al, 2006). Jagim et al (2019) measured RMR via indirect calorimetry in male and female athletes engaging in a variety of disciplines. The researchers found that the five measured prediction equations significantly underestimated male athletes RMR, with the Harris-Benedict equation demonstrating the smallest mean difference (-266 ± 204 kcal/day). In female athletes, the mean difference between measured and predicted RMR was not significantly different from the Cunningham equation (p = 0.111, -39 ± 108 kcal/day). Conversely, male adolescent Korean athletes demonstrated significant under-estimation of RMR compared to measured values using the Harris-Benedict but not the Cunningham formula (Kim et al, 2015).

Additionally, energy expended during daily activities, which can be further expressed as exercise energy expenditure, non-exercise activity thermogenesis and the thermic effect of feeding contribute to energy expenditure (Compher et al, 2006). The greatest modifying factor is the energy expended during activities and is variable between both individuals and days (Broad & Cox, 2008). As such, athletes tend to expend greater energy than sedentary individuals (Black, 2001) and thus have greater dietary energy requirements.

Energy expenditure can be measured via multiple methods; indirect calorimetry in which o^2 consumption and co^2 output is measured to calculate substrate oxidation and energy expenditure and direct calorimetry in which heat loss is directly measured (Levine, 2005). DLW is a non-invasive and non-obtrusive method in which stable isotopic oxygen and hydrogen are introduced via the water into the body; the rate of co^2 production can be measured during free-living conditions and thus energy expenditure (Speakman et al, 2019). As DLW is the gold-standard for measuring energy expenditure in the free-living human its utilisation is more applicable to measuring the daily energy cost of an athlete (Westerterp, 2017). Measurement of energy intake occurs via analysis of dietary intake; the various methods of measuring dietary intake will be discussed later in the review.

Energy for rugby

Rugby is an energetic sport with players experiencing significant physical and metabolic stress in response to training and match-play (Hudson et al., 2021). Great distances covered during match-play are aerobically demanding whilst intermittent sprints, explosive movements and collision-based events rely primarily on anaerobic metabolism. Furthermore, variable training and competition loads, individual body composition goals and involvement in employment alongside athletic obligations, particularly in sub-elite or amateur players, can result in considerable inter-individual variability in both energy intake and expenditure (Desbrow, Slater & Cox, 2020). As such, ensuring the rugby athlete consumes an energy-sufficient diet can be challenging for the nutrition practitioner.

As the energy demands of rugby extend beyond match-play, multiple groups have sought to quantify energy expenditure across 2-weeks in professional athletes. Morehen et al (2016) observed a mean daily energy expenditure of 5374 ± 644 kcal in professional rugby league players. In a mixed rugby union and league cohort, Smith et al (2018) observed energy expenditures of 4010 ± 744, 4414 ± 688 and 4761 ± 1523 kcal in U16, U20 and U24 players. Furthermore, the authors report daily energy expenditures of 62 ± 8, 66 ± 10 and 60 ± 18 kcal·kg FFM.

Several authors have noted that energy expenditure is greater in response to collision-based training and matched non-collision activity (Costello et al, 2018) and the day following rugby match-play than prior to games (Hudson et al, 2020). Despite the increased energy cost, a compensatory consumption of energy in the meals following rugby over non-collision-based activity may not be observed (Thivel et al, 2015). Such observations appear similar over extended training periods (Nagayama et al, 2019). During a six-day camp, elite adolescent male rugby players engaged in an average of 340 minutes rugby activity daily. Energy expenditure and intake were estimated across 4 days; additional measures of pre and post subjective appetite and *ad libitum* energy intake were undertaken. The authors observed a significant decrease in *ad libitum* energy intake following the camp, along with a non-significant daily energy deficit of 213 ± 503 kcal·d (Nagayama et al, 2019). Whilst non-significant in the four days of monitoring, such a deficit may result in energy insufficiency over a prolonged period, particularly if the athlete is aiming to maintain or gain mass.

Meeting energy requirements should be a priority for rugby players and failure to do so can present a multitude of physiological, psychological, and behavioural impairments (Logue et al, 2018). Low energy availability occurs when dietary energy intake does not meet the demands for normal physiological and metabolic function after accounting for exercise expenditure (Schofield et al., 2020). Such a situation may be easily encountered due to the high energetic costs previously observed (Morehen et al, 2016; Smith et al, 2018) particularly if habitual energy intake is compromised (Nagayama et al, 2019).

Macronutrients

Protein

Proteins are the major cellular structural component in the body and comprise hormones, enzymes, cytokines, and other functional structures (Hoffman & Falvo, 2004). Dietary protein is essential for provision of an exogenous supply of nitrogen and sulphur (Wu, 2016); following digestion into the constituent amino acids and absorption into the body, proteins are directed to either functional synthesis of new proteins, or oxidised (Moughan, 2005). The rates of both protein synthesis and protein degradation determine overall protein turnover (Phillips and van Loon, 2011) and thus the creation of and re-modelling or degradation of new and old or damaged proteins, respectively.

The current RDA for protein intake sits at 0.8g·kg·d and represents a minimum value for the maintenance of nitrogen balance in the body (Rand, Pellett, & Young, 2003). As such, it does not reflect dietary protein intake for optimal health, function and repair and re-modelling of tissue (Wu, 2016). Dietary protein intake at intakes greater than the RDA are beneficial for the management of various chronic health conditions, glycaemic control (Layman, 2009) and may be an important modulator of sleep quality (Sutanto et al, 2020). Despite the definition stating that the number reflects a minimum intake to meet the requirements for most healthy individuals (Wolfe & Miller, 2008), the RDA is commonly used when promoting dietary recommendations and may be used as a ‘goal’ intake (Phillips, Paddon-Jones & Layman, 2020) which may not be nutritionally adequate for ageing or exercising individuals (Phillips, Chevalier & Leidy, 2016).

Early research into human protein metabolism led to observations of significantly enhanced muscle protein synthesis, whole-body protein synthesis and RNA activity following feeding compared to fasting (Rennie et al, 1982). A net positive protein balance was observed in the feeding condition whilst a net negative protein balance was observed in the fasting condition (Rennie et al, 1982).The response of protein synthesis to a meal is dictated by amino acid availability (Millward et al, 1996; Volpi et al, 1998); a peak in the anabolic response is observed two hours after increased amino acid availability, after which it sharply declines (Bohé et al, 2001), however this can persist for five hours when preceded by resistance exercise (Moore et al., 2009b). Additionally, insulin may contribute to overall protein balance by inhibiting protein breakdown (Pacy et al, 1989).

Protein for rugby

Amino acid consumption is vital for athletes as low availability of substrates for repair, remodeling and synthesis of proteins will limit the extent of adaptation from a structured exercise programme. Following a bout of exercise, dietary amino acid availability is necessary to repair structural myofibrillar proteins and synthesise both mitochondrial proteins and enzyme complexes required for energy metabolism, depending on the exercise modality (Atherton & Smith, 2012; Moore et al., 2014). When exercise is performed with low carbohydrate availability, amino acid oxidation is elevated and net protein balance negative, suggesting muscle proteins are used to support oxidative metabolism (Howarth et al, 2010).

Strength and power are important characteristics for those involved in collision sports (Duthie et al. 2003; Duthie, 2006); as such, rugby players engage in resistance training programmes alongside sport-specific training to develop skeletal muscle mass, strength, and power (Argus et al., 2010; Harries et al., 2015). Skeletal mass grows when a positive protein balance is achieved, whereby muscle protein synthesis exceeds breakdown (Kumar et al., 2009).

Protein turnover significantly increases following a bout of resistance exercise due to stimulation of both MPS (Ferrando et al, 1997) and MPB (Biolo, Fleming & Wolfe, 1995; Phillips et al, 1997), however protein breakdown appears to be lower in resistance-trained than untrained individuals (Phillips et al, 1999) and following mixed nutrient provision (Tipton et al., 2018). MPS stimulation following resistance exercise appears to be due to increased RNA activity, with enhanced translation but not transcription observed following heavy resistance exercise (Chesley et al., 1992). Additionally, resistance exercise can upregulate the expression of skeletal muscle amino acid transporters (Drummond et al., 2011) increasing the potential for amino acid delivery. Acute studies suggest that in the absence of protein feeding, protein balance following resistance exercise does not become positive (Biolo et al. 1995; Tipton et al. 1999) as MPB remains elevated to provide amino acids for MPS response (Burd et al., 2009). Furthermore, only EAA ingestion may be required to stimulate a greater anabolic response following resistance exercise (Børsheim et al, 2002; Tipton et al, 1999; Tipton et al, 1999; Tipton et al, 2012). Decreased protein turnover and greater amino acid retention is observed following prolonged resistance training protocols (Hartman, Moore & Phillips, 2006; Moore et al. 2007); nonetheless, resistance training individuals and those engaging in strength sports should consider dietary protein above which maintains nitrogen balance, and instead provides substrates for optimal protein re-modelling (Atherton & Smith, 2012; Phillips, 2012).

Team sports such as football and rugby contain unique movement patterns (variable-intensity intermittent running, rapid change of direction) and utilisation of both anaerobic and aerobic energy systems. Nutritional requirements can be challenging to determine and generalise as differences in match demands, pitch sizes and season length influence requirements between disciplines, and even positional differences in sports such as rugby may change the requirements of different substrates (Holway & Spriet, 2011).

Packer et al (2017) aimed to determine whether movement patterns like those of team sport athletes influenced protein requirements post-exercise using the IAAO method. Participants performed a version of the Loughborough Intermittent Shuttle Test, comprised of four blocks of 15-minutes activity separated by five minutes rest. During the activity blocks, participants performed variable intensity movement patterns designed to mimic those experienced during a team sport match (Nicholas, Nuttall, and Williams, 2000). Following the exercise trial, participants consumed various amounts of protein, with a breakpoint of phenylalanine oxidation identified at 1.2g·kg·d and an upper 95% CI of 1.4g·kg·d, which is much lower than that of endurance athletes (Kato et al, 2016). A similar study protocol was employed in young active females, five of whom would be considered team sport athletes (Wooding et al, 2017). A breakpoint in phenylalanine oxidation was reported at 1.41 g·kg·d and an upper 95% CI of 1.71 g·kg·d, values of which are greater than those identified in males (Packer et al, 2017).

The results from these studies must be interpreted with caution. It would be unwise to imply that team sport athletes have greater protein requirements based on data collected from small sample sizes. Additionally, whilst most of the female participants appeared to be team sport athletes, the male participants were described as trained only. Another consideration is that variability in the demands of team sport matches may influence protein requirements

(Carling et al, 2016; Gregson et al, 2010). An athlete may engage in more high intensity runs, collisions with opposing players and changes in direction from one match to the next, which may all contribute to different protein requirements to facilitate muscle damage repair and replace oxidised amino acids. As such, further work to develop team-sport specific protein requirements would allow for more accurate recommendations to be made.

Consuming adequate dietary protein during a period of energy restriction can preserve lean mass by upregulating MPS and maintaining a positive state of protein turnover (Pasiakos, Margolis & Orr, 2015). Cellular energy deprivation can lead to reductions in mTORC activity via activation of AMPK which acts to conserve ATP by down-regulating MPS (Smiles, Hawley & Camera, 2016) and thus strategies to counter-act this when restricting energy for the purpose of weight loss are essential. Rates of MPS are suppressed during periods of dietary energy deprivation (Areta et al, 2014; Pasiakos et al, 2013) however prolonged consumption of protein at levels greater than the RDA appears to correct this response (Pasiakos et al, 2013). High-protein diets in conjunction with energy restriction appear to be better protective of lean mass than lower-protein diets over a two week experimental period in trained males (2.3 g·kg·d vs. 1.0 g·kg·d) (Mettler, Mitchell & Tipton, 2010) but not trained females (1.7 g·kg·d vs. 0.9 g·kg·d) (Pearson et al, 2021). Combined resistance training and dietary protein intake at 2.4 g·kg·d resulted in a lean mass increase and fat mass decrease over four weeks in young men compared to 1.2 g·kg·d (Longland et al, 2016). Rugby players often demonstrate a desire or requirement to reduce fat mass (Sharples et al., 2021; Black et al., 2019). As this will entail the individual maintaining an energy deficit, increased dietary protein can assist in the preservation of functional lean tissue, and greater intakes are often recommended depending on the severity of energy restriction (Aragon et al. 2017; Hector & Phillips 2018; Helms et al. 2014; Phillips 2014; Phillips van Loon 2011).

Exercise-induced muscle damage occurs in response to unaccustomed exercise involving eccentric muscle action, in which the muscle force is less than an external force, causing the muscle to lengthen (Howatson & van Someren 2008). Muscle damage occurs in response to various exercise modalities, particularly resistance training, downhill and/or prolonged running and high-intensity exercise utilising rapid acceleration, deceleration and change in direction (Owens et al, 2019). The muscle damage response can be characterised in two phases, with the initial damage response likely caused primarily by mechanical overload of myofibers (Howatson & van Someren, 2008) resulting in impairment to the muscle ultrastructure and extracellular matrix (Baumert et al, 2016). Secondary damage occurs due to an influx of immune cells including macrophages and neutrophils to the damaged tissue. Whilst essential to the inflammatory process that promotes clearance of degraded tissue and muscle repair and remodelling, they can produce reactive oxygen species and cytotoxic enzymes that may exacerbate tissue damage (Owens et al, 2019).

Due to the movement patterns exhibited on the pitch, team sport athletes are susceptible to exaggerated muscle damage. Variable-intensity sprints, change of direction, jumping and other sport-specific movements cause repeated eccentric strain (Poulios et al, 2019) that may result in subsequent impaired force production and muscle soreness for multiple days post-exercise (Howatson and Milak, 2009). Additionally, congested schedules involving training, competition and travel and high exercise volumes may impair a team sport athletes' ability to adequately recover from potential muscle damage (Heaton et al., 2017). Due to the importance of dietary protein for muscle remodelling via provision of substrates for tissue synthesis, consumption will theoretically enhance the repair process following damaging activities and reduce markers of muscle damage (Pasiakos, Lieberman & McLellan, 2014; Poulios et al, 2019).

Milk-based carbohydrate and protein supplementation has demonstrated an ability to limit decrements in variables pertinent to team sport performance such as jumping and sprinting following exercise-induced muscle damage protocols in both male and female athletes (Cockburn et al., 2013; Kirk et al., 2017; Rankin et al., 2018, 2015) with post-exercise consumption likely more beneficial at attenuating these changes compared to pre-exercise (Cockburn et al., 2010). Additional protein supplementation without carbohydrate resulted in the mitigation of high-intensity activity following an association football-specific muscle damage protocol in competitive males (Kritikos et al., 2021). Whey protein hydrolysate supplementation following repeated sprints maintained strength during recovery and improved flexibility compared to placebo 72-hour post-intervention in active females (Brown et al., 2018). Poulios et al. (2018) measured muscle damage recovery with additional protein supplementation across a seven-day congested association football training period. Participants engaged in two simulated matches and four training sessions; experimental supplementation involved consuming 80 g protein in a pulsed fashion over a six-hour post-match recovery window, with an additional 20 g protein supplement consumed on non-game days. Greater impairments to knee flexor and extensor strength were observed for multiple days in the placebo group, alongside a greater decrease in high intensity running across the course of the second match.

The muscle damage process experience during rugby union match-play and other associated collision sports presents a unique situation. Athletes are likely to present with exercised-induced muscle damage due to the intermittent nature of play however additional impact-induced muscle damage can be expected. Impact-induced muscle damage results in contusions to the muscle, which range in severity. The resultant muscle damage, tissue necrosis and inflammatory response are likely augmented compared to the eccentric damage response (Naughton et al., 2018a). The addition of collisions to an Australian Football stimulation resulted in greater perceived soreness, inflammatory biomarkers, and impairment of vertical jump performance 48-hours post-exercise than the same protocol without collisions (Singh et al., 2011). Carbohydrate and protein co-ingestion did not positively influence muscle damage recovery or soreness following a rugby union simulation in experienced players (Roberts et al., 2011). Muscle damage induced by exercise will result in an increased protein turnover (Evans and Cannon, 1991) and structural protein degradation as evidenced by the presence of actin and myosin amino acids and collagen metabolites in circulation in the days following rugby match-play (Hudson et al., 2021). As such, dietary protein ingestion will provide a substrate for replacement of damaged myofibrillar proteins. Despite limited evidence and variable research designs in team sport athletes regarding the role of extra protein supplementation for the promotion of muscle damage recovery (Poulios et al., 2019), ensuring rugby athletes consume adequate dietary protein is of the utmost importance.

Considering the additional demands placed on amino acid metabolism and the requirement of amino acids as substrates for structural re-modelling, repair and adaptation, recommendations for dietary protein intake have been proposed in the literature. It is generally accepted that recommendations in athletes are greater than sedentary individuals with large ranges of dietary protein advised (1.2 – 2.0 g·kg·d) (Jäger et al., 2017; Thomas et al., 2016) and greater requirements if the athlete is in an energy deficit and seeking minimal lean mass loss (Helms et al., 2014; Aragon et al., 2017; Phillips, 2014; Hector and Phillips, 2018; Phillips and van Loon, 2011).

Protein dose response

The dose response to protein ingestion following resistance training in recreationally active males was examined by Moore et al. (2009a). Participants received beverages containing 0, 5, 10, 20 and 40 g protein and measurement of muscle and albumin protein synthesis, intracellular signalling molecule phosphorylation and leucine oxidation was performed. Cell signalling responses were not significantly different between protein doses. MPS and leucine oxidation were stimulated greater following 20 and 40 g than lower protein amounts, with no significant difference between 20g and 40 g. These findings were similarly observed by Witard et al. (2014) who observed greater MPS responses following ingestion of 20 g and 40 g whey protein following resistance training. No significant difference between 20 g and 40 g was observed, however phenylalanine oxidation was greater after the larger amount.

It may appear that a modest dietary protein intake following resistance training is adequate to stimulate an anabolic response. A bilateral mixture of leg exercises and a unilateral session with two exercises were employed by Moore et al. (2009a) and Witard et al. (2014), respectively. Whilst appropriate to elicit an anabolic response, larger utilisation of muscle mass during an exercise bout may differently influence the post-exercise protein requirements. Recreationally trained males completed a full-body resistance bout (three lower body exercises and latissimus pull-down) following which they consumed either 20 g or 40 g whey protein. When participants were stratified into low lean body mass and high lean body mass groups, no significant differences were observed however a combined effect was observed with 40 g whey protein resulting in a greater MPS stimulation. Additionally, phenylalanine oxidation was greater following 40 g protein ingestion.

Whilst often considered only in the context of muscle growth (Cintineo et al., 2018), protein intake is an important determinant of the endurance athletes' ability to recover from activity, promote favourable adaptations and assist the re-synthesis of muscle glycogen (Gibala, 2007). Furthermore, prolonged exercise increases protein turnover, specifically catabolism (Rennie et al., 1981; Pikosky et al., 2006), however this effect can be attenuated with consistent endurance training (McKenzie et al., 2000). The dose-response to anabolic stimulation of endurance exercise appears similar to unilateral resistance training (Churchward-Venne et al., 2020) with no additional benefit conferred from excessive consumption (Rowlands et al., 2014).

Team sport athletes engage in concurrent aerobic and anaerobic movement patterns. Upregulation of MPS but not mitochondrial protein synthesis was observed following a single bout of concurrent resistance exercise and subsequent ingestion of 25 g whey protein compared to placebo (Camera et al., 2015). Collectively, these findings suggest that the consumption of dietary protein following exercise can support and enhance the adaptive response, however the individual dose required for an optimal response is dependent on the individual anthropometric characteristics, exercise modalities and muscle mass utilisation. Additionally, none of the research concerning the protein dose response to exercise employed trained athletes, utilised sport-specific movement patterns or explored practical outcomes, meaning direct translation of the findings to practical settings may be unsuitable.

Per-meal dietary protein distribution

Daily protein distribution describes the concept that MPS is stimulated up to a "saturable dose limit" (Hudson, Bergia, and Campbell 2020); that is, MPS stimulation peaks at a certain threshold of amino acid provision and amino acids beyond this will not produce a greater anabolic response. Instead, excess amino acids beyond this limit will be contribute to greater synthesis in other tissues, will suppress protein breakdown, or will be oxidised (Atherton et al., 2010; Kim et al., 2015a). Evenly distributing protein intake at the saturable dose limit throughout the day compared to consuming sub-optimal protein at some meals may theoretically result in a greater overall anabolic response and, over a prolonged period, result in the maintenance or procurement of functional proteins (Mitchell et al., 2015).

Patterns of protein intake appear to be skewed across the lifespan, with low intakes at breakfast compared to later in the day (Cardon-Thomas et al., 2017; Hone et al., 2020; Smeuninx et al., 2020). Whilst overall daily protein recommendations were met in all groups, protein intake was <0.25 g·kg at breakfast in young, middle-aged, and old adults and <0.4 g·kg at lunch in old adults (Smeuninx et al., 2020). In athletes, protein intake was skewed in various disciplines (Anderson et al., 2017; Gillen et al., 2017), however youth and senior elite soccer players appear to distribute protein intake similarly across the three main meals (Bettonviel et al., 2016).

The influence of protein distribution on acute protein synthetic responses has been explored by numerous groups. Mamerow et al. (2014) measured protein synthesis rates following seven-day habituation to either an even distribution of protein across three meals or a disproportionate, isoenergetic and isonitrogenous intake. The authors observed significantly greater protein synthesis following both a 30 g vs. 10 g breakfast and following habituation to the even protein distributed diet from day one to seven (Mamerow et al., 2014). A comparison of multiple even distribution patterns was performed by Areta et al. (2013). In the post-resistance training period, trained males consumed 80 g whey protein evenly distributed over one of three conditions: eight x 10 g, four x 20 g and two x 40 g feeding occasions. The researchers demonstrated that ingestion of four x 20 g servings of whey protein resulted in greater daily MPS rates than the other conditions, however intracellular signalling responses associated with protein synthesis were greater following two x 40 g servings.

An even protein distribution can result in positive clinical outcomes for lean mass and muscle performance (Arciero et al., 2013; Bollwein et al., 2013; Loenneke et al., 2016; Hayashi et al., 2020) and body fat loss (Arciero et al., 2013; Farsijani et al., 2020). An incremental decreased odds of physical disability was observed in older adults when ≥0.25 g·kg protein was consumed at up to four meals (McGrath et al., 2020). In younger untrained men Yasuda et al. (2020) demonstrated that a sub-optimal intake of protein at breakfast may result in less lean mass accretion than an even distribution across the three main meals, however increased protein intake at specific meals does not confer benefit in all studies. No association was found in older adults between muscle mass and strength the number of meals containing 0.4 g·kg·d protein by Gingrich et al. (2017), however the number of meals providing 0.4 g·kg·d protein and 2.5g leucine daily were 0.72 and 1.11, respectively. This may not be enough to stimulate an anabolic response in this population, with nearly 6 g leucine being estimated as a requirement for the population studied based on recent work by Szwiega et al. (2021).

Experiments conducted in the Arciero lab have sought to investigate how protein distribution (termed 'protein pacing' by the investigators) may influence a variety of clinical outcomes. Distributing a high-protein intake (35% total energy) throughout the day can increase diet-induced thermogenesis, as shown in overweight individuals following both a four-week energy balance and four-week energy deficit phase compared to moderate protein (16%) across three meals or high protein (35%) across three meals (Arciero et al., 2013).

The clinical benefits of an even protein distribution may translate to athletic populations, however this concept has been poorly studied. In a sample of 24 elite developing rugby athletes, MacKenzie-Shalders et al (2016) observed whether consumption of a whey protein supplement (23 g protein) either alongside or between main meals over a six-week period influenced lean mass levels. No significant difference was observed in lean mass between conditions (+1.4 ± 1.5 kg & 1.5 ± 1.4 kg in the at meals or between meals conditions, respectively). The authors note a high daily protein intake in both the at meals (2.7

± 0.6 g·kg) and between meals (2.6 ±0.6 g·kg) group, suggesting an adequate protein intake at least three occasions throughout the day (0.9g·kg at three meals assuming no other meals are consumed). As such, a greater frequency of protein feeding may not be required to optimise lean mass gains in this cohort. Similarly, (Taguchi et al., 2021) observed no significant difference between consuming a high-protein diet (2.6 – 2.7 g·kg·d) on lean mass gains in university rowers when either three or six meals were consumed for eight weeks.

Due to the inconsistencies in results from current studies, Hudson et al. (2020) conclude that promoting a theoretically-optimal daily protein distribution is not warranted over total daily protein intake for positive muscle-related outcomes. Considering most studies identified by the authors were in non-exercising elderly individuals and were largely observational in nature, the translation to athletic populations is inconclusive. As such, further exploration into the effects of daily dietary protein distribution on muscle, performance and health-related outcomes in athletes is warranted.

Carbohydrate

Carbohydrates represent a diverse group of substances that play a central role in energy metabolism in humans (Cummings and Stephen, 2007). A minimum intake of 130 g of carbohydrate per day (Murray and Rosenbloom, 2018) is recommended to support energy production for the brain, of which glucose is a preferred substrate for neurons (Brown and Ransom, 2007). Additionally, glucose is utilised rapidly to support muscle contraction; whilst creatine phosphate provides immediate phosphates to ADP following the onset of contraction this is quickly overwhelmed, and glycolytic metabolism allows for the sustained re-synthesis of ATP (Greenberg et al., 2006). Carbohydrate stores in the body are limited, with ~350-700 g stored in skeletal muscle for localised energy provision; the amount stored will vary depending on training status, diet, muscle fibre and body composition and sex (Knuiman et al., 2015). A further ~100 g is stored in the liver (Knuiman et al., 2015) to facilitate the maintenance of euglycemia when fasted (Gonzalez et al., 2016).

Carbohydrate for athletes

A century ago, carbohydrate was identified as a more economical source of energy provision for working skeletal muscle than fat (Krogh and Lindhard, 1920). In the 1960s, the importance of muscle glycogen as a fuel source for exercise metabolism was highlighted. Muscle biopsies were drawn in seminal studies in which the relationship between muscle glycogen content and work capacity during prolonged exercise was established (Ahlborg et al., 1967). It was observed that greater carbohydrate consumption both greatly enhanced muscle glycogen content and endurance exercise capacity (Bergström et al., 1967) and that muscle glycogen is a localised source of energy production, only utilised within working skeletal muscle (Bergström and Hultman, 1966). Additionally, biopsy analysis demonstrated an enhancement of localised muscle glycogen re-synthesis following exhaustive exercise (Bergström and Hultman, 1967) and the timing of carbohydrate ingestion may influence the degree of glycogen re-synthesis post-exercise, with a significant reduction in glycogen re-synthesis over a four hour period when carbohydrate feeding was delayed by two hours compared to immediately ingested following a variable-intensity cycling protocol (Ivy et al., 1988).

The intermittent sprints, great distances covered during matches and high-intensity movement patterns such as jumps, and tackles ensure carbohydrates represent a vital component of the rugby athletes' diet. Both glucose and dietary fat can be aerobically metabolised, however the process is slower than anaerobic metabolism (Williams and Rollo, 2015). Glucose, either from the blood or glycogen stores, can undergo rapid metabolism via glycolysis allowing for fast re-synthesis of ATP. During a 30 second sprint, glycolysis may represent ~60% of the ATP produced, with the majority remainder from the phosphocreatine energy system (Cheetham et al., 1986). Despite the benefits to endurance performance via ingestion of multiple-transportable carbohydrates (King et al., 2018), their consumption was not able to better enhance recovery and subsequent performance in rugby union athletes (Hengist et al., 2021). Between two bouts of rugby-specific small-sided games separated by three hours, participants consumed 0.3 g·kg.h whey protein alongside 0.8 g·kg.h of either glucose or a glucose-fructose blend. Whilst subsequent performance was maintained, the choice of carbohydrate did not result in significant differences (Hengist et al., 2021).

Metabolic analysis immediately following rugby union match-play indicates that glycolysis and gluconeogenesis via protein degradation play major roles in the production of energy due to the increased presence of lactate and alanine (Hudson et al., 2021). Carbohydrate recommendations for the rugby player will vary based on the daily training volume and level of play. Broadly, intakes between 3-7 g·kg are recommended (Burke et al., 2011) with elite athletes engaging in multiple daily training sessions likely to benefit from consumption at the higher end of said recommendations. Furthermore, carbohydrate intake may be strategically manipulated during the day and throughout the week to promote optimal muscle glycogen saturation for matches (Bradley et al. 2015; Posthumus et al. 2021; Williams and Rollo 2015).

Numerous authors have detailed the carbohydrate intakes of both professional and semi-professional rugby union players, which are presented in Table 1. Muscle glycogen is a major fuel source for ATP resynthesis during a rugby match, with professional players demonstrating a significant reduction in muscle glycogen content following simulated rugby matches (Bradley et al., 2017, 2016). Sixteen professional players completed a simulated rugby league match and experienced significant *vastus lateralis* muscle glycogen depletion following either 36 hour high-carbohydrate (6 g·kg·d; 45 ± 9.5%) or low-carbohydrate (3 g·kg·d; 38.2 ± 17.5%) intake. Additionally, Bradley et al. (2017) reported lower reductions in muscle glycogen concentration in athletes habituated to a 7-day 6 g·kg·d carbohydrate diet post-simulation. Athletes consuming carbohydrates immediately following exercise demonstrated a significantly greater glycogen repletion rate (51 ± 47%) compared to when feeding was delayed by two hours (24 ± 49%) 48 hours following rugby league simulation. Such an observation is not surprising based on the observations of Ivy et al. (1988). Despite being rugby league simulations, the fundamental movements and match-play time (Geeson-Brown et al., 2020) are similar enough to extrapolate and suggest rugby union may induce similar levels of depletion. Nonetheless, individual on-pitch demands, other nutrition practices and variability in movement patterns between games may influence the rates of both pre- and post-match glycogen levels. As glucose is a preferred substrate for neuronal ATP-provision (Brown and Ransom, 2007) carbohydrate ingestion prior to engaging in rugby activity may improve tackling technique (Dobbin et al., 2022). Association football players may benefit from improved skill performance when carbohydrate ingestion occurs both prior to and during activity (Russell and Kingsley, 2014); whilst the demands are different to rugby, both athletes engage in intermittent sprints and apply decision making during match-play.

Table 1. Reported energy and macronutrient intake of male rugby union players

							Absolute				Relative					
Author	**Year**	**Country**	**Age**	**Body Mass**	**Participants (n)**	**Level**	**Energy (kcal)**	**Protein (g)**	**CHO (g)**	**Fat (g)**	**Energy (kcal·kg)**	**Protein (g·kg)**	**CHO (g·kg)**	**Fat (g·kg)**	**Assessment Method**	**Duration of Assessment**
Black et al.	2019	New Zealand	Weight gain: 23.4 ± 3.1 Weight maintenance: 24.6 ± 1.8 Weight loss: 23.6 ± 2.3	106.3 ± 13.3 kg	23	Professional	3875 ± 907					2.1 ± 0.4	3.7 ± 1.2	1.6 ± 0.5	Mixed methods – RFPM and researcher observations	3 days
Bradley et al.	2015	United Kingdom	Forward: 24.4 ± 4.0 Back: 24.2 ± 2.0	Forward: 108.1 ± 7.5 Back: 89.5 ± 5.0	20	Elite	Forward: 14.8 ± 1.9 Back: 13.3 ± 1.9 (MJ)					Forward: 2.5 ± 0.3 Back: 2.6 ± 0.2	Forward: 3.3 ± 0.7 Back: 4.1 ± 0.4	Forward: 1.0 ± 0.3 Back: 1.0 ± 0.3	Dietary recall	2 × 2 training days
Bradley et al.	2015	United Kingdom	Forward: 28.0 ± 2.8 Back: 25.1 ± 3.8	Forward: 110.1 ± 6.2 Back: 93.6 ± 5.9	14	Elite	Forward: 16.6 ± 1.3 Back: 14.2 ± 1.2 (MJ)					Forward: 2.7 ± 0.5 Back: 2.7 ± 0.3	Forward: 3.5 ± 0.8 Back: 3.4 ± 0.7	Forward: 1.4 ± 0.2 Back: 1.4 ± 0.3	Estimated food diary	6 days
Burrows et al.	2016	Australia	16.0 ± 2.0	76.5 ± 10.0	25	Sub-elite	10,372 ± 4974 (KJ)	108.1 ± 75.9	317.0 ± 153	88.5 ± 54.9		1.5 ± 0.9	3.6 ± 2.4		FFQ	
Hitendre et al.	2022	United Kingdom	23.0 (21.5, 27.5) (Median/IQR)	96.6 ±10.8	24	Semi-professional	2472 (1767, 3374) (Median/IQR)	139.8 ± 51.1	266 (199, 341) (Median/IQR)	97.0 (68.3, 150.3) (Median/IQR)	26.3 ± 9.2	1.4 ± 0.4	3.0 (2.0, 3.0)	36.2 ± 3.7	FFQ	

Hudson et al.	2021	United Kingdom	20.0 ± 2.7	102.5 ± 13.7	7	Professional	3323 ± 630					2.4 ±0.3	3.2 ± 0.4		RFPM	7 days
Imamura et al.	2013	Japan	Forward: 19.5 ± 0.9 Back: 19.5 ± 1.0	Forward: 87.3 ± 8.9 Back: 72.6 ± 7.4	34	Collegiate	Forward: 3579 ± 848 Back: 2963 ± 111	Forward: 92.7 ± 22.3 Back: 79.9 ± 31.5	Forward: 567.0 ± 160.1 Back: 457.4 ±192.2	Forward: 91.5 ± 25.0 Back: 77.2 ± 30.8					FFQ	1-2 months
MacDougall et al.	2015	USA	30.2 ± 1.1		15	Collegiate	2378 ± 126					1.7 ± 0.8	3.4 ± 1.1		Dietary recall	3 days
MacKenzie et al.	2015	Australia	20.5 ± 2.3	100.2 ± 13.3	25	Developing elite	3250 ± 869	211.0 ± 62.0	352.0 ± 115.0	101.0 ± 34.0		2.2 ± 0.7	3.6 ± 1.3	1.1 ± 0.5	Food record	7 days
Posthumus et al.	2021	New Zealand	27.6 ± 2.8	103.0 ± 13.6	34	Professional	Forward: 4606 ± 719 Back: 3761 ± 618	Forward: 280 ± 39 Back: 220 ± 37	Forward: 399 ± 77 Back: 340 ± 59	Forward: 210 ± 43 Back: 169 ± 41	Forward: 40.5 ± 7.2 Back: 41.9 ± 7.2	Forward: 2.5 ± 0.4 Back: 2.4 ± 0.5	Forward: 3.5 ± 0.8 Back: 3.7 ± 0.7	Forward: 1.8 ± 0.4 Back 1.8 ± 0.5	RFPM	7 days
Potgieter et al.	2014	South Africa	N/A*	N/A*	11	Collegiate					45.4 ± 9.0	2.4 ± 0.7	4.3 ± 0.4	1.9 ± 0.5	Mixed-methods – food record and 24 h recall	7 days
Smith et al.	2016	United Kingdom	Under 16: 15.8 ± 0.5 Under 19: 18.1 ± 0.8	Under 16: 83.7 ± 12.3 Under 19: 91.4 ± 13.4	52	Elite academy	Under 16: 3269 ± 766 Under 19:3412 ± 670	Under 16: 155.4 ± 56.4 Under 19: 210.7 ± 46.7	Under 16: 392.2 ± 108.2 Under 19: 416.2 ± 107.2	Under 16: 112.3 ± 34.2 Under 19: 111.8 ± 34.8	Under 16: 37.9 ± 10.4 Under 19: 38.2 ± 9.8	Under 16: 1.9 ± 0.6 Under 19: 2.3 ± 0.5	Under 16: 4.8 ± 1.1 Under 19: 4.7 ± 1.4	Under 16: 1.4 ±0.5 Under 19: 1.3 ± 0.5	Food record	4 days

Zyla et al.	2014	Poland	Forward: 24.0 ± 4.3 Back: 22.0 ± 1.7	Forward: 92.6 ± 14.7 Back: 80.8 ± 8.6	44	Amateur	3613 ± 943	157.7 ± 51.6	404.5 ± 128.4	158.3 ± 52.1		1.9 ± 0.7	4.8 ± 1.7	1.9 ± 0.7	Dietary recall	3 days

Fat

Dietary fat is recognised as a crucial consideration of the diet; consumption allows for the meeting of requirements for essential fatty acids (Desbrow, 2021), the transportation and facilitation of the intestinal absorption of the fat-soluble vitamins (A, D, E, K), structural components of cell membranes (Thomas et al. 2016) and provision of a concentrated source of energy to the body (Lichtenstein et al., 1998). Dietary fat stores are significantly richer in energy than endogenous carbohydrates, both due to the greater absolute stores (Newsholme, 1981) and per gram (Rolls, 2000). Triglycerides, free fatty acids and adipose stores represent major sources of metabolic energy production during both fasted resting and light intensity exercise bouts (RER ≤ 0.85); only when RER exceeds this do carbohydrates become the predominant source of metabolic fuel (Lowery, 2004).

Fat for athletes

Recommendations for dietary fat intake in athletes tend not to be expressed relative to body-weight. Within energy requirements athletes are advised to prioritize protein and carbohydrate and consume 20 – 35% total energy intake in the form of dietary fat (Broad and Cox, 2008). Whilst dietary fat recommendations are provided in a broad range, the source of these fats may be of greater consideration for long-term health of the athlete. A recent Cochrane review of RCTs suggests prolonged reduction of saturated fat intake can reduce the risk of experienced adverse cardiovascular events (Hooper et al., 2020). Increasing both saturated and trans-fat intake are associated with increased all-caused and CVD mortality (Kim et al., 2021). The WHO recommends limiting saturated fat and *trans*-fat intake to <10% and <1% of total energy intake, respectively (World Health Organization, 2020). Furthermore, the replacement of these fats with unsaturated fats, particularly polyunsaturated fats, is recommended (World Health Organization, 2020; Hooper et al., 2020) with increased PUFA consumption associated with a reduction in CVD mortality (Kim et al., 2021).

Excess fat intake, at the expense of dietary carbohydrates, has been postulated to enhance prolonged exercise performance due to adaptation to said dietary pattern increasing skeletal muscle fat utilisation capacity (Burke, 2015). Reducing exogenous carbohydrate provision will result in a depletion of muscle glycogen and a shift towards fat utilisation; as fat is of greater abundance in the body this theoretically allows for greater energy production (Volek et al., 2015) particularly in endurance-trained athletes who can expect enhanced fat oxidation as an adaptation of this training (Achten and Jeukendrup, 2004). Despite this hypothesis, literature does not support a performance benefit when adopting a HFLC diet. Meta-analysis data indicates that a ketogenic HFLC diet significantly reduces RER, however no significant difference between habitual diets and KHFLC diets was observed for Vo2 max, time to exhaustion, maximal heart rate or RPE (Cao et al., 2021). As dietary habituation for the included studies ranged from five days to 12 weeks and participants were variably endurance- trained further research is required to elucidate the influence of macronutrient composition on endurance performance in different populations.

High-intensity activities will typically demonstrate a greater RER, indicating a shift of substrate utilisation towards carbohydrates. Muscle uptake of glucose and oxidation of glycogen increase linearly with exercise intensity, whereas lipolysis is stimulated greater at low intensity exercise levels and fatty acid release from adipocytes decreases as exercise intensity increases (Romijn et al., 1993). Indeed, whilst carbohydrate oxidation appears to increase linearly with exercise intensity, fat oxidation increases from 25% to 65% of VO2max then decreases at 85% VO2max (Achten and Jeukendrup, 2004) an intensity of which may be expected during a rugby match (Cunniffe et al., 2009). As such, during exercise modalities that incorporate high-intensity movement patterns impairments may be expected when carbohydrate intake is compromised for dietary fat ingestion.

Fat for rugby

As displayed in Table 1, fat intake is presented in numerous studies that report overall energy and macronutrient intakes in rugby players, however these are likely considered of lower importance than protein and carbohydrate to report due to the inherent importance of protein (lean mass, muscle re-modelling and adaptation) and carbohydrate (substrate for both prolonged and high-intensity performance) for these athletes. Nonetheless, aerobic metabolism contributes significantly to the demands of the rugby player; greater aerobic contributions to energy metabolism during repeated sprints occur as time progresses (Bogdanis et al., 1996). As such, provision of both endogenous and exogenous triglyceride represents a major source of energy provision for the rugby athlete.

Diet Quality

Athletes represent a unique population in that specific meal patterns are recommended in relation to timing and nutrient composition to best optimise performance and recovery. Additionally, due to the high energy costs associated with physical activity (Capling et al., 2021) in certain athletic disciplines, a greater consumption of food and beverages is often warranted. Despite much sports nutrition research focusing on determining optimal timings and quantities of nutrients around training and competition, ensuring a high-quality and nutrient-sufficient diet is of the utmost importance for both athleticism and health (Capling et al., 2021; Burrows et al., 2016).

Due to the provision of vital micronutrients, fluids and fibre, fruit and vegetable intake may be an indicator of diet quality. Recommendations for fruit and vegetable intake are typically around five servings per day, which may vary by country or organisation (Ministry of Health, 2020). In a cohort of athletes from various disciplines, fruit (2.4 ± 1.0) and vegetable (3.6 ± 1.1) intake may meet recommendations (Capling et al., 2021). The diet quality of adolescent male rugby union players was assessed via a validated diet quality index. Intakes of iron and calcium, nutrients of importance for developing individuals, were above recommendations. Despite this, the average serving of vegetables was significantly below recommendations; athletes consuming a median of 5.8 servings of fruit and vegetables, with only 1.1 of these coming from vegetables (Burrows et al., 2016). Smith et al. (2016) identified fruit and vegetable intakes above recommendations in U19 rugby union players but not U16. Inadequate fruit (0.82 ± 0.64), vegetable (1.3 ± 0.81) and fibre (18.8 ± 6.3) daily servings were observed in club rugby players (Macdougall et al., 2015).

Determinants of food choices

Nutrition recommendations for athletic activities vary depending on the activity modality, current body composition, competition demands, goals for adaptation and training cycle (Jenner et al., 2019). As mentioned, broad macronutrient recommendations for athletes (Jäger et al., 2017; Burke et al., 2011; Thomas et al., 2016) and manipulation of meal timing to promote optimal performance and recovery (Jeukendrup, 2017; Mujika et al., 2018) may contribute to an athletes' food choices.

Despite this, individuals' dietary intake is dictated by more than the requirement for training and competition. Determining food choices is a multi-factorial and complex decision that is influenced by personal beliefs and ideals, taste, social factors, body composition desirability and availability of food and resources (Sobal and Bisogni, 2009; Heaney et al., 2008; Klein et al., 2021). Cost and convenience are major factors influencing an athletes' food choices, particularly in developing athletes who often receive little to no financial support for their engagement in sport (Eck and Byrd-Bredbenner, 2021; Heaney et al., 2008; Birkenhead and Slater, 2015; Stokes et al., 2018; Jagim et al., 2021). Rugby players with large overall nutrient requirements due to greater body mass and training demands may face difficulty meeting these due to food volume (Black et al., 2018) and cost (Eck and Byrd-Bredbenner, 2019) presenting a barrier; this issue will be exacerbated if the athlete is required to gain lean mass (Eck and Byrd-Bredbenner, 2019; Black et al., 2019).

Upbringing can influence nutrition habits and relationships with food progressing into adulthood (Ono et al., 2012), with rugby players growing up in larger families perceiving their dietary choices to be sub-optimal (Sharples et al., 2021). Additionally, family and friends may provide nutrition advice and recommendations, information of which may be positive or negative depending on the beliefs and knowledge of those imparting the advice (Trakman et al., 2019; Stokes et al., 2018). Traditional and social media represent major sources of nutrition information for athletes particularly when limited direct nutrition support is provided (Sharples et al., 2021; Birkenhead and Slater, 2015; Klein et al., 2021; Trakman et al., 2019). Collectively, these can be problematic as athletes may adopt misinformation and bad dietary practices. Indeed, the sports nutrition practitioner has a difficult job in facilitating not only the meeting of nutrient requirements for optimal athleticism but understanding individuals' motives, facilitators and barriers to ideal dietary practices.

Nutrition knowledge is a major factor determining food choices by athletes; a lack of understanding of energy and macronutrient requirements for health and performance, considerations for a nutrient-dense diet and confounding from unreliable sources such as social media and team-mates may lead an individual to adopt a nutrient-insufficient diet (Jagim et al., 2021). As such, athletes presenting greater nutrition knowledge are likely to meet energy requirements (Jenner et al., 2018) and consume more fruit and vegetables (Vázquez-Espino et al., 2022; Spronk et al., 2015; Jenner et al., 2018).

Nutrition knowledge in athletes may be partly dictated by the knowledge, attitudes and beliefs of influential figures such as coaches or senior members of staff. (Andrews et al., 2016). This is particularly likely at amateur and developmental levels, where access to sports nutrition professionals may be minimal. In New Zealand club rugby environments, many coaches appeared to provide athletes with nutrition advice whilst likely not demonstrating appropriate knowledge levels themselves (Zinn et al., 2006). Additionally, developing athletes may seek to emulate dietary practices demonstrated by senior players in the hope of achieving similar body composition, adaptation, and performance outcomes (Long et al., 2011); advice and information may be distributed amongst peers (Stokes et al., 2018).

Providing education is a staple role of the sports nutrition practitioner (Trakman et al., 2016). Provision of nutrition education interventions in team sport athletes may result in improvements in nutrition knowledge, dietary intake and body composition related to food choices, energy, and macronutrient intake in athletes (Sánchez-Díaz et al., 2020; Tam et al., 2019; Boidin et al., 2021). Despite this, significant variability in the methods, length, and contact time during delivery of education, methods for analysing nutrition knowledge and intake and participants means the impact of such services is inconclusive. Furthermore, the incorporation of nutrition practitioners into team environments is likely to be of more benefit to athletes as it allows for greater exposure and accountability with nutrition-related services (McCabe et al., 2021).

Athletes in professional environments are likely to receive individualised nutrition support, access to qualified practitioners and extra services to support their health, performance, and recovery. Prior to this, nutrition support is likely to be generic advice (Beck et al., 2015) from individuals lacking appropriate knowledge (Zinn et al., 2006). The importance of ensuring nutrient intake in provincial academy rugby players in New Zealand supports health, performance and recovery is paramount. Furthermore, nutrition periodisation accounting for congested schedules and optimising fuel availability and adaptive responses (Mujika et al., 2018) indicates the developing athlete would benefit from full-time practitioner support (Hull et al., 2016, 2017). Team-sport athletes indicate this is preferred (Trakman et al., 2019) and the provision of individual consultation and support beneficial (Jenner et al., 2018). As such, the evaluation of such services in the provincial rugby athlete in New Zealand is warranted.

Summary

To summarise, rugby is an intense sport with high-intensity and intermittent movement patterns, collisions and high training volumes contributing to large energy expenditures. Additionally, variability in body composition and match demands will result in players requiring specific consideration for nutritional requirements to ensure energy sufficiency, optimise performance and adaptation, and reduce injury and energy insufficiency risk. Broad recommendations for rugby players regarding carbohydrate and protein intake are typically advised, alongside the consumption of a micronutrient-dense diet. Whilst sports nutrition practitioners are expected to facilitate this practice in athletes in their care, access to such individuals is often limited and as such, individuals may not be receiving evidence-informed advice and recommendations. Whilst it is acknowledged that developing athletes would benefit from full-time support no research investigating the impact of this in an environment where prior support is limited has been conducted.

Mechanistic research suggests that the distribution of dietary protein throughout the day may be beneficial for promoting an anabolic response following exercise, with 0.4 g·kg advised to be consumed across 4-6 evenly spaced feedings daily. Despite this, no research detailing the relative intake across meals in rugby players has been published, and the wider impact on recovery in a rugby context warrants investigation to ensure best-practice recommendations are made.

Dietary analysis in athletes

Assessment of the diet is required to ensure the athlete is not only in a state of nutritional adequacy but that their food and beverage intake reflects the demands of the sport and training. A variety of tools have been used within practical and research settings to track food and beverage choices and thus quantify nutrient intake in athletes.

Food frequency questionnaires and dietary recalls represent common retrospective methods of assessing dietary intake. Despite being easier to administer than prospective methods their validity is questionable for the analysis of habitual intake due to under-reporting (Larson-Meyer, 2019); an inability to accurately recall food and beverages consumed (Schoeller, 1995) via both memory lapses and misjudging true portion sizes (Poslusna et al., 2009) likely contributing to variability in estimated nutrient intake.

Prospective food intake is measured via weighed food diaries (Magkos & Yannakoulia, 2003). In athletic populations, 3-14-day food diaries are commonly used to assess dietary intake (Larson-Meyer et al., 2018). Variability in dietary patterns and food choices mean that such monitoring periods may still not be representative of ones' overall nutrition status (Larson-Meyer et al., 2018), however employing a greater number of days is likely to induce recording fatigue and thus potential under-reporting (Trabulsi & Schoeller, 2001).

Accurate reporting of food intake and subsequent analysis of nutrition content has long been recognized as challenging for researchers and practitioners working with athletes (Braakhuis et al, 2003). Discrepancies in reported energy intake and expenditure in prolonged body-weight stable athletes suggest that energy intake is under-reported in these individuals (Mulligan & Butterfield, 1990). Prior to the development of DLW for assessing free-living energy expenditure, it was believed that athletes were more 'metabolically efficient' and thus able to operate and compete with lower energy intake than expenditure (Hill & Davies, 2001). Dietary recalls, weighed food diaries, and food frequency questionnaires are self-reported and as such they are prone to bias and under-reporting (Capling et al, 2017). Unconscious dietary under-reporting may be due to individuals forgetting to record meals or snacks consumed (Maurer et al., 2006). Athletes may selectively under-report due to social desirability bias (Scagliusi et al., 2003; Vuckovic et al., 2000) or the perception that certain foods may not align with body composition goals (Jenner et al., 2018; Maurer et al., 2006). Measuring habitual diet over a prolonged period is difficult as methods presenting theoretically superior accuracy impose a high burden on participant (Stumbo, 2013; Thompson & Subar, 2017) and may lead to lack of compliance, misreporting or adjustment of the diet to reduce the burden (Vuckovic et al., 2000; Ferraris et al., 2019). Self-reported methods for measuring food intake in collision sport athletes include food diaries of variable lengths (MacKenzie et al, 2015; Bradley et al, 2015; Smith et al, 2016), FFQs (Alaunyte et al, 2015) and dietary recalls (Bradley et al, 2015).

Recently, nutrition practitioners and researchers have capitalised on the wide-spread use of visual technologies such as wearable cameras and mobile phone applications to reduce participant burden and improve the accuracy of dietary intake (Pettitt et al., 2016; Stumbo, 2013). Utilising such technologies or implementing them alongside traditional methods may allow participants to accurately record food intake with a much lower burden; thus, a greater likelihood of consistent measurement may be expected (Boushey et al, 2016). Compared to using an estimated food diary alone, energy intake across a single day was reported to be greater in trainee jockeys (10.7%), elite Gaelic footballers (17.7%) and physically active university students (10.1%) when combined with a wearable camera (O'Loughlin et al, 2013).

The Snap-N-Send methodology, whereby participants send a photograph of their meals and foods against a grid to standardize portion sizes, was validated in adolescent male rugby league players across various free-living and researcher-observed periods (Costello et al, 2017). Participants received pre-weighed food and drinks for the free-living assessment period. During the researcher-observed period, food and beverages were again weighed and available *ad libitum* to participants in a laboratory setting. The authors noted that energy intake was significantly under-reported using Snap-N-Send across all free-living and researcher-observed periods, however the degree of under-reporting was less when compared to an estimated food diary (Costello et al, 2017). As athletes appear to better prefer and report positive experiences with taking food photographs compared to traditional methods of dietary logging (Simpson et al, 2017) it appears logical to apply such methods in practical settings.

Costello et al (2018) used an image-based application in conjunction with assessment of energy expenditure via DLW during pre-season training and established that eating habits in professional rugby league players are likely not appropriate to compensate for the energy expended. Awareness of the potential downsides with image-based dietary assessment is important. Practitioners assessing the pictures must be well-trained enough to accurately distinguish food and portion sizes. Furthermore, there is still the potential for participants to either willingly or unwillingly omit certain foods from measurement (for example, if they deem the food 'unhealthy' and are embarrassed about consumption).

Whilst such technologies may provide a low burden and accurate method of recording dietary intake, large inter-individual variation may be apparent in those analysing images of food and meals. Stables et al (2021) assessed the ability of both experienced and inexperienced sports nutrition practitioners to accurately identify energy and macronutrient intake in simple and complex meals using the snap-n-send methodology. Simple meals were those presented such that each component of the meal could be easily identified, whereas complex meals such as a stir-fry contained 'hidden' ingredients. The authors observed underestimation for energy and intake in both practitioner groups for both meals, whilst the protein intake of complex meals was underestimated by both groups. Protein intake was estimated to be higher for simple meals by the experienced group but not the inexperienced group than the actual nutrient content; this is an interesting observation as it indicates that level of experience in the nutrition field may not translate to accurate estimation of photos. Considerable variance was observed in the estimation values between practitioners for all nutrients, particularly for complex meals (Stables et al, 2021). Within a practical setting, this is likely to be how food and meal images will be presented by athletes and participants and as such must be considered when interpreting results both in practice and research.

To summarise, conducting accurate dietary analysis is a major component of the sports nutrition practitioner role, however the practice is prone to error. Additionally, the collection of dietary intake data is confounded by the impracticality of the practice. As such, the use of technology to assist practitioners has gained popularity in recent years. Whilst preliminary research suggests validity and acceptability of the RFPM in athletes, the adoption of the tool in practical situations that athletes are most likely to benefit from utilising such a tool is unknown. As such, the ecological validity of such technologies requires further investigation.

Chapter 3: The influence of COVID-19 lockdown restrictions on perceived nutrition habits in rugby union players

Roberts, C. J., Gill, N., & Sims, S. (2020). The Influence of COVID-19 Lockdown Restrictions on Perceived Nutrition Habits in Rugby Union Players. Frontiers in Nutrition. https://doi.org/10.3389/fnut.2020.589737

Roberts, C., Gill, N., & Sims, S. The Influence of COVID-19 Lockdown Restrictions on Perceived Nutrition Habits in Rugby Union Players, oral presentation at conference, *Sport and Exercise Science New Zealand conference*, Christchurch, New Zealand (November 2020)

Prelude

On 25th March 2020, New Zealand entered Alert Level Four lockdown restrictions in response to the rapid global spread of COVID-19. The implementation of lockdown restrictions required all but essential businesses to close. Essential businesses, such as supermarkets, pharmacies, and general practitioners, were allowed to remain open with hygiene measures implemented such as the wearing of masks, provision of hand sanitiser and encouragement of social distancing between individuals. Furthermore, mixing of individuals from different households was prohibited.

Engagement in rugby activities was adversely affected by lockdown measures, with individuals unable to attend training venues typically frequented such as gyms and clubs. Additionally, players were unable to train with team-mates and under the direct supervision of coaches. Finally, games were forced to cancel, thus interrupting the playing season for many individuals.

Collectively, these restrictions suggest training and nutrition habits were likely influenced. As restrictions were implemented during the initial data collection period of the present thesis, the following chapter is presented chronologically, with the aim of exploring the perceived impact of said restrictions on training and nutrition habits in rugby players.

Abstract

The global outbreak of COVID-19 has led to governments and local authorities implementing nationwide lockdowns to encourage social distancing and minimize the spread of the virus. Only essential businesses have been able to remain open, with non-essential businesses and activities either closing or restricting services. With no group training sessions allowed, cancelled matches, an inability to work and the closure of eating establishments, Rugby Union players have experienced disruption to their daily lives. Two surveys were distributed among Rugby Union athletes to explore (1) the influence of COVID-19 lockdown restrictions on Rugby Union players' nutrition and training habits and (2) how nutrition habits in New Zealand Rugby Union players change after lockdown restrictions were lifted. In total, 258 respondents completed Survey 1 (84.1% male, 26.4% professional/semi-professional). Of the respondents, 58% indicated they lived with family during lockdown. Total food intake was reported to be higher in 36% of respondents. Fruit and vegetable intake was lower (17%) and packaged/convenience food intake higher (26%) in a minority of respondents. In total, 106 respondents completed Survey 2 (84.9% male, 34.0% professional/semi-professional). Of the respondents, 72% prepared and 67% purchased their own food. Less than half of respondents consumed high-protein food more than twice daily either during or following lockdown. Motivation to train and exercise was greater in 58% of respondents following lockdown compared to during lockdown. Dieticians and nutritionists within clubs provided most of the nutrition knowledge to athletes however other unreliable sources were identified, such as social media and family members. The ongoing pandemic has presented significant challenges for athletes concerning training and nutrition habits and the current study provides some insight into these. Coaches and performance staff should ensure athletes receive appropriate nutritional and training support whilst being aware of the unique demands the individuals may face.

Introduction

COVID-19 is a novel strain of coronavirus that can cause severe acute respiratory distress. It is spread via droplets generated by sneezing, coughing, or talking and is therefore easily transmitted between humans. COVID-19 was declared a global pandemic by the World Health Organization on 11th March 2020 (World Health Organisation, 2020) and measures have been implemented by governments and local authorities to minimize the spread of the virus. These measures include social distancing (aiming to keep people from different households separate unless required) and rigid hygiene protocols (wearing masks when out in public, regular washing and sanitizing of hands and surfaces). The implementation of these guidelines has since resulted in global travel bans and restrictions on engaging in activities deemed “non-essential”.

In New Zealand, Alert Level Four lockdown restrictions were enforced between 25th March 2020 and 27th April 2020, with businesses that aren't deemed essential such as supermarkets and pharmacies being forced to close. Between 27th April 2020 and 13th May 2020, Alert Level Three was enforced in New Zealand which brought around changes (e.g., fast food establishments could operate a take-away service only), however gatherings of more than 10 people from different households were not permitted. Following the reduction to Alert Level Two on 13th May 2020, which allowed for most restaurants, businesses, and activities to resume provided appropriate contact tracing, social distancing and hygiene rules were enforced, most people were able to resume habitual activities. On 8th June 2020, Alert Level One meant no restrictions were enforced in New Zealand with the exception of border entry being strictly controlled to allow only citizens and permanent residents entry following a two-week quarantine.

Organizations and individuals involved in sport and physical activity have experienced significant restrictions due the COVID-19 social distancing measures. Sporting events at all levels, from schools and clubs to large international events such as the 2020 Olympic Games, have been cancelled or postponed. This has resulted in organized training sessions being deemed non-essential with many athletes forced to reduce their training volume drastically. Additionally, stresses related to illness and health, economic uncertainty and prolonged social isolation may lead to unfavourable or additional mental health outcomes in athletes (Mattioli & Puviani, 2020; Pfefferbaum & North, 2020).

Engaging in regular physical activity has been encouraged (Dwyer et al., 2020) although social distancing guidelines may affect team and contact sports. Although some athletes were able to continue training and preparing for competition, sports requiring physical contact face additional issues surrounding training preparation. Rugby is a combative sport with a high incidence of players engaging in physical contact in the form of tackles, rucks, mauls, and scrums (Deutsch et al., 2007) thus social distancing guidelines have particular relevance to collision-based team sport athletes. Rugby athletes have been unable to participate in sport-specific activity during lockdown restrictions, which vary from country to country. Strict lockdown measures restricting access to habitual training environments and contact with other players mean coaches and practitioners are faced with challenges regarding developing or maintaining essential attributes required by rugby athletes such as lean mass, strength, power, speed, agility, sport-specific skills, and decision-making ability (Stokes et al., 2020).

Not only have training and competition been affected by COVID-19, but lockdown restrictions are also likely to have influenced athletes' perceived nutrition habits. For example, habitual eating patterns will have changed significantly with the closure of eating establishments and food delivery services. Furthermore, stressors as a direct result of COVID-19 lockdown restrictions may result in unfavourable food choices (Leigh Gibson, 2006). Additional challenges associated with monitoring nutrient intake during lockdown are likely to be encountered by clubs due to less direct contact with nutrition practitioners. It is vital athletes receive the appropriate nutritional support during lockdown as an abrupt return to training and play once restrictions are lifted may result in increased risk of injury (Moreira and Bilezikian, 2017) and it is likely good dietary habits may alleviate this (Tipton, 2015; Close et al., 2019).

Numerous surveys have been distributed across different populations and countries to identify the effect of COVID-19 lockdown measures on dietary patterns (Scarmozzino and Visioli, 2020; Sidor and Rzymski, 2020), however no data has been reported in rugby athletes. The purpose of this study is to explore (1) the influence of COVID-19 lockdown restrictions on rugby players' nutrition and training habits and (2) how nutrition habits in New Zealand rugby players change after lockdown restrictions were lifted.

Methods

The research instruments consisted of two surveys administered via an online survey-hosting website (Survey Monkey, Palo Alto, CA, USA). Within human ethics research regulations, this study was deemed to be low risk. All participants granted informed consent prior to commencing any of the surveys.

The first survey, entitled “Nutrition & Training Habits in Rugby Union Players – COVID-19 Lockdown” was administered from April 19th 2020 to May 22nd 2020, during and immediately following full lockdown restrictions being enforced in New Zealand and many countries globally. Initially, management staff and/or coaching staff from Rugby

Union teams located in New Zealand, Australia, and the United Kingdom were approached via e-mail. The purpose of the survey was explained, and management staff were asked to distribute the survey web link to their players. The survey consisted of 30 questions organized into three sections—general information, nutrition, and training.

The second survey, entitled "Post-Lockdown Nutrition & Training Habits in Rugby Union Players" was administered from 2nd June 2020 to 2nd July 2020. The survey consisted of 28 questions. Management staff from Rugby Union teams in New Zealand were contacted via e-mail due to the complete relaxation of lockdown restrictions. An information page was presented prior to the survey and consent was gained via a consent statement and check box.

Descriptive analysis of results are presented as percentages (%) of responses.

Results

For a full breakdown of Survey 1 and 2 questions and responses, please see Supplementary Materials. Relevant results will be discussed in the subsequent sections.

Survey 1

Relevant results will be discussed in this section.

In total, of the 314 survey link clicks, 258 respondents (82% total) completed Survey 1. Demographics for the survey respondents are presented in Table 2. Most respondents were 18–25 years of age (59.7%), male (84.1%) and living in New Zealand (92.2%). Only 26.3% of respondents reported playing at either a semi-professional or a professional level, with amateur players representing competitive club level or academy teams. Living with family accounted for 58.5% of responses. During lockdown, 39.2% of respondents indicated their motivation to train was lower than usual, with 32.6% reporting no change in motivation levels and 28.3% stating motivation to train had increased during lockdown.

Table 2. Demographic information for survey 1 (during lockdown) and survey 2 (after lockdown).

Question	Groups	During Lockdown N (%)	After Lockdown N (%)
Age	<18 years	14.3	17.9
	18 - 25 years	59.7	66.0
	26 - 35 years	21.3	16.0
	>35 years	4.7	0.0
Sex	Male	84.1	84.9
	Female	15.1	15.1
	Prefer not to say	0.8	0.0
Country of Residence	New Zealand	92.2	100.0
	Australia	3.5	0.0
	United Kingdom	4.3	0.0
How would you best describe your level of play?	Professional	9.0	17.0
	Semi-professional	17.3	17.0
	Amateur	73.7	66.0
How would you best describe your living situation before lockdown restrictions were enforced?	Alone	2.3	
	With a partner	13.2	
	With family (e.g parents, siblings)	36.8	

	With family (e.g partner, children)	9.7	
	With friends	4.7	
	Flatting	26.4	
	Other	7.0	
How would you describe your current living situation?	Alone	1.9	2.8
	With a partner	13.2	17.9
	With family (e.g parents, sublings)	58.5	33.0
	With family (e.g partner, children)	9.7	2.8
	With friends	3.9	7.6
	Flatting	10.1	31.1
	Other	2.7	4.7

Most respondents reported consuming breakfast daily (63.2%), eating 2–3 meals (67.1%) and 1–2 snacks (63.6%) per day. Respondents reported that a family member was most likely to purchase their food during lockdown (42.6%). Whilst 44.6% of respondents prepared their own food and meals, family members (23.6%) and a combination of people (23.3%) (the respondent and others in the household) were also involved in the food/meal preparation process.

Total food intake was reported to be greater during lockdown in 35.7% of respondents. During lockdown, 83.3% of respondents' fruit and vegetable intake was the same or greater than before lockdown, with the remainder indicating their intake was lower than before the restrictions. Packaged/convenience food intake was lower in lockdown for 41.9% of participants.

Nutrition knowledge in respondents was primarily from a dietician or nutritionist associated with the club (61.6%) however coaching staff (25.2%), teammates (27.1%), family members (30.6%), the internet (31.1%) and social media also contributed. When asked about the frequency of consumption of complete high-protein foods, 49.2% of respondents reported greater than two daily feedings. Respondents who consumed no dietary supplements during lockdown consisted of 53.3% of total responses.

Survey 2

In total, of the 112 survey link clicks, 106 respondents (95% total) completed Survey 2. Demographics for the survey respondents are displayed in Table 2. Respondents were 18–25 years old (66.0%) and male (84.9%). In total, 34.0% of respondents perform at a semi-professional or professional level. Most respondents reported living with family (33.0%) or flatting in shared accommodation (31.1%). Motivation to train and exercise was greater in 59.5% of respondents compared to during lockdown.

As with Survey 1, most respondents reported daily breakfast consumption (72.6%), eating 2–3 meals (51.9%) and 1–2 snacks (71.7%) per day. Most respondents purchased (67.0%) and prepared their own food and meals (71.0%). Eating out at takeaways, cafes and restaurants at least once per week was reported in 45.3% of respondents, with 8.4% indicating their frequency of eating out was ≥3 times weekly.

Dieticians or nutritionists associated with the club provided 68.9% of respondents' nutrition knowledge, with coaching staff (26.4%), teammates (33.0%), family members, the internet (31.1%) and social media (22.6%) again contributing. Consumption of ≤1 complete, high-protein food source daily was reported by 50.9% of respondents. No supplement use was reported in 32.1% of respondents.

Comparison Between Survey 1 and Survey 2

To compare results between surveys, responses from athletes located in countries other than New Zealand were filtered out. Relevant results are displayed in Figures 1–8 as comparisons between results presented by amateur players and semi-professional/professional players.

The relaxation of lockdown restrictions caused a change in living situations. Living with family accounted for 58.5% of responses during lockdown compared to 33.0% following lockdown, and flatting in shared accommodation accounted for 10.1% of responses during lockdown and 31.13% after lockdown (Figure 3). Following lockdown, the responses indicate a shift to athletes becoming more self-reliant and both purchasing (67.0% compared to 38.0%, Figure 2) and preparing (71.7% compared to 44.6%, Figure 1) their own food and meals. Post-lockdown, respondents reported a much higher motivation to train (57.9%) compared to during lockdown (28.7%) (Figure 4).

Most respondents reported no change in nutrition habits from during lockdown to post-lockdown (50.9%) whilst 35.9% indicated that their nutrition habits were better (Figure 6). Additionally, total food (44.3%, Figure 5), fruit and vegetable (53.8%, Figure 7) and packaged/convenience food (45.3%, Figure 8) was reported to be the same following lockdown.

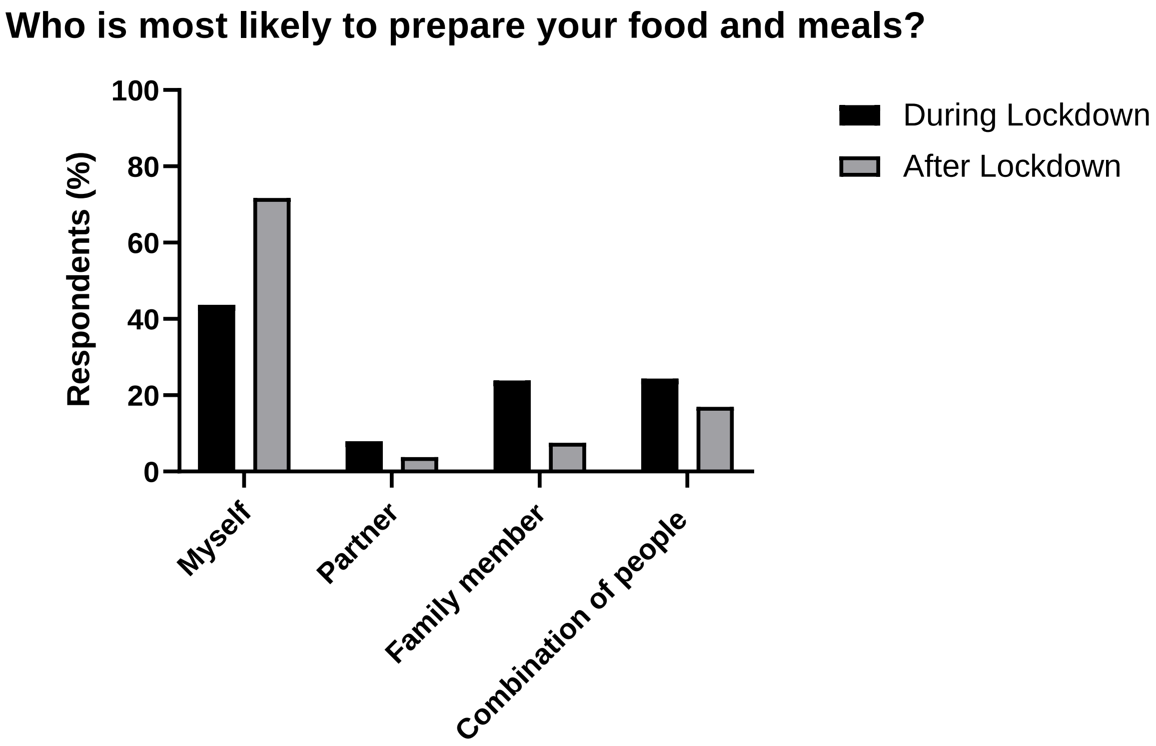

Figure 1. Responses for food and meal preparation during (survey 1) and after (survey 2) lockdown.

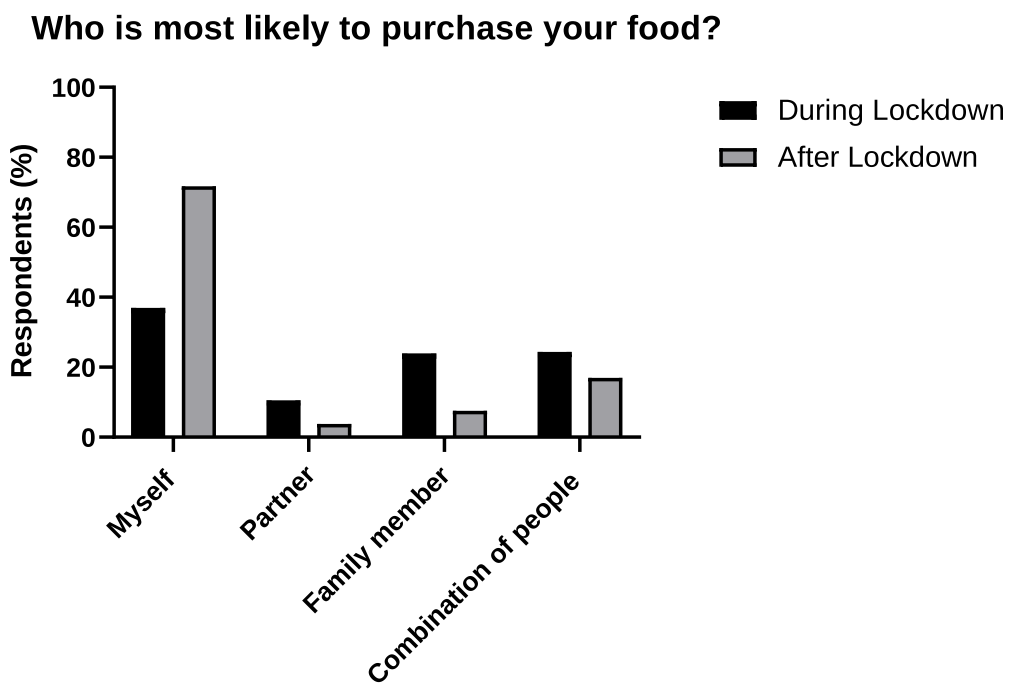

Figure 2. Responses for food purchasing during (survey 1) and after (survey 2) lockdown.

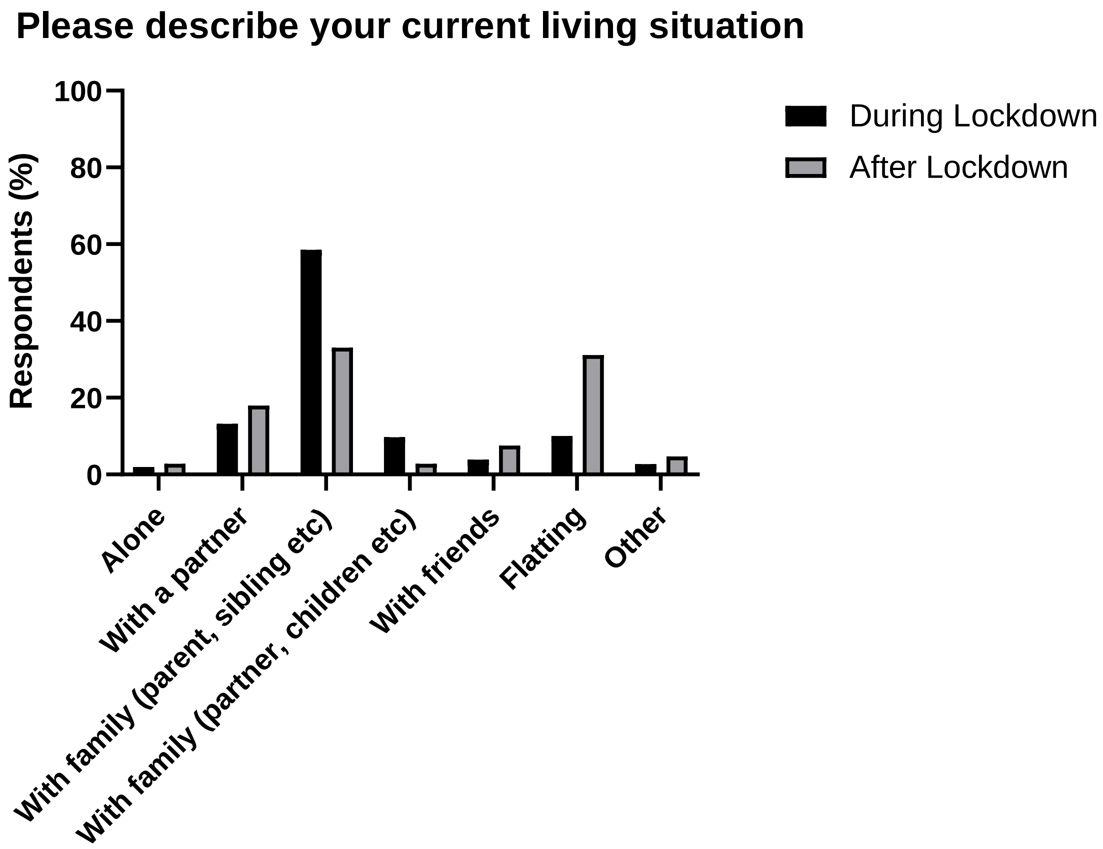

Figure 3. Responses for living situations during (survey 1) and after (survey 2) lockdown.

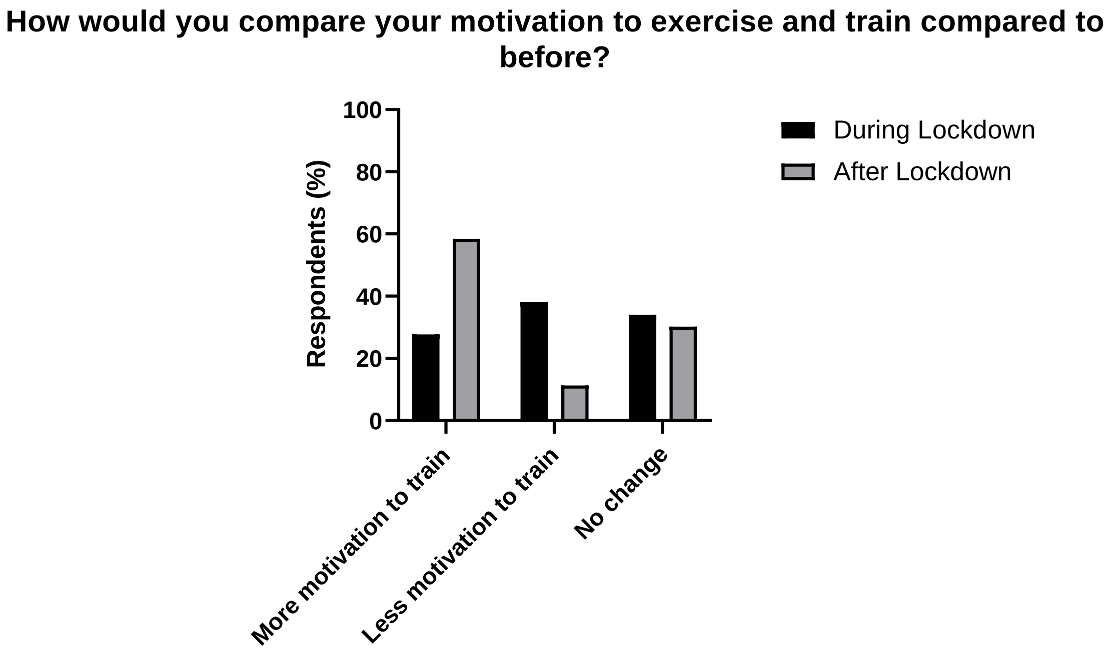

Figure 4. Responses for motivation to train during (survey 1) and after (survey 2) lockdown.

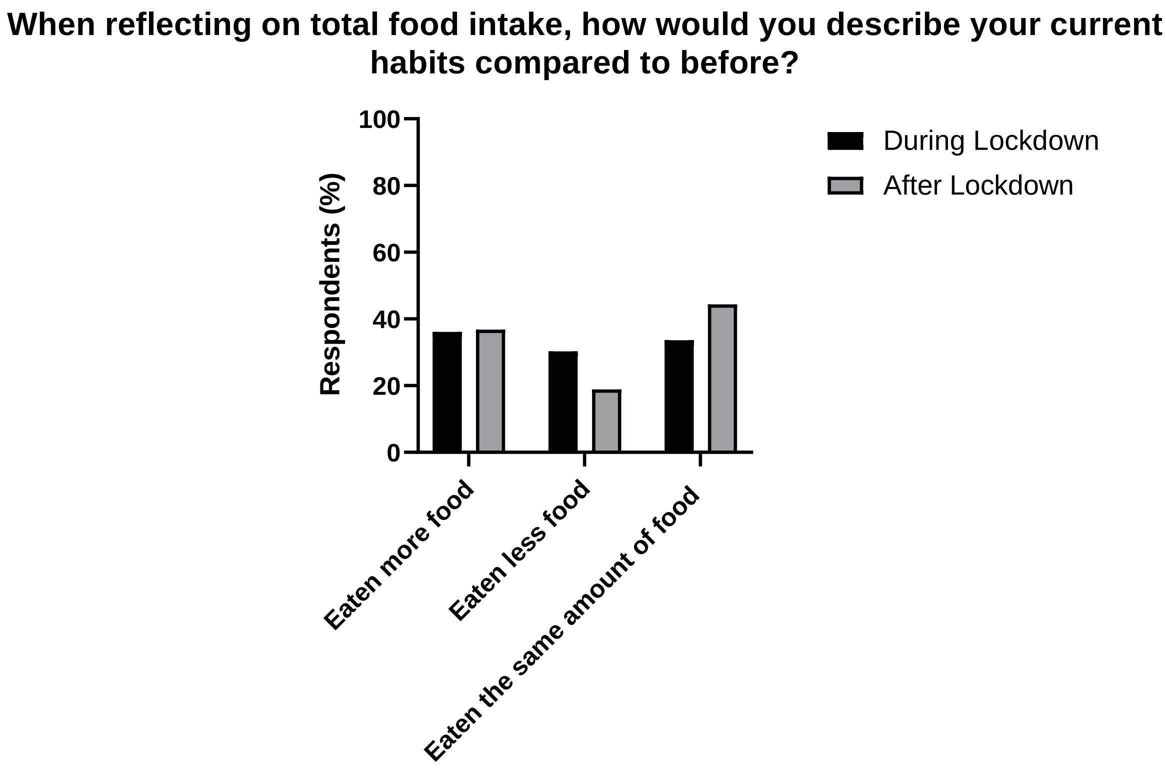

Figure 5. Responses for total food intake during (survey 1) and after (survey 2) lockdown.

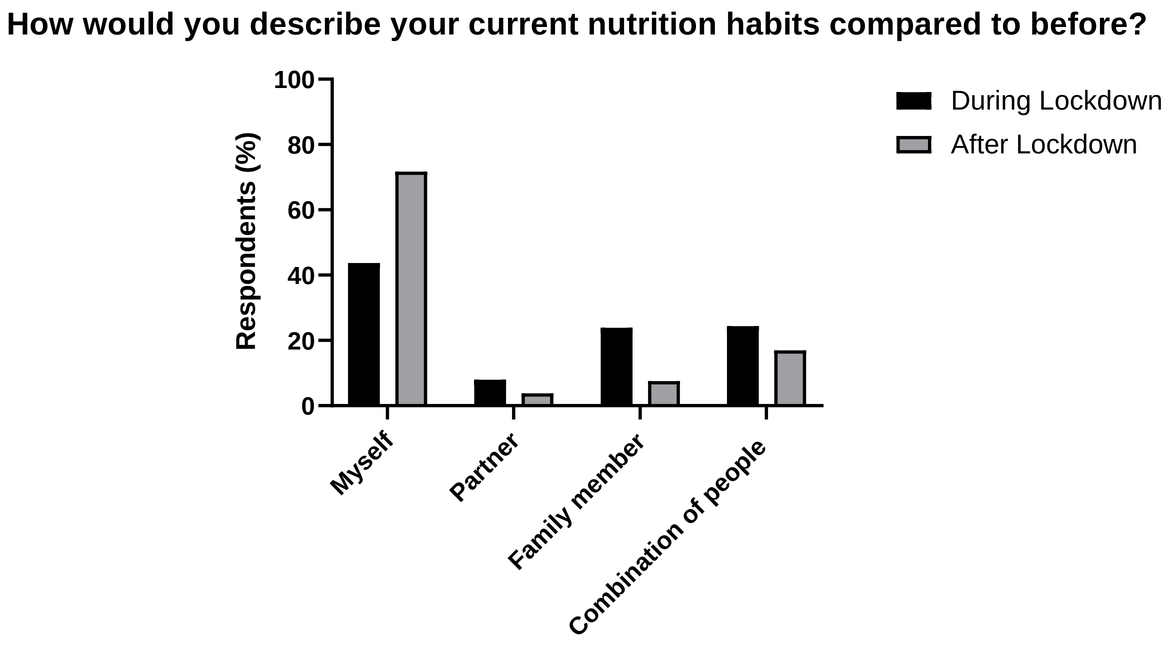

Figure 6. Responses for nutrition habits during (survey 1) and after (survey 2) lockdown.

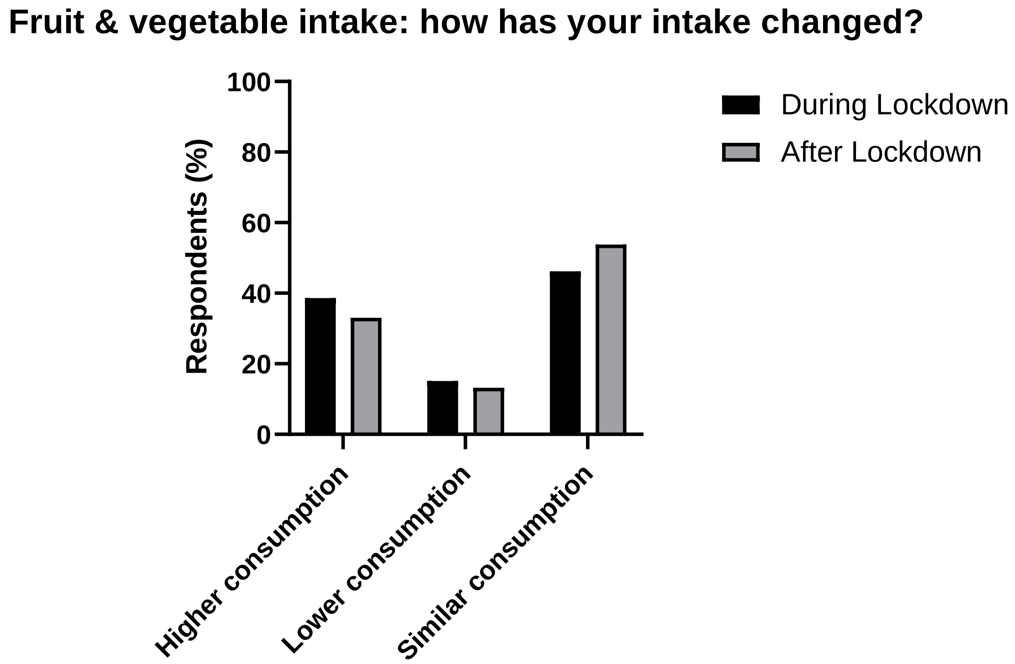

Figure 7. Responses for fruit & vegetable intake during (survey 1) and after (survey 2) lockdown.

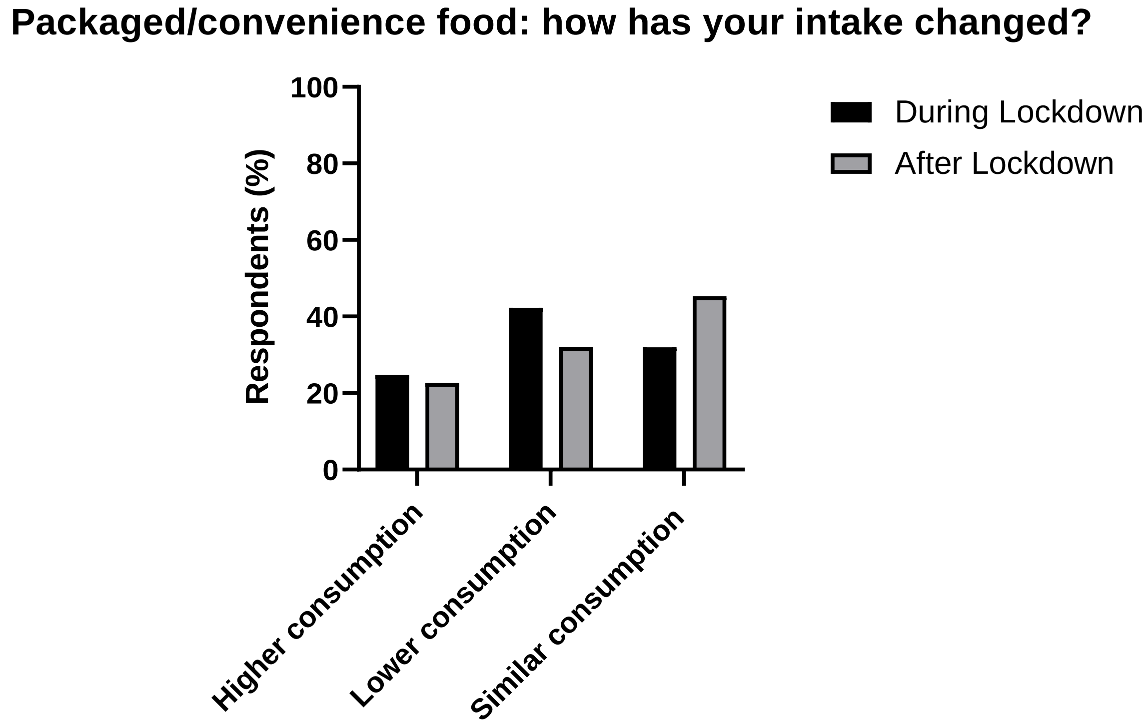

Figure 8. Responses for packaged/convenience food during (survey 1) and after (survey 2) lockdown.

Discussion

The purpose of this study was to explore (1) the influence of COVID-19 lockdown restrictions on Rugby Union players' nutrition and training habits and (2) how nutrition habits in New Zealand Rugby Union players were affected by the relaxation of lockdown restrictions. Nationwide lockdowns are unprecedented and as such no data is currently available describing how the combinations of (1) disruption to daily life (2) inability to train and eat habitually and (3) stress due to the global pandemic may have influenced these factors in athletes.

During Lockdown

Most responses indicated that food intake during lockdown either remained the same or increased. Whilst the long-term implication of COVID-19 lockdown restrictions on body composition have not been reported, athletes would be wise to reduce total energy intake to reflect the reduction of physical activity (Narici et al., 2021). Many respondents engaged in regular training sessions (89.4% reported completing ≥3 sessions per week), however the shift from habitual practices likely resulted in a large reduction in daily energy expenditure. Factors influencing energy expenditure during lockdown in athletes include a requirement to perform training sessions either at home or in local outdoor areas such as parks, a lack of equipment such as free weights and machines and no competition between teammates being present. These factors mean minimal rugby-specific training sessions were performed.

The temporary closure of restaurants, fast food outlets, cafes and bars may have resulted in better food choices in athletes. Most respondents indicated that fruit and vegetable intake during lockdown either remained the same or increased from pre-lockdown.

Additionally, packaged and convenience food intake either remained the same or was lower during lockdown. These contrast with general population surveys distributed during COVID-19 lockdown restrictions, with one third of 1097 Polish respondents not consuming fresh fruit or vegetables daily (Sidor and Rzymski, 2020). In a global survey distributed through 35 research institutions, respondents reported eating in an unhealthier pattern along with consuming more snacks and meals when COVID-19 lockdown restrictions were enforced (Ammar et al., 2020).

Ingesting adequate protein (1.2–2.0 g·kg·d) (Jäger et al., 2017) is an important factor in ensuring lean mass retention. When inadequate dietary protein is consumed, negative protein balance can result in muscle protein catabolism, adversely affecting muscle mass and function (Carbone and Pasiakos, 2019). In Survey 1, only 43.9% of respondents reported consuming a whole-food, high biological value protein source more than twice daily, which may not be optimal for retaining lean mass during a prolonged lockdown period.

During lockdown, most of respondents implied they consumed no dietary supplements. High heterogeneity exists in the evidence-base surrounding dietary supplement use among athletes and prevalence recorded between studies is variable (Knapik et al., 2016). Additionally, consultation with a nutrition professional should occur to consider the benefits and risks involved with consuming certain supplements (Maughan et al., 2007). Nonetheless, consumption of certain supplements may be beneficial for athletes provided training, nutrition and recovery habits are sound. Due to the additional stressors of the lockdown, supplement use may not have been a priority for athletes.

Protein supplementation is a beneficial strategy for athletes to reach daily requirements (Cintineo et al., 2018). Whilst protein intake is recommended to primarily come from whole foods, whey and casein are of a high quality, and consumption is considered safe and convenient (Jäger et al., 2017). With most survey respondents reporting consuming a high-protein food source ≤ once daily, this may be a useful strategy for athletes to minimize the detrimental effects of a reduction in training volume, a lack of appropriate equipment and limited rugby-specific training (Stokes et al., 2020).

Post-lockdown

As many athletes appeared to return to the family home for the lockdown period, there would likely be a greater reliance and/or sharing of responsibilities surrounding nutrition. Following lockdown, those staying with family appeared to decrease and those flatting in shared accommodation increased. Therefore, there was a large shift in respondents indicating becoming more self-reliant, with many athletes reporting purchasing their own food and preparing meals themselves. Reliance on others to prepare and cook meals can be a major barrier to healthy eating in athletes when those preparing meals do not possess appropriate sports nutrition knowledge. Furthermore, athletes cooking/shopping skills and cost can present further challenges in athletes at all levels of play (Heaney et al., 2008). These factors should be considered by sports dieticians/nutritionists when aiming to improve athletes' nutrition knowledge and food intake.

Sports nutrition knowledge in respondents from both surveys appeared to mainly come from dieticians or nutritionists associated with the clubs, however a large number also reported other sources including other individuals (coaching staff, teammates, family members) or through seeking it themselves (internet, social media). Many coaches provide nutrition advice to athletes; however, these individuals do not often possess the appropriate level of knowledge required to do so (Zinn et al., 2006). Teammates and family members who have not received appropriate training can provide incorrect and potentially harmful information. Additionally, it is important that athletes are aware of the possibility of unreliable information being presented through digital channels (Bourke et al., 2019).

Fast food outlets, cafes and takeaways were able to re-open following the relaxation of lockdown restrictions in New Zealand. Numerous athletes reported eating out on >3 occasions weekly. Eating out can indeed be incorporated into an optimal diet for an athlete, however it is important for these individuals to be aware of how to make appropriate choices. Increased frequency of fast-food consumption is associated with poorer diet quality, perhaps due to displacement of appropriate food choices (Barnes et al., 2016). Less frequent food preparation and more frequent fast-food consumption are associated with poorer diet quality, however time-restraints are a major influence on these factors (Larson et al., 2006). As most respondents identified as amateurs, it is likely these athletes also had full-time obligations in the form of work and/or studies. Furthermore, the social aspect of being involved in a team may outweigh focusing on eating for optimal performance, recovery, and health in amateur athletes (Birkenhead and Slater, 2015).

Unsurprisingly, most athletes indicated their motivation to exercise and train was higher once lockdown restrictions were relaxed. The physical and aggressive nature of the game, on and off-field interactions with teammates and feelings of achievement and success are some of the factors previously reported to increase participation motivation in elite female Rugby Union athletes (Kerr, 2021). Lockdown restrictions would indeed cause major disruption to all of these factors. Additionally, the closure of habitual training facilities such as clubhouses and gyms and stressors associated with the pandemic are likely to have influenced athletes' motivation to train during lockdown.

Respondents of both Surveys 1 and 2 reported consuming high biological-value protein sources from whole foods less than once per day. These responses may indicate a lack of knowledge of the importance of regular protein consumption throughout the day for athletes. As with during lockdown, athletes concerned with maximizing lean mass and strength gains are recommended to consume a minimum of 1.6 g·kg·d spread evenly across at least 4 meals of 0.4 g·kg (Schoenfeld and Aragon, 2018; Morton et al., 2015; Areta et al., 2013; Mamerow et al., 2014). Although athletes during lockdown will be experiencing different levels of exercise stimulation due to a lack of resistance training equipment and minimal rugby-specific training which likely resulted in reductions in lean mass, strength and skill, adequate protein consumption may allow for a faster return to pre-lockdown body composition and performance levels. Minimizing lean mass catabolism is also an important factor in reducing injury risk when rugby training and match play resumes, with the development of muscle tissue important for withstanding external forces associated with collision sport play (Stokes et al., 2020).

A major limitation of the present study is that the accuracy of the responses cannot be verified. Due to the anonymous nature of the online surveys distributed for this study, responses may not truly indicate how a respondent feels. Additionally, the nature of the questions means accurate results are difficult to obtain, such as asking participants whether their food intake has changed due to lockdown restrictions, and information on macronutrient intake other than protein was not requested. Furthermore, respondents may not have answered truthfully due to the additional stressors resulting from COVID-19, such as economic struggles, feelings of isolation or health worries.

Participants were not asked to describe the nature of training sessions performed during lockdown, which presents another major limitation. It is likely that the implementation of lockdown measures would adversely affect resistance training and sport-specific training in athletes. With no access to commercial gym equipment, athletes are required to make use of limited to no home equipment. If inadequate resistance training is performed, changes associated with muscle disuse such as lean mass and strength loss and increased fat mass may rapidly occur (Wall et al., 2013). It has been suggested that low-volume and low-intensity contractions are adequate at stimulating muscle protein synthesis and preventing muscle wasting (Glover and Phillips, 2010). Resistance training protocols utilizing bands and bodyweight exercises have previously demonstrated efficacy in promoting lean mass gains in healthy older individuals (Krause et al., 2019), however this is not likely to be enough to maintain strength in Rugby Union athletes. Indeed, athletes are unlikely to have access to the equipment required to perform key exercises for developing or maintaining maximal strength (multi-joint resistance exercises such as squats and deadlifts) (Corcoran and Bird, 2009) at sufficiently heavy loads (≥75% 1-repetition maximum) (Schoenfeld et al., 2014). For optimal performance and injury prevention, rugby athletes are expected to possess high levels of strength and power whilst engaging in high metabolic training volumes and rugby-specific sessions (Gamble, 2004) and re-building these attributes before competitive matches resume will be crucial. Most respondents indicated they completed at least three training sessions per week however no information was gathered as to the nature of these sessions and as such, the ability of the respondents to offset muscle disuse wasting cannot be predicted.

Conclusion

In conclusion, the COVID-19 pandemic and associated restrictions to encourage social distancing and delay the spread of the virus have presented significant challenges for athletes of all levels and disciplines. Appropriate nutritional and training support may assist athletes retain adequate performance, lean mass, strength, and cardiorespiratory fitness during lockdown scenarios, however no data is currently available to support this. Coaches and performance staff can assist athletes by promoting greater protein intakes and feeding frequency, encouraging safe supplement use and keeping players engaged in interesting training sessions that can be completed from home. Staff must also be aware of the challenges athletes may be facing, related or unrelated to the ongoing pandemic.

Chapter 4: Ecological validation and practical challenges of conducting dietary analysis in athletic individuals using a novel remote food photographic method mobile phone application

Prelude

The remote-food photography method has been suggested as a valid (Costello et al., 2017) and preferred tool (Simpson et al., 2017) for the collection of dietary intake data in athletes. As such, this method was chosen for dietary intake data collection in the present thesis. Whilst Costello et al (2017) suggest the tool is valid in adolescent rugby league athletes, the validity was not measured in a true ecological fashion. As athletes were not recording their dietary intake whilst engaging in activities such as eating at home and restaurants, the practical application of the tool in athletes is currently inconclusive. As such, the present study aimed to test the ecological validity of a mobile phone application for the collection and interpretation of dietary intake data.

Abstract

Dietary analysis is an important part of the sports nutrition practitioners' role, however the ability to accurately collect and analyse dietary intake data is questionable. The RFPM has been proposed as a low-burden and potentially valid approach to collecting and interpreting dietary intake data. Preliminary research suggests this is valid in some athletic populations, however the ecological validation in real-life settings warrants further investigation. Twenty athletic individuals completed simultaneous three-day RFPM diaries and weighed food diaries for the analysis of energy, protein, carbohydrate, and fat. Participants were required to provide details alongside provided photographs that did not include food weights to allow for the estimation of nutrient intake from minimally invasive photographs and descriptions. RFPM demonstrated non-significant random and systematic error against the weighed food diary for energy, protein, carbohydrate, and fat at -20.0 ± 455.5 kcal, -2.9 ± 34.6 g, -12.4 ± 49.3 g and 2.3 ± 26.8 g, respectively. CV suggest acceptable agreement between RFPM and weighed food diary for energy and poor agreement for protein, carbohydrate, and fat. Considerable variability is observed in the individual calculated values, with the least and greatest difference being 0% and -83.0%, respectively. The results indicate that the RFPM may be an ecologically valid tool for the collection and analysis of dietary intake data on a group level; on an individual basis, data and subsequent recommendations based on this must be applied with caution.

Introduction

Athletic individuals have unique nutritional demands as consideration must be made not only for maintaining health and nutrient sufficiency, but also to ensure tissue repair, facilitate adaptation and enhance performance (Thomas et al., 2016). Whilst recreational athletes can meet requirements for health and training by following national healthy eating guidelines (Desbrow et al., 2020) care must still be taken to ensure adequate energy and nutrient consumption is observed. Ensuring athletic individuals follow appropriate dietary patterns to support health, performance and recovery is a crucial role for the sports nutrition practitioner; depending on the training volume and level of competition, specific needs may need to be adhered to surrounding training (Spriet, 2019). As such, monitoring of dietary intake in a non-invasive and accurate manner is essential.

Numerous prospective and retrospective methods of dietary analysis are utilised with athletic individuals in sports nutrition research, including weighed and estimated food diaries, dietary recalls and food frequency questionnaires (Capling et al., 2017). Retrospective methods such as the food frequency questionnaire, dietary recall and diet history are prone to under-reporting due to participant memory (Black, 2001). Prospective methods are also prone to under-reporting due to the burden imposed on the individual; weighing individual food items and writing them down may result in an individual altering food intake to reduce burden or simply neglecting to log (Black, 2001). Practitioner variability in the interpretation and delivery of such methods can lead to considerable differences in the final nutrient data output (Braakhuis et al., 2003).

The methods above are utilised frequently in both practice and sports nutrition research (Noll et al., 2017; Jenner et al., 2019), however the applicability in a free-living situation is questionable. For example, an athlete provided with a weighed food diary who eats out at restaurants frequently may not be able to provide accurate enough information for the determination of nutrient intake. Recently, the RFPM has sought to address this. Individuals are required to provide images of the food and beverages consumed via various methods such as wearable body cameras (O'Loughlin et al., 2013) or smartphone photographs (Costello et al., 2017). When images are provided alongside descriptions of the meals, this may allow for the practitioner to better identify dietary trends and intakes of those in their care. Energy intake measured via the smartphone RFPM was under-reported against DLW in some (Most et al., 2018; Rollo et al., 2015) but not all (Martin et al., 2012) validation trials.

As the RFPM only requires access to a camera-embedded smartphone, the user is faced with less burden. Whilst such technologies may be more accessible to the individual engaging in dietary monitoring (Simpson et al., 2017), the analysis of food images requires the practitioner to estimate portion sizes and/or ingredients in the meal unless weights and household measures are included. Like traditional methods of dietary intake monitoring (Braakhuis et al., 2003), such interpretations can be variable amongst practitioners independent of level of experience (Stables et al., 2021).

The aim of the present study was to evaluate the relative validity of analysing energy and macronutrient intake using the remote food photography method via a free smartphone application in athletic individuals in a free-living environment.

Methods

Participants

Twenty-eight participants expressed interest in taking part in the study. Individuals were recruited if they self-identified as 'athletic individuals' defined as engaging in a sport or physical activity ≥ 3 days per week. Individuals expressing interest were invited to a session outlining the requirements of the study, and to sign informed consent forms if they wished to participate. Ethical approval for the study was obtained from the University of Waikato Human Research Ethics Committee (HREC(Health)2020#87).

Study Design

Participants were required to log their dietary intake across three days using both a weighed food diary and the RFPM. Initially, participants attended an informed consent session to discuss the requirements of the study. During this session, the lead researcher demonstrated how to record their dietary intake using both methods to ensure appropriate analysis of the information could occur. Participants were advised to log the same items using both methods but to avoid including the weight of foods in the photo logs. If common household measures such as cups or spoons were used, this was deemed acceptable as they would be more practically accessible in a free-living situation than food scales.

Materials

For the weighed food diaries, participants were provided with household digital scales (Kmart, Melbourne, AU) sensitive to 1g and the capacity to measure fluid volume. A generic template food diary was provided as a hard copy to participants, with additional instructions included to assist with appropriate logging of food and beverage items.

The RFPM was conducted via a smartphone application (MealLogger, Wellness Foundry, Ashburn, VA). MealLogger was chosen as it allows for users to upload photographs with descriptions to assist with the identification and analysis of foods or items. Additionally, the application has been identified as a preferred method to traditional dietary analysis methods in athletes (Simpson et al., 2017) and has demonstrated validity and reliability in young rugby athletes (Costello et al., 2017). The photographs were uploaded via the application in real-time allowing for the lead researcher to enquire about inadequate photos, however unclear photos due to complex meals or inadequate descriptions were not enquired about to test the practical validity of the tool. Participants were required to take a clear photo of the entire food item or meal both before and after consumption to account for leftovers. Photographs were to be taken from between a 90° and 45° to allow for the judgement of depth of the food. Participants were asked to place either a hand, pen or cutlery next to the food item as a size marker.

Analysis of both the written food diaries and RFPM was conducted using FoodWorks 10 (Version 10.0.4266, Xyris Software, Australia) as it contains a comprehensive database of food items in both Australia and New Zealand. If a food item was not present in FoodWorks, energy and macronutrient information was collected from food labels or the company website. Analysis of the photographs occurred as they were returned to the lead researcher. Written diaries were returned without names or identifying information attached and were analysed as a group to ensure blinding of the participants.

Statistical Analysis

Data were grouped into the average of days logged for each participant. Normality testing was conducted using Shapiro-Wilk test, with data deemed to be normally distributed. The strength of the relationship and proportional bias were assessed via Pearson correlations between the mean of both measures with the residuals and absolute residuals of the measures, respectively. Bland-Altman analysis was conducted to measure and visualise the systematic bias between RFPM and weighed food diaries. Mean % difference at both group and individual level and CV were calculated to measure the level of agreement between RFPM and weighed food diaries. CV thresholds were interpreted using thresholds described by Stables et al (2021): <2% (excellent), <5% (good), <10% (acceptable),>10% (poor), and >20% (very poor).

Statistical analysis was conducted on Statistical Packages for Social Sciences (SPSS, IBM Corporation, Chicago, Illinois, USA) and GraphPad Prism (GraphPad Software Inc., San Diego, CA, USA). Descriptive data are displayed as mean ± SD. Significance was set at $p < 0.05$.

Results

Participants

Of the 28 individuals expressing interest, 20 were included in the final analysis (33.0 ± 9.3 years, 173.6 ± 9.8cm, 76.0 ± 15 kg). Nineteen participants completed three days of logging that were of an acceptable quality for analysis, with one participant completing two days that were of acceptable quality for analysis. The flow of participants is presented in Figure 1.

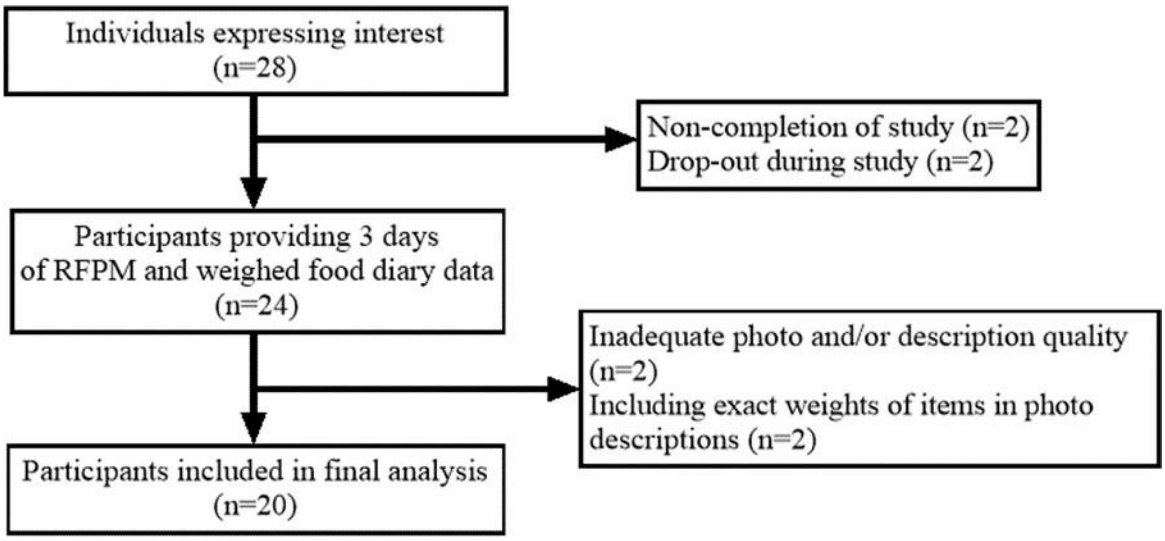

Figure 9. Flow of participants

Validation

A strong positive relationship between RFPM and weighed food diary was observed for energy (r=0.74, p<0.001), protein (r=0.73, p<0.001), carbohydrate (r=0.80, p<0.001) and fat (r=0.66, p=0.001). Assessment of proportional bias indicated a weak non-significant relationship between RFPM and weighed food diary for energy (r=0.43, p=0.062) and protein (r=0.42, p=0.063); a significant moderate relationship for carbohydrate (r=0.58, p=0.007) and fat (r=0.59, p=0.007) indicates greater heteroscedasticity. Bland-Altman plots for visualisation of the agreement between RFPM and weighed food diaries are presented in Figure 2. Systematic and random error were not significantly different for energy (-20.0 ± 455.5 kcal), protein (-2.9 ± 34.6 g), carbohydrate (-12.4 ± 49.3 g) and fat (2.3 ± 26.8 g).

Individual values for analysed nutrients and mean % difference are presented in Supplementary Materials. CV suggest acceptable agreement between RFPM and weighed food diary for energy (CV = 9.9%) and poor agreement for protein (CV = 13.1%), carbohydrate (CV = 10.0%) and fat (CV = 14.6%). Mean % difference of the grouped data is acceptable, however considerable variability is observed in the individual calculated values, with the least and greatest difference being 0% and -83.0%, respectively.

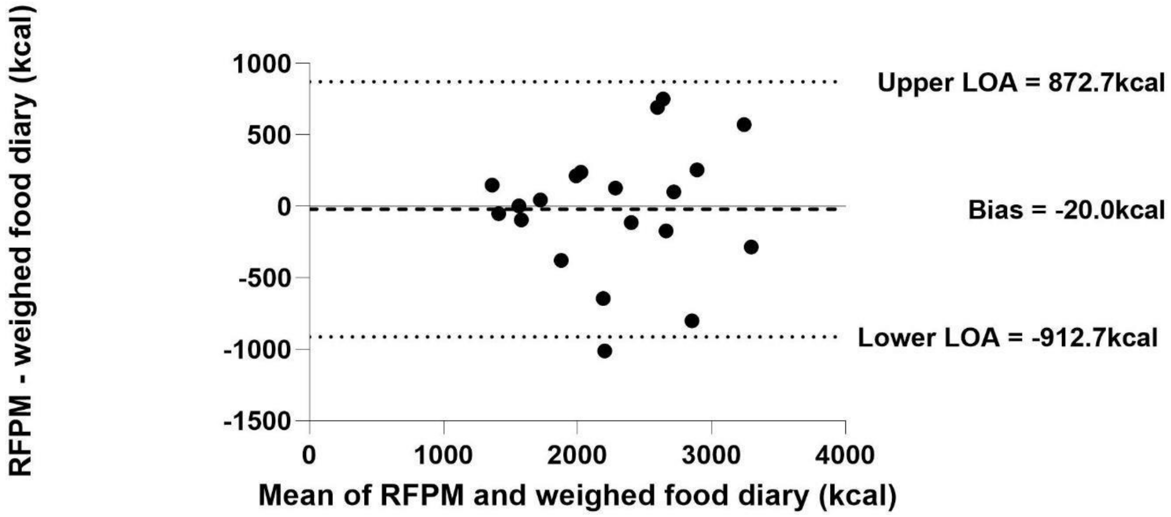

Figure 10. Bland-Altman plot for energy intake calculated using RFPM and weighed food diary. RFPM, Remote Food Photography Method. LOA, limits of agreement.

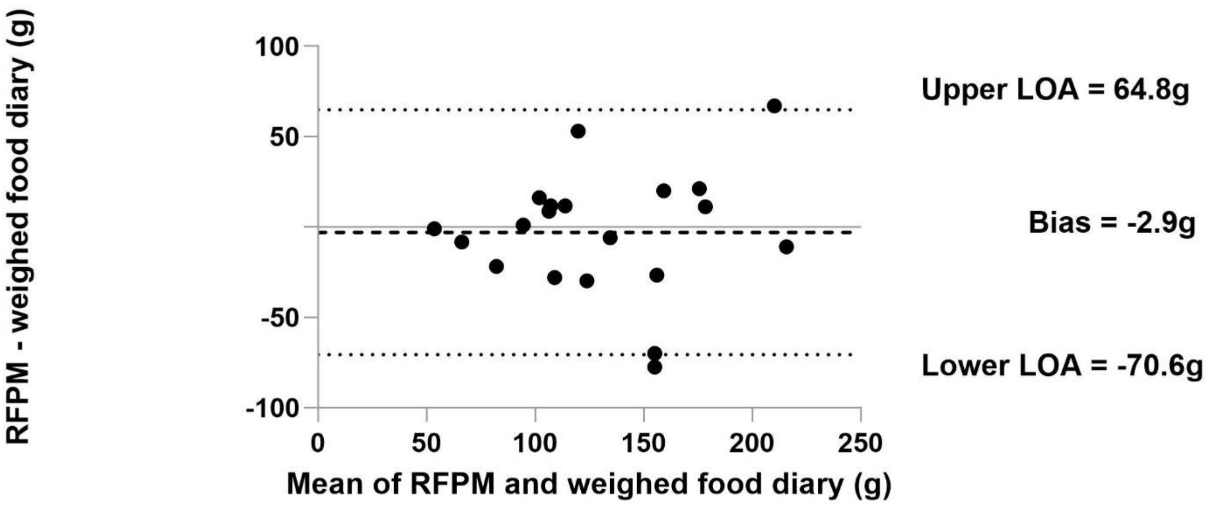

Figure 11. Bland-Altman plot for protein intake calculated using RFPM and weighed food diary. RFPM, Remote Food Photography Method. LOA, limits of agreement.

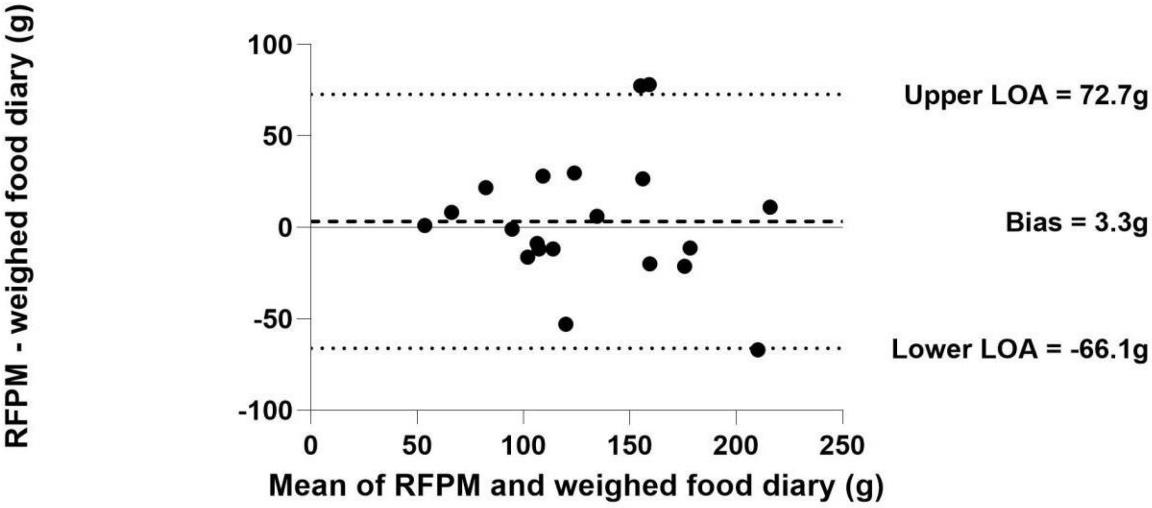

Figure 12. Bland-Altman plot for carbohydrate intake calculated using RFPM and weighed food diary. RFPM, Remote Food Photography Method. LOA, limits of agreement.

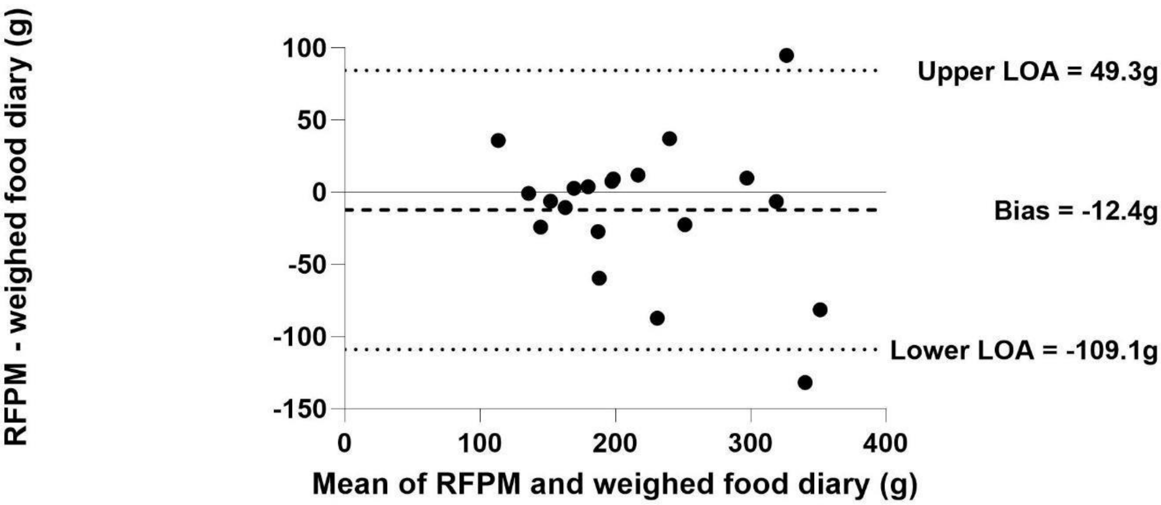

Figure 13. Bland-Altman plot for fat intake calculated using RFPM and weighed food diary. RFPM, Remote Food Photography Method. LOA, limits of agreement.

Discussion

The purpose of the present study was to examine the ecological validity of the RFPM to measure energy and macronutrient intake in free-living athletic individuals against a weighed food diary. Upon initial interpretation, agreement represented by low levels of bias warrants the practical use of the RFPM for measurement of energy and macronutrients at a group level; however proportional bias, large limits of agreement and poor CV (>10%) indicates that macronutrient values are not valid on an individual level and caution should be applied when interpreting results. Furthermore, observation of individual mean % difference between RFPM and weighed food diaries for energy and macronutrient intake suggest under-estimation and over-estimation in individuals.

A strong positive relationship was observed for energy and macronutrient intake, however proportional bias analysis, observation of the individual datapoints, mean % difference and visualisation of Bland-Altman plots suggests considerable inter-individual variability in the estimation of nutrient intake. Such a finding is interesting as Pearson correlation should demonstrate the strength of the relationship at the individual level (Lombard et al., 2015) which occurs when corrected for absolute residuals to assess proportional bias. The energy and macronutrient intake demonstrates larger differences at greater intakes. Similar observations have been made in athletes during validation of an adapted 24-hour recall for energy and macronutrient intake (Baker et al., 2014a), 24-hour recalls for protein intake (Wardenaar et al., 2015) and FFQ for antioxidant intake (Braakhuis et al., 2011). A possible explanation for this finding could be that as greater food and beverage intakes are analysed, the potential for errors in the analysis increases. Practitioners must consider these differences, with athletes likely to require elevated energy requirements and thus food intake due to training and competition volume and intensity (Thomas, Erdman

& Burke, 2016). The agreement between RFPM and weighed food diary was acceptable for energy but poor for protein, carbohydrate, and fat intake.

The agreement between RFPM and weighed food diary was acceptable for energy but poor for protein, carbohydrate, and fat intake. Similar to the studies demonstrating proportional bias between dietary assessment methods in athletes (Baker et al., 2014b; Braakhuis et al., 2011; Wardenaar et al., 2015) agreement was deemed weaker than overall group validity. Such an observation in the present data was expected due to the considerable variability in individual differences in nutrient intake between methods; the difference in fat intake was 0% for one individual and -89% for another, whilst overall mean % difference for fat intake was -3.5%.

Whilst the results of the present validation study indicate the RFPM may be a valid tool for analysing energy and macronutrient intake on a population level in athletic individuals, several limitations have been identified. On a population level the RFPM may be a valid tool for analysing nutrient intake, such as within a team, however the individual data indicates RFPM is prone to both under-estimating and over-estimating energy and macronutrient intake when compared to a weighed food diary. As such, practitioners delivering specific nutrition advice and recommendations based on monitoring of dietary intake using RFPM must remain cautious. Combining elements of both a weighed food diary and RFPM may be beneficial to reduce measurement error. Additionally, we were unable to detect true reporting bias as both methods are self-reported. Accessibility, acceptability, and cost mean the application of additional biomarker methods such as DLW is often unfeasible and thus the data collected using self-reported dietary analysis methods may not reflect true nutrient intake.

A major limitation in the analysis of dietary intake is the presence of inter-individual variability between practitioners during the food diary analysis process. In the present study, a single trained sports nutritionist interpreted both the RFPM and weighed food diaries. Previous studies have identified variability between practitioners when coding both weighed food diaries (Braakhuis et al, 2003) and food photographs (Stables et al, 2021) provided by athletes.

Conclusion

In conclusion, the present study demonstrated the RFPM using a mobile phone application to record both photographs and descriptions of food, meals and beverages is a valid tool for analysing energy and macronutrient intake in athletic individuals at the group level. For individuals, considerable variability is apparent and therefore it may not be appropriate for practitioners to prescribe detailed recommendations and feedback based on the date collected from such tools.

Practical Recommendations

Several observations were made during data collection which may explain the variability between RFPM and weighed food diary measurements in some participants. These observations should be considered by both practitioners and researchers when seeking to collect and interpret dietary analysis data.

- Few participants included finer details when recording their dietary intake. Important details were often missed, such as not including whether oil was used for cooking, not being descriptive about the cut and/or leanness of meat and not including the type of milk used (Ji et al., 2020). In the FoodWorks software used to analyse dietary intake in the present study, meat has different options (rump steak, trimmed, semi trimmed or not trimmed) which can confound the nutrient analysis if details are not included (Figure 14). Whilst it did not negatively influence the group validity values, this would be detrimental for practitioners or researchers aiming to accurately understand an individuals' dietary intake or eating patterns.

- Variability in the detail added in the description indicates that whilst the use of food photographs may reduce burden for some individuals, following-up with those who do not provide adequate complementary details may increase the burden and increase non-compliance (Figure 16)

- Individuals not including brands in the description alongside photographs or when completing food diaries may confound the true nutrient intake as the nutrient content of items can be variable between brands. Furthermore, the interpretation of a 'serving' in dietary analysis software may be different to that of a brand. This can be problematic as the nutrient content information may be variable.

- Athletes may eat out at restaurants and cafes, may visit establishments where accurate logging of food intake is impractical, such as when visiting the cinema, and are likely to purchase pre-made food items (wraps and sandwiches) that cannot be adequately logged without disassembly. Using either weighed food diaries or food photographs can be impractical in these situations. Furthermore, when meals are prepared at home, care must be taken to present the food or meals such that analysis can occur if the individuals' dietary intake is being monitored (Figure 17).

- As above, situations where individuals eat out may be impractical for taking clear photographs. This may also apply to other scenarios, such as during the preparation of complex meals whereby the volume of individual items cannot be accurately estimated as they are hidden, such as meat and vegetables in a curry or stir-fry.

- Many foods may not be present in the dietary analysis database and appropriate nutrition information may be absent online. In such situations, estimation of the nutrient content is likely warranted but threatens the accuracy of the information provided. Additionally, food purchased from a takeaway, such as a curry, presents a multi-faceted problem as this may not be present in food databases and is a complex meal and is thus difficult to determine the contents of the meal.

- The presentation of food can result in imprecise interpretation of the nutrient content. If the meal is presented in a bowl or as stir-fry it can be difficult to determine the amounts of individual ingredients using photos if a detailed description is not added (Figure 15).

- Individuals may not prepare food for themselves. This is common in young athletes who still live with parents or caregivers who purchase and prepare the foods and meals consumed by the athlete. This may confound dietary analysis as inadequate presentation of the foods and/or meals, others preparing meals for multiple people or others misremembering or not considering the portion sizes, cooking methods and other fine details of the food preparation process can influence the information the athlete ultimately provides the practitioner.

- Similarly, athletes may be in a situation where they are cooking for family or friends. This would likely make logging impractical, particularly if a complex meal is being prepared and requires multiple photographs.

Figure 14. Example of food items that present when searching for 'steak' in FoodWorks.

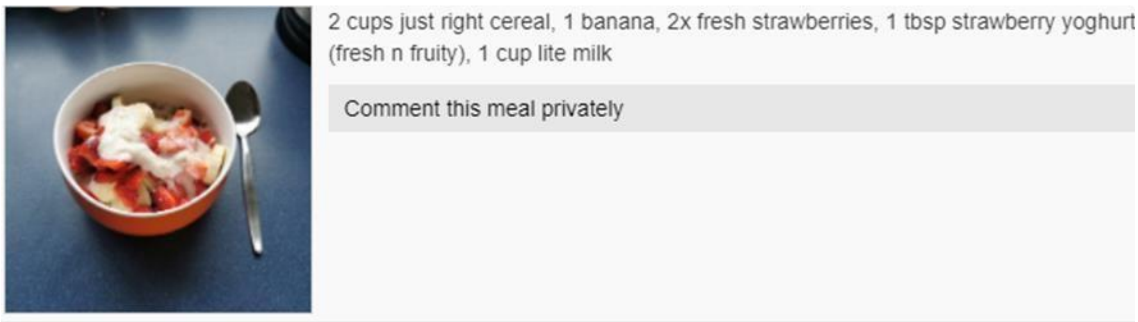

Figure 15. Example of meal logged that is difficult to interpet due to presentation.

Figure 16. Example of meal logged without adequate description for detailed analysis.

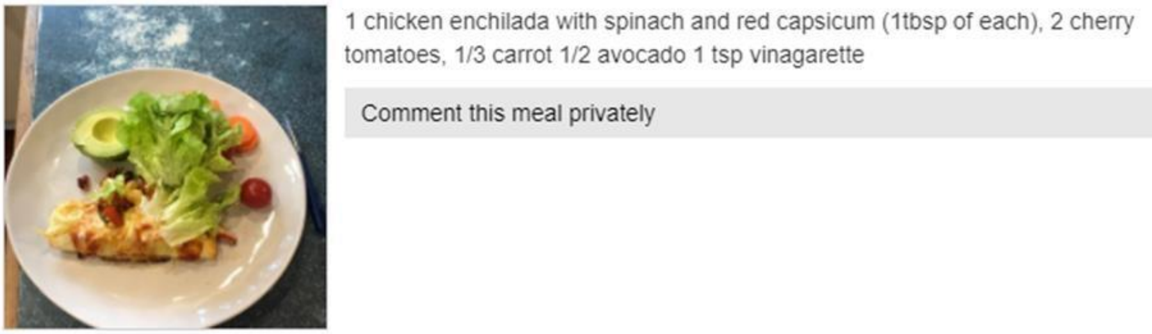

Figure 17. Example of meal prepared at home

Chapter 5: Daily protein distribution patterns in professional and semi-professional male rugby union players

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. https://doi.org/10.36905/jses.2022.01.05

Prelude

Mechanistic research indicates that the even distribution of 0.4 g·kg of dietary protein across 4 – 6 daily meals may be optimal for ensuring a positive protein balance and thus promoting anabolic responses to exercise and supporting the repair and re-modelling of damaged muscle tissue (Morton et al, 2015; Schoenfeld & Aragon, 2018). Previous research in rugby players concerning the daily distribution of dietary protein has been published, however this examined the number of eating occasions of an absolute 20g dietary protein, a value of which may be inadequate to facilitate an anabolic response when considered relatively due to greater body mass in this population (Moore, 2019a; Morton et al, 2015; Schoenfeld & Aragon, 2018). As such, the following section aims to quantify daily protein distribution patterns in professional and semi-professional rugby players with consideration for both absolute and relative to body mass values.

Abstract

Mechanistic research in healthy adults suggests an even distribution of protein throughout the day may result in greater stimulation of muscle protein synthesis compared to a disproportionate intake, with 0.4 g·kg per meal at a minimum of four eating occasions proposed to optimise anabolism. In rugby players, this may be of benefit to exercise adaptations, recovery, and performance. In the present study, semi-professional forwards (n=19), semi- professional backs (n=6) and professional (n=10) rugby players recorded dietary intake for seven days. Both absolute (g) and relative to body mass (g·kg) protein intake was calculated across six eating occasions. Relative protein intake at breakfast, AM snack, lunch, PM snack, dinner and evening snack were 0.3, 0.1, 0.4, 0.2, 0.6 and 0.1 g·kg, respectively. Total protein intake was significantly different between groups ($p<0.05$). All groups demonstrated differences in protein intake between eating occasions ($p<0.01$). Protein intake was highest at dinner in all athletes, with professionals consuming significantly greater protein than semi- professionals. Rugby players do not appear to meet the recommended per-meal protein dose of 0.4 g·kg at a minimum of four eating occasions. Consumption of additional protein outside of main eating occasions as snacks may be beneficial to greater stimulate muscle protein synthesis and result in improvements to adaptation, recovery, and performance.

Introduction

Rugby union players are exposed to unique demands during matches and training that can influence energy and nutrient requirements. The sport can be classified as an intermittent team sport, with teams of 15 engaging in repeat-sprints, jumps and collisions (Duthie et al., 2003). Additionally, rugby is unique in that large positional variation is observed in both the match demands and body composition of the players (Zemski et al., 2019a). It is recommended that rugby players focus on building fat-free soft tissue muscle to meet the demands of the sport and maintaining an appropriate body composition profile is critical for individual players to fulfil their roles on the pitch (Zemski et al., 2019a). For example, a greater fat-free mass in the prop position (94.4 ± 7.9 kg) is considered advantageous due to the requirement to exert greater force than the opponent whilst contesting the ball whereas lower fat-free mass in inside back positions (78.8 ± 8.2 kg) can allow for greater agility and mobility (Smart et al., 2013). While engaging in high-volume training and competition, rugby players nutritional strategies require careful consideration (Argus et al., 2009).

Rugby players can expect significant physiological, psychological, and endocrine disruption in response to matches (Slimani et al., 2018). The repetitive high-intensity efforts and collisions invokes exercise-induced muscle damage and cellular disruption (Naughton et al., 2018b). Metabolic, endocrine, and neuromuscular function may not return to baseline for up to 36-hours following a rugby match. Moreover, mood disturbances are apparent for up to 12-hours post-match, possibly due to competitive stress or fatigue (West et al., 2014). A longer period of disequilibrium as denoted by an impairment of 10m sprint performance, and elevated creatine kinase following a full match was observed in amateur-level rugby players (da Silva et al., 2020). Data from professional players demonstrate the magnitude of muscle damage may be predicted by the number of collisions and high-speed running performance (Jones et al., 2014). With the potential for high training volumes players risk inadequate recovery between matches and training sessions (Argus et al., 2009). As such, ensuring dietary intake is designed to support optimal recovery is of the utmost importance.

Protein intake is an important consideration for athletes to support optimal performance, recovery, and health (Kreider and Campbell, 2009; Phillips, 2012; Phillips and van Loon, 2011; Phillips et al., 2016). Rugby players engage in activity encompassing both strength and endurance demands, which may require both mitochondrial and myofibrillar adaptations along with preventing amino acid oxidation in response to prolonged and intense activity (Lemon, 1994; Kato et al., 2016; Packer et al., 2017). Researchers have sought to quantify protein requirements for athletic populations and various position statements have been published through organisations such as the International Society of Sports Nutrition (Jäger et al., 2017) and the American College of Sports Medicine (Thomas et al., 2016). These position statements provide a comprehensive and critical review of the literature on protein intake in healthy, exercising individuals to determine requirements. Ranges such as 1.4-2.0 g·kg·d and 1.2-1.7 g·kg have been proposed as sufficient for most endurance and/or strength-trained individuals within the International Society of Sports Nutrition and American College of Sports Medicine position statements, respectively. It is important to note that these values are unlikely to consider the unique demands experienced by rugby union athletes, and most of the research in the consensus statements utilised resistance or endurance-training protocols. Nonetheless, rugby athletes appear to consume protein in excess of recommendations (Jenner et al., 2019) with common intakes above 2.0 g·kg·d observed.

Protein ingestion has the potential to stimulate muscle protein synthesis for two to three hours, after which the process begins to decline (Layman et al., 2015; Bohé et al., 2001). A positive balance between muscle protein synthesis and breakdown, termed an anabolic response (Kim et al., 2018), is a determinant of protein within a muscle and may be crucial to allow for the repair and re-modelling of damaged muscle tissue following exercise (Tipton, Hamilton, and Gallagher 2018). Investigations have reported that ingestion of 20 g high-quality protein following leg-based resistance exercise is sufficient to stimulate a positive protein balance greater than no ingestion of protein, however 40g induced similar protein synthesis rates but greater amino acid oxidation (Moore et al., 2009a; Witard et al., 2014). Conversely, Macnaughton et al (2016) observed a greater anabolic response in resistance-trained males following full-body resistance training with ingestion of 40g compared to 20g.

With consideration to the influence of protein ingestion on the anabolic response in the physically active general population, recent investigations have aimed to identify an optimal daily protein distribution pattern. Over a 12-hour post-exercise period, Areta et al (2013) noted the anabolic response to 80 g of protein was greatest when 20 g was consumed at 3-hour intervals compared to 10 g at 1.5-hour intervals or 40 g at 6-hour intervals. When matched for energy and protein, Mamerow et al (2014) demonstrated that an even distribution of protein across three eating occasions (breakfast, lunch, dinner) resulted in a greater muscle protein synthetic response than a skewed protein intake, with the bulk consumed in the evening meal. It is collectively suggested in the literature (Morton et al., 2015; Schoenfeld and Aragon, 2018) that a per-meal relative protein dose of 0.4 g·kg may be optimal for mechanistic anabolic stimulation, as this amount consumed at 4-6 daily meals would result in overall daily recommendations being met, and accounts for the greater stimulation noted in the above studies.

The timing of protein and per meal doses throughout the day may be of worthwhile consideration to the rugby player due to mechanistic observations that protein balance is greater under such conditions (Areta et al., 2013; Mamerow et al., 2014) and the high training volumes and congested schedules rugby players engage in, with a focus on greater per-meal protein intakes likely to result in an overall daily intake. Despite this, limited research has explored protein intake and distribution in these athletes. MacKenzie et al (2015) reported that rugby players engaged in 3.8 eating occasions daily wherein 20 g or greater protein was consumed, however protein intakes of this amount may not be optimal for the athletes in the study. At a bodyweight of 100.2 ± 13.3 kg, this would result in a relative dose of 0.2 g·kg which does not reach the current proposed threshold of 0.4 g·kg for maximally stimulating muscle protein synthesis (Morton et al., 2015; Schoenfeld and Aragon, 2018). MacKenzie and colleagues (2015) noted that individual per meal protein target was 30.0 ± 4.0 g, however it is not known how much protein was consumed at each sitting. The purpose of the present study was to observe and quantify dietary protein distribution patterns across the day in professional and semi-professional rugby athletes. Based on previous research in athletes (Anderson et al., 2017; Gillen et al., 2017) we hypothesised that rugby athletes in New Zealand would not consume dietary protein in line with updated recommendations for the development or maintenance of lean mass on a per-meal basis (0.4 g·kg per meal across 4-6 eating occasions).

Methods

Participants

Thirty-five participants were recruited from a semi-professional rugby club in New Zealand. The sample size was based on the availability of players in the team; players were initially approached by the strength and conditioning coach of the club. If interested, participants were briefed further by the lead researcher. Data was granted from a parallel project in professional players due to the current project exploring different parameters. As such, a further ten players from a separate professional club were included in the dataset.

During briefing, the participants were informed that they were required to record their dietary intake for analysis, that their participation in the study was voluntary and that they were able to withdraw at any time without providing a reason. Following briefing of the purpose of the study, participants signed informed consent forms. This study was approved by the University of Waikato Human Research Ethics Committee (HREC(Health)2020#06).

Study Design

Prior to data collection, participants height (Stadiometer, SECA, Hamburg, Germany) and body mass (Electronic Flat Scale, SECA, Hamburg, Germany) were recorded. Data was collected during the 2020 national provincial pre-competition season (August-September).

Dietary intake data was collected over a seven-day period for each player using a RFPM mobile-phone application (MealLogger, Wellness Foundry, Helsinki, Finland). The application allows for a secure and private connection between the researcher and the participants.

Participants were briefed in person and provided with materials to assist with providing appropriate data for analysis. Participants were asked to take photographs of all food, supplements and fluid consumed. A photograph before and after consumption (if a food or meal was partially consumed) allowed for analysis of the total amount of food consumed. Participants were asked to place a hand or other object next to their plate/bowl as a reference of the size of the meal and to ensure the photograph was from an angle that allows for easy identification of the components and quantity of the meal. The morning after each collection day, participants were contacted by a member of the research team to enquire about any items they may have forgotten to log and to provide further clarification to logged meals if required.

Participants were asked to provide details about the food and/or meals consumed with photo upload. The inclusion of details such as brand labels, measurements, cooking methods and items within meals was encouraged. To reduce possible measurement error participants were asked to weigh food and/or ingredients if possible.

Dietary Analysis

Photographs were analysed for nutrient intake using FoodWorks (Version 10, Xyris Software, Brisbane, Australia). The information was entered manually into FoodWorks by a single member of the research team to ensure consistency. Participants' food intake was separated into six main eating occasions throughout the day, as described previously by other groups (Gillen et al., 2017; Anderson et al., 2017). Simply, participants were able to indicate which meal was consumed when uploading photographs with a corresponding timestamp on each photo. The main meals were recorded as 'breakfast' 'lunch' and 'dinner'. Items consumed between 'breakfast' and 'lunch' were recorded as 'AM snack'. Items consumed between 'lunch' and 'dinner' were recorded as 'PM snack'. Finally, items consumed after 'dinner' were recorded as 'evening snack'.

Statistical Analysis

Statistical analysis was performed on SPSS Statistics (Version 26, IBM, Chicago, Illinois, USA). Descriptive statistics are displayed as means ± SD. Total (absolute) and body mass adjusted (relative) values for protein intake were calculated. Significance was set at $p<0.05$. Frequency graphs were created to display distribution of relative protein intake in all participants at each eating occasion. Semi-professional participant data was analysed by position (forwards and backs).

Data was deemed to be non-normally distributed using a Shapiro-Wilk test. As such, non-parametric tests were used for the analysis of data. To analyse protein intake between eating occasions, the Related-Samples Friedman test was applied. In the event of a significant result, post-hoc analysis was applied using Wilcoxon signed-rank test and Bonferroni adjustment for multiple tests. Multiple Independent-Samples Kruskal-Wallis Tests were applied to analyse differences in eating occasions and total protein intake between groups, with post-hoc analysis conducted using Wilcoxon signed-rank test and Bonferroni adjustment for multiple tests.

Results

Participant Characteristics

Of the 35 recruited semi-professional participants, 25 were included with 10 professional rugby union athletes included in the final analysis. Ten participants were excluded for failing to provide adequate photographs and/or descriptions on ≥ three days to allow for analysis of the dietary information. Two semi-professional forwards and one semi-professional back provided six days of dietary analysis. Two professional athletes provided five days of dietary analysis. Participant characteristics are presented in Table 3.

Professional athletes had a greater age than both semi-professional groups ($p<0.01$). Significant differences were observed between all groups for body mass ($p<0.05$). Height was not different between groups.

Table 3. Participant characteristics.

	n	Age (years)	Height (cm)	Body mass (kg)	Total protein intake (g.day)	Total protein intake (g·kg·day)
Semi-professional						
Forward	19	24.2 ± 3.5	186.8 ± 8.2*	114.3 ± 8.2*	151.5 ± 64.6**	1.4 ± 0.5*
Back	6	24.4 ± 4.7	185.5 ± 6.8	93.8 ± 6.2*	178.7 ± 47.3	1.9 ± 0.5
Professional	10	31.4 ± 3.0*	187.2 ± 9.3	104.9 ± 12.0*	203.7 ± 68.1	2.0 ± 0.6

Note: * denotes significant difference from both other groups ($p<0.05$) ** denotes significant difference from professional cohort only ($p<0.05$)

Table 4. Per-meal protein intake in professional and semi-professional rugby players.

	Breakfast	AM Snack	Lunch	PM Snack	Dinner	Evening Snack
Absolute protein intake (g)	28.8 ± 18.6	13.6 ± 19.0	46.3 ± 30.7	17.1 ± 24.7	61.7 ± 34.7	7.9 ± 15.9
Relative protein intake (g.kg)	0.27 ± 1.8	0.13 ± 0.18	0.43 ± 0.29	0.16 ± 0.23	0.58 ± 0.33	0.07 ± 0.14

Total Protein Intake

Daily total protein values are displayed in Table 3. For absolute values, semi-professional forwards consumed significantly less protein than professional participants ($p<0.05$). Adjusted for body mass, semi-professional forwards consumed significantly less protein than both semi-professional backs and professional participants ($p<0.05$).

Protein Intake Between Eating Occasions

Combined average protein intake between eating occasions for all participants are displayed in Table 4. Protein intake between the AM snack and PM snack at an absolute and relative level were similar. A significant difference ($p<0.01$) was observed for protein intake between all other meals.

Total and body mass adjusted protein intake per meal between semi-professional forwards, semi-professional backs and professionals are displayed in Figure 18 and Figure 19, respectively. When comparing protein intake across eating occasions, lunch and dinner protein intakes were not significantly different in semi-professional forwards and backs, with forwards also consuming similar protein amounts across the AM, PM, and evening snack. Protein intake between PM snack – evening snack and breakfast – lunch was not significantly different in professionals. Differences between all other meals were significant ($p<0.05$). All differences were observed similarly following analysis of absolute and relative intake.

Frequency graphs are displayed in Supplementary Materials. At breakfast, lunch, and dinner, ≥0.4 g·kg protein was consumed at 19.2, 52.0 and 70.3% of eating occasions, respectively. No protein was consumed at the AM snack, PM snack and evening snack for 45.9, 41.0 and 59.4% of potential eating occasions, respectively.

Protein Intake Within Eating Occasions

Semi-professional backs consumed significantly greater relative protein intake at lunch than semi-professional forwards or professional participants ($p<0.05$). Differences between relative breakfast protein intake ($p<0.01$) were observed between semi-professional forwards and backs. Additionally, differences in both absolute and relative dinner were observed ($p<0.01$), with professional participants consuming greater absolute protein than either semi-professional group and all groups consuming different amounts of protein relatively.

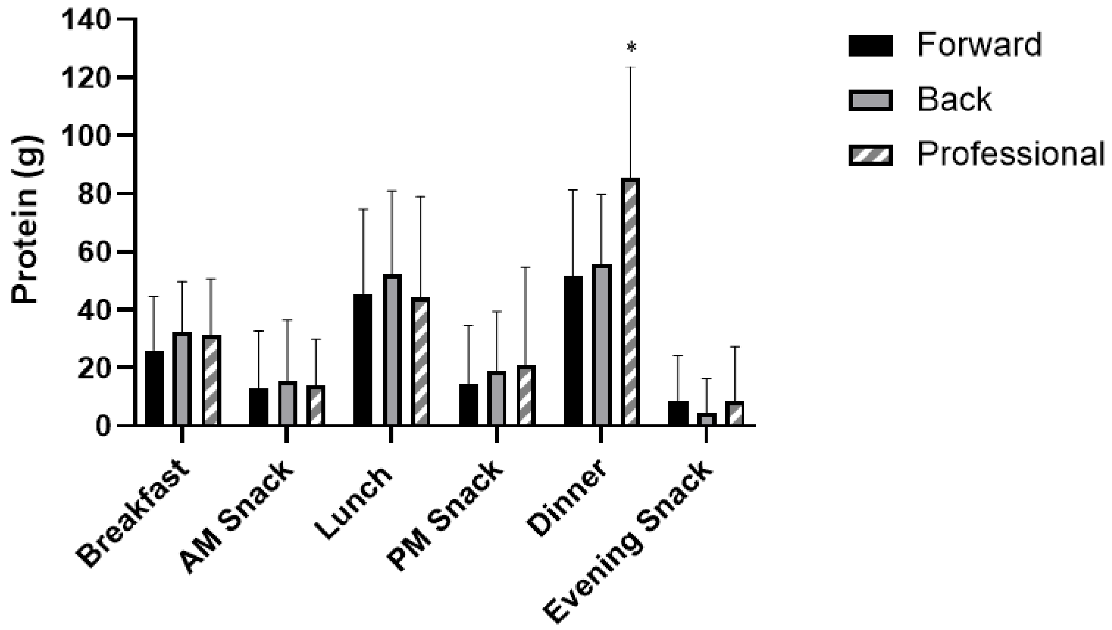

Figure 18. Absolute daily protein distribution.

Note: * denotes a significant difference (p < 0.05) from both other groups at eating occasion.

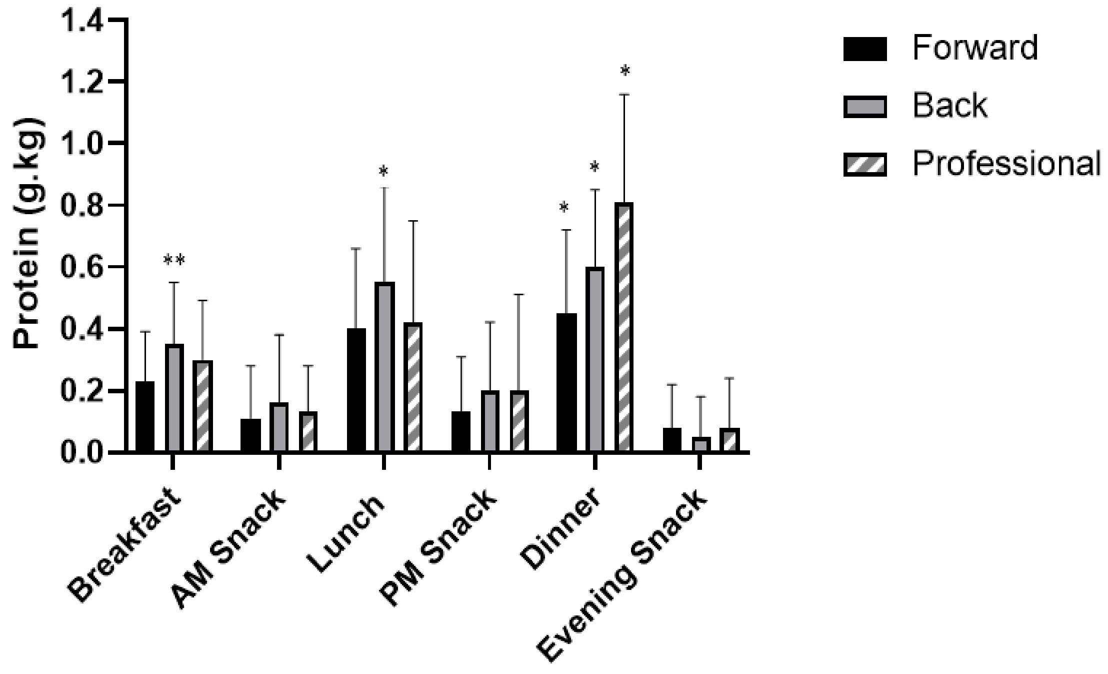

Figure 19. Relative daily protein distribution.

Note: * denotes significance (p < 0.05) from both other groups at eating occasion. ** denotes a significant difference from semi-professional forwards at eating occasion.

Discussion

The purpose of this study was to observe and quantify dietary protein distribution patterns across the day in professional and semi-professional rugby athletes. In line with the original hypothesis, all groups did not consume 0·4 g.kg protein in at least four meals daily, with most protein consumed in the main evening meal compared to earlier in the day. Results from the professional cohort analysed suggest these players eat in a more disproportionate pattern than semi-professional athletes.

Total daily protein intake was lower in semi-professional forwards than professionals for absolute intake and both semi-professional backs and professionals for relative intake. Daily protein intake for semi-professional backs (1.9 g·kg·d) and professionals (2.0 g·kg·d) was towards the higher end of recommendations (Jäger et al., 2017). At 1.4 g·kg·d, protein intake in semi-professional forwards is considerably lower than previously reported in rugby athletes at both professional and semi-professional levels (Jenner et al., 2019). Although 1.4 g·kg·d is at the lower end of recommendations set forth by the International Society of Sports Nutrition (Jäger et al., 2017) (1.2-2.0 g·kg·d) and the American College of Sports Nutrition (Thomas et al., 2016) (1.2-1.7 g·kg·d), rugby players in particular may benefit from greater consumption of protein to facilitate recovery from intense exercise (Tipton, 2011) and support lean mass growth to meet the demands of the sport (Smart et al., 2013). Additionally, lean mass loss may be offset with a high protein intake (Phillips and van Loon, 2011) which would be beneficial for athletes seeking body fat reduction, with greater (up to 2.4 g·kg·d) requirements for greater energy deficits (Hector and Phillips, 2018; Helms et al., 2014).

Semi-professional players consumed non-signficantly different protein at both lunch and dinner whereas professional players consumed protein in a disproportionate hierarchal fashion (dinner > lunch > breakfast) similarly to other investigations exploring daily protein distribution patterns in athletes (Anderson et al., 2017; Gillen et al., 2017). In the professional group, consumption of protein at dinner was similar to the total RDA for adults (0.8 g·kg·d) (Phillips et al., 2016) with total and relative protein intakes of 85.6 g and 0.81 g·kg, respectively. A similar intake of protein at dinner has been observed previously in professional football players (Anderson et al., 2017). This large intake seems to be responsible for the disproportionate pattern of protein ingestion throughout the day as opposed to a compensatory lack of protein at earlier eating occasions. It is unknown whether a per-meal intake of the magnitude seen in the professional cohort is likely to confer additional anabolic benefits. Moore et al. (2009a) demonstrated no significant benefit on MPS response following the ingestion of 40 g vs. 20 g whey protein following a leg-extension exercise session, the demands of which are much different to those of a professional rugby player. When measuring whole-body protein kinetics, (Kim et al., 2015a) found that a meal containing 70 g protein increased protein balance over a meal containing 40 g. This increase in whole-body protein balance is mainly attributed to a greater reduction in protein breakdown. Greater protein intakes per eating occasion may promote muscle repair, re-modelling, and development via reductions in muscle protein breakdown due to protein balance dictating the quantity of proteins in muscle.

The frequency graphs indicate that no protein was consumed at 59.4% of evening snack eating occasions. This could be explained in some situations by players simply eating dinner later and possibly not having time or the desire to consume food afterwards or due to intentionally avoiding food after the main evening meal. Nonetheless, consumption of protein pre-sleep may be a useful strategy to optimise skeletal muscle re-modelling and recovery from exercise-induced muscle damage in rugby players. Research has consistently shown a benefit to consumption of post-sleep casein protein on the overnight whole-body protein synthetic response when resistance training was performed (Reis et al., 2021) which certainly holds relevance to high level rugby players with congested training schedules. Regarding chronic responses, (Snijders et al., 2015) found that a daily multi-nutrient supplement (27.5 g casein protein + 15 g carbohydrates) versus a non-caloric placebo consumed before sleep increased both upper and lower-body strength, quadriceps cross-sectional area and type II fibre size. Consumption of the supplement provided more daily total protein (1.9 g·kg vs. 1.3 g·kg) which likely explains the findings, however pre-sleep ingestion of protein is theoretically likely to confer some benefit to athletes. During sleep muscle protein synthesis rates appear to be low and the body can digest and absorb protein efficiently, increasing amino acid availability and thus anabolism (Trommelen and van Loon, 2016). Rugby players may benefit from provision of protein prior to this long period of rest as lean mass levels are predicated by a prolonged positive protein balance (Tipton et al., 2018).

The supplemental frequency graphs indicate a large range of protein intakes at each meal. For example, mean total protein intake at breakfast was adequate to stimulate muscle protein synthesis according to (Witard et al., 2014) (>20 g). However, visualization of the frequency graphs indicates many participants did not appear to consume adequate protein at the breakfast occasion in accordance with Morton et al. (2015) and Schoenfeld and Aragon (2018) who suggest that a per-dose protein intake of 0.4 g·kg is likely to maximally stimulate muscle protein synthesis in young men; in the present study, 79.9% of potential breakfast eating occasions contained less protein than this threshold. Consuming adequate protein regularly throughout the day may not always be practical for high-level athletes due to various reasons including busy lifestyles and congested training schedules, appetite suppression due to intense exercise and fear of gastrointestinal disturbances (Burke et al., 2003), however this should be encouraged to stimulate and provide substrates for the anabolic processes required for supporting lean mass adaptations (Schoenfeld and Aragon, 2018; Morton et al., 2015).

It is important to consider the context of the results in relation to the current research. Enhanced muscle protein anabolism in response to an even distribution of protein throughout the day has been demonstrated in a limited number of studies in populations dissimilar to the one in the present investigation. In a cross-over study, MacKenzie-Shalders et al. (2016) aimed to identify whether the provision of protein between main eating occasions would increase lean mass in rugby players. Participants were provided with liquid protein supplements and instructed to consume them either with or between main meals for six weeks. Participants were educated and instructed to consume at least 20g protein as part of their main eating occasions. The authors observed no difference in lean mass gains between groups, despite 5.9 ± 0.7 eating occasions of at least 20 g protein in the distributed condition, compared to 4.0 ± 0.8 in the opposite condition. As such, it is currently inconclusive how increased protein distribution throughout the day may influence rugby players in the context of body composition, performance, and recovery improvements.

This is the first study to quantify protein intake per eating occasion relative to body mass in rugby players. This may be especially important as positional differences in rugby can lead to large variations in total and lean body mass, match demands, and training volumes. Although 20 g of protein is proposed to maximally stimulate muscle protein synthesis when consumed at four equal intervals over a 12-hour period compared to 40 g at two intervals (Areta et al., 2013), this amount may not be sufficient for rugby players. When considered on a relative basis, 20 g protein does not reach the threshold for young men to experience a maximal anabolic response (0.4 g·kg) (Morton et al., 2015; Schoenfeld and Aragon, 2018) in either an 80 kg back (0.25 g·kg) or a 120kg forward (0.16 g·kg). As such, future research should focus on the anabolic response to protein ingestion between individuals of significantly different body compositions.

An acknowledgement of the limitations associated with the present study is warranted. Difficulties with practical research in athletes mean data from a subset of players from one semi-professional and one professional team are presented across a week. As such, the results cannot be generalised to all rugby players or even to the same population at different time-points. Additionally, such difficulties led to six days of dietary analysis being recorded for two semi-professional forwards and one semi-professional back and five days for two professional athletes. As with any dietary analysis study, the practice of collecting dietary intake via self-reported methods is prone to under and misreporting (Capling et al., 2017). Despite the method used for collecting dietary intake information due to its' low burden and favourability in athletic populations (Simpson et al., 2017) it is possible the athletes intentionally or unintentionally omitted food or beverages. There are numerous reasons for this, such as social desirability bias when athletes consume foods deemed "unhealthy", not being aware of ingredients in a meal from a restaurant or simply forgetting to record their dietary intake.

Conclusion

In conclusion, it has been demonstrated that the pattern of protein intake throughout the day is disproportionate in rugby union athletes at both the semi-professional and professional level, with dietary protein not consumed in line with updated recommendations for the development or maintenance of lean mass on a per-meal basis (0.4 g·kg per meal across 4-6 eating occasions).. Whilst total protein intake is within International Society of Sports Nutrition and American College of Sports Medicine recommendations, promotion of an even distribution throughout the day may be beneficial for athletes, particularly those with large training volumes engaging in high-intensity impact sports. Future research should focus on the influence of protein distribution on body composition, performance, and recovery in team sport athletes and how differences in body composition may affect the anabolic response to exercise and protein ingestion.

Practical Recommendations

- Practitioners working with rugby players should encourage multiple feedings of protein across the day, with four feedings of 0.4 g·kg per meal being a minimum target to optimise anabolism and thus recovery and adaptation.

- Practitioner and athlete awareness of different absolute protein values to meet relative protein requirements is necessary. This will allow for individualised recommendations to be made for appropriate portion sizes.

- A food first approach to protein intake is recommended as non-protein nutrients contained within protein-rich whole foods may potentiate the post-exercise utilization of amino acids for anabolic purposes (Burd et al., 2019). Nonetheless, batch-tested dietary protein supplements can assist athletes in meeting both total daily and per-meal protein requirements. Due to the convenience and palatability of supplements they may be preferred following training sessions or during congested schedules.

Chapter 6: 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

Roberts, C., Gill, N., Beaven, C., Posthumus , L., & Sims , S. 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. under review in the *International Journal of Sport Science and Coaching*

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

Roberts, C., Gill, N., Beaven, C., Posthumus , L., & Sims , S. Nutrition knowledge in New Zealand rugby union athletes, poster presentation at conference, *International Society of Sports Nutrition conference*, Fort Lauderdale, USA (June 2022)

Prelude

Mechanistic research suggests individuals aiming to maximise the maintenance or development of skeletal muscle may more greatly benefit from consuming 0.4 g·kg dietary protein per meal, spread across 4-6 daily eating occasions. Such a strategy will result in an overall consumption of 1.6-2.4 g·kg·d, values of which are recommended for those looking to maintain or develop skeletal tissue (Schoenfeld and Aragon, 2018; Morton et al., 2015). Developmental rugby players engage in field-based training and strength and conditioning sessions aimed at promoting adaptations to aerobic and anaerobic capacity, strength, power and skill. As such, this population are likely to benefit from following the recommendations made in the literature.

Following the observation of sub-optimal dietary protein intake patterns in professional and semi-professional rugby players in Chapter 5, the original aim of Chapter 6 was to implement an intervention aimed at manipulating per-meal protein intake. During the observation period detailed later in this chapter, overall nutrient intake was deemed insufficient in numerous participants based on best-practice guidelines (Thomas et al., 2016; Jäger et al., 2017). As such, the running of an intervention manipulating per-meal dietary protein intake would likely confer no benefit. The following chapter concerns the delivery of a nutrition support protocol, in which a member of the research team worked as a full-time practitioner to deliver both group and individual-level nutrition support and evaluating the influence of this on nutrient intake, nutrient meal distribution, nutrition knowledge, body composition, and well-being.

Abstract

Provincial academies represent an important bridge between amateur and professional level rugby union in New Zealand. Athletes are provided with professional-level coaching, however limited direct nutrition support is available. Congested training schedules and the requirement to work or study due to a lack of financial support may present a challenge towards athletes meeting nutrition requirements. The aim of the study was to facilitate improvement in nutrient intake, body composition and subjective well-being in provincial academy athletes via the implementation of a nutrition-support protocol based around behaviour change techniques. Significant increases in relative energy (pre: 24.6 ± 8.9 kcal·kg; post: 25.8 ± 8.3 kcal·kg), total protein (pre: 131.1 ± 50.9g; post: 155.2 ± 51.5g) and relative protein (pre: 1.3 ± 0.5g·kg; post: 1.5 ± 0.5g·kg) were observed. Significant increases were observed for protein on both low-volume (breakfast, AM snack, evening snack) and high-volume (post-gym, AM snack, evening snack) training days. Carbohydrate intake post-intervention was significantly greater at the pre-gym eating occasion but lower at PM snack and dinner eating occasions on high-volume days. Significant differences in subjective sleep quality, stress, mood and upper body soreness were observed following the intervention. No changes were observed in body composition, carbohydrate, or fat intake. Significant variability in nutrition and body composition changes highlights the importance of applying an individualised approach to nutrition support provision in developmental athletes. Practitioners working within these environments should be aware of the challenges and influences contributing to athletes' nutrition choices and habits.

Introduction

Rugby Union is a popular intermittent team sport in which players engage in high-intensity activity bouts interspersed with low-intensity periods. Additionally, players engage in contacts and collisions in the form of tackles, scrums, rucks, and mauls (Roberts et al, 2008). Major differences in both body composition and on-pitch roles lead to homogenous training and match demands in rugby players. Forwards are taller and possess greater total, lean and fat mass than backs (Posthumus et al., 2020). Backs cover greater distances during matches (6127 ± 724 vs 5812 ± 666 m) and spend more time performing high intensity running (1.6 ± 0.5 vs 1.1 ± 0.4%), however forwards engage in more high intensity activity (11.5 ± 1.8 vs 3.8 ± 1.3% total match time) due to involvement in static exertion events such as scrums (Roberts et al., 2008). Furthermore, forwards engage in a greater number of high force collisions during matches than backs (Grainger et al., 2018). Due to the unique and variable demands and characteristics, rugby players would benefit from an individual approach to their nutrition recommendations and requirements.

Energy intake must be adequate to maintain normal physiological functioning (Loucks et al., 2011) and meet the unique demands of the sport. Across a two week in-season period, elite rugby union players expended 4365 ± 1122 kcal daily, representing 61 ± 10 kcal·kg·FFM (Smith et al., 2018). Furthermore, a single bout of training containing 20 collisions resulted in a likely greater energy expenditure over the succeeding five days (Costello et al., 2018). Whilst differences between forwards and backs are apparent, both groups can expect to engage in >20 collisions per match (Schoeman et al., 2015; Reardon et al., 2017) resulting in alterations to energy metabolism. Indeed, energy expenditure following game days (GD+1 and GD+3) appears greater than before (GD-1) likely due to the collisions experienced during match-play (Hudson et al., 2020a).

Rugby players utilise both aerobic and anaerobic metabolic pathways to replenish ATP during match-play and suboptimal carbohydrate availability can interfere with both, resulting in fatigue. Furthermore, low carbohydrate availability for the brain can impair cognitive function and result in sub-optimal decision making and concentration. Muscle glycogen can be depleted rapidly in response to high-intensity intermittent activity such as that observed in rugby match-play (Murray and Rosenbloom, 2018); previous research has demonstrated a 40% muscle glycogen depletion following a rugby match, supporting the reliance on carbohydrate as a fuel source for rugby players. Additionally, those engaging in multiple daily training sessions should prioritise carbohydrate intake following early exercise to optimise glycogen re-synthesis and ensure effective re-fuelling (Burke et al., 2011).

Dietary protein is essential for health, repair and re-modelling of damaged tissue following exercise and promoting adaptations (Phillips et al., 2007; Phillips, 2012; Phillips and van Loon, 2011). Total and per-meal protein intake are important considerations for enhancing the muscle protein synthetic response and eventual lean fat free mass development (Phillips and van Loon, 2011; Trommelen et al., 2019) which can positively influence speed, power and endurance (Duthie, 2006). Requirements for protein intake in athletes are broad (1.2-2.0 g·kg·d) (Jäger et al., 2017; Thomas et al., 2016) with no difficulty in meeting these requirements found in professional (Bradley et al., 2015b, 2015a; Black et al., 2019; Posthumus et al., 2021) and/or developmental rugby players (MacKenzie et al., 2015; Smith et al., 2016).

Many young and developing athletes are unlikely to possess appropriate nutrition awareness or an ability to purchase and prepare meals resulting in a risk of under-fuelling (Gilbert, 2008; Quatromoni, 2008; Birkenhead and Slater, 2015). These barriers may be influenced by poor nutrition knowledge, a potential major factor in the athlete making appropriate food choices to support sporting performance and health (Spronk et al., 2015; Wardle et al., 2000; Alaunyte et al., 2015). Rugby athletes in provincial developmental squads are less likely to have contact with dieticians or registered nutritionists and as such may seek information and implement strategies from unreliable sources such as social media or the internet (Sharples et al., 2021).

In New Zealand, there are unique opportunities for developmental rugby players to be selected to participate in academies. Academies are designed to provide young players with coaching support, professional level programming and access to facilities to prepare the individual for either professional level play and/or a future outside rugby. Academy rugby players in New Zealand are a unique population in that they engage in academy sessions with the aim to develop and potentially play as professional athletes whilst still training and playing at the local amateur club level. Due to the lack of financial assistance associated with receiving a professional contract, academy players need to consider additional obligations such as work and study. This represents a unique challenge for the athlete meeting appropriate nutrition requirements, particularly when multiple daily training sessions are required (Burke et al., 2011), and may require specific guidance due to the high training volumes, with convenience, food availability and family likely to influence choices athletes make (Stokes et al., 2018).

A lack of data exists regarding nutrition in New Zealand developmental players despite representing an important bridge between club and provincial level rugby and the athletes engaging in high training volumes. The present team-based case study aimed to explore the impact of nutrition support on nutrient intake, nutrition knowledge, body composition and subjective well-being in academy rugby union players. We hypothesised that provision of nutrition support would facilitate improvements in the aforementioned variables.

Methods

Participants

Seventeen players from a provincial rugby union academy volunteered to participate in the study. At the time of data collection, all participants trained with both the provincial academy and their local club alongside engaging full-time in outside obligations, such as work and study. Training demands of the participants during data collection are described in Table 5. At the time of data collection, nutrition support for the team totalled six hours per week, spread across all teams (contracted male players, contracted female players and academy players). Participants provided informed consent and ethical approval was obtained by the University of Waikato Human Research Ethics Committee (HREC(Health)2020#46).

Table 5. Participants' weekly training schedule

	AM	PM
Monday	Academy – Strength & Conditioning – 05.30-07.30	
Tuesday	Academy – Strength & Conditioning – 05.30-07.30	Club training – 18.30-20.00
Wednesday		Academy – Field – 18.00-19.30
Thursday	Academy – Strength & Conditioning – 05.30-07.30	Club training – 18.30-20.00
Friday		
Saturday		Club match – 14.45-16.20
Sunday		

Study Design

The current study utilised a cross-over design, with participants completing both a monitoring and intervention period. During the monitoring period, participants logged their full dietary intake including all meals, snacks, and beverages; a high-training volume, low-training volume and rest day were monitored each week. Following a four-week monitoring period, basic nutrition education was provided during a one-week wash-out period. Dietary intake was then monitored for another four weeks, with active input provided to assist with optimising nutrition intake in-line with best practice sports nutrition recommendations (Jäger et al., 2017; Thomas et al., 2016). Body composition was measured using a three-dimensional optical scanning device prior to the monitoring period and both prior to and following the intervention period. Nutrition knowledge was measured using a validated questionnaire prior to delivery of the nutrition education and following the four-week intervention period. Finally, subjective fatigue, sleep quality, muscle soreness, stress and mood were measured weekly following the Monday morning training session.

Nutrition Support Intervention

The delivery of nutrition support was provided by the lead researcher, a certified nutritionist, and was provided on both an individual and group level. The nutrition support implemented behaviour change techniques as described by Michie et al. (2013). The behaviour change techniques implemented in the present study are detailed in Table 1.

As a group, participants attended a sixty-minute seminar detailing their collective macronutrient intake during the monitoring period. Information regarding meeting macronutrient requirements and improving diet quality, from both a health and athletic standpoint, was provided along with strategies to facilitate this. Participants were provided with hand-outs containing information detailing how to appropriately structure a core meal to meet nutrition requirements for an athlete. Ranges of nutrients were provided to account for the homogeneity in body composition and on-field demands of the participants, which were then customised during individual consultations. Hand-outs were also provided to address example meals and snacks, recipes for example complex meals and a grocery list.

During the week following delivery of the group seminar, each participant was provided with a third party-tested whey protein supplement (Combat 100% Whey, MusclePharm, Calabasas, CA, USA batch #A163830620A) and had an individual 10-minute consultation to discuss personal goals for the intervention period. During these consultations, the lead researcher and participant identified strategies to assist them in reaching their overall and per-meal nutrition targets. Such strategies included choosing meals which could be prepared with minimal time available and/or in bulk, identifying meals which align with family and/or friends' preferences and goals and choosing convenience and takeaway options that provide appropriate nutrient composition and density.

Throughout the intervention period, regular contact was maintained with participants both in-person during the academy gym training sessions and using a free cellular messaging application (WhasApp, Inc., Santa Clara, CA, USA). This contact allowed the lead researcher to monitor food intake, suggesting changes and re-enforcing good practices where appropriate.

Table 6. Behaviour change techniques applied during the nutrition support intervention.

No.	Label	Definition	Implementation in Study
1.1	Goal Setting (Behaviour)	Set or agree on a goal defined in terms of the behaviour to be achieved	Each participant attended an individual consultation with the lead researcher to set and define goals to allow for the meeting of nutrient requirements based on the participants habitual food intake observed during the observation period e.g. participants who did not regularly consume 3 main meals daily were set the goal to consistently consume breakfast, lunch and dinner based on the information provided during the group seminar and hand-outs
2.7	Feedback on outcome (s) of behaviour	Monitor and provide feedback on the outcome of performance of the behaviour	Participants were monitored and maintained regular contact with the researcher, both in-person and using a cellular messaging application, where feedback was provided in real-time to encourage changes where appropriate/re-enforce appropriate food choices
3.1	Social support (unspecified)	Advise on, arrange, or provide social support or non-contingent praise or reward for performance of the behaviour	Support was provided by the lead researcher, both in-person and using a cellular messaging application. Additionally, participants were supported by performance staff at the academy

4.1	Instruction on how to perform a behaviour	Advise or agree on how to perform the behaviour	Participants were advised on how to prepare simple meals which meet nutrition requirements based on their individual characteristics and to support athletic performance and recovery
5.1	Information about health consequences	Provide information about health consequences of performing the behaviour	Participants were informed of the health consequences of making appropriate food choices and the increased risk of illness and injury if poor nutrition habits are adhered to
6.1	Demonstration of the behaviour	Provide an observable sample of the performance of the behaviour, directly in person or indirectly	Participants were provided with a demonstration on how to prepare certain simple meals to meet nutrition requirements
7.1	Prompts/cues	Introduce or define environmental or social stimulus with the purpose of prompting or cueing the behaviour. The prompt or cue would normally occur at the time or place of performance	The lead researcher would attend morning academy training sessions to encourage consumption of appropriate food pre and post-training
9.1	Credible source	Present verbal or visual communication from a credible source in favour of or against the behaviour	During the group seminar, a nutrition practitioner working with international-level teams provided information about how professional players are expected to eat to meet the demands of the sport

11.3	Conserving mental resources	Advise on ways of minimising demands on mental resources to facilitate behaviour change	Participants were provided with handouts including: a grocery list, how to structure a meal appropriate for athletes with visual cues, examples of appropriate meals and snacks, cooking instructions for some complex meals
12.5	Adding objects to the environment	Add objects to the environment in order to facilitate performance of the behaviour	Provision of a batch-tested whey protein supplement to assist with increasing protein intake and to allow for preparation of practical meals/snacks
13.1	Identification of self as a role model	Inform that one's own behaviour may be an example to others	Participants were informed that their high level of competition results in club players & team-mates (at the time of data collection, participants were engaged with both the provincial academy and club teams simultaneously) seeing them as role-models and that setting a good example would be beneficial
15.1	Verbal persuasion about capability	Tell the person that they can successfully perform the wanted behaviour, arguing against self-doubts and asserting that they can and will succeed	The lead researcher maintained regular contact with the participants, both in-person and via a cellular messaging application, to provide positive feedback whether goals at the time were being met and enforce the participants ability to succeed in meeting nutrition targets

Body Composition

Body composition was measured using a three-dimensional optical scanning device (FIT3D®, San Mateo, CA, USA) (Tinsley et al., 2020). Such scanners produce a three-dimensional avatar of the body allowing for anthropometric assessment. The device was installed in a room with no natural light interference and shiny surfaces covered. Participants were instructed to create an account with Fit3D, allowing for repeated use and their own access to body composition results. Following account creation, users are presented with instructions via the attached monitor for accurate body composition analysis. The participants were asked to remove all clothing to underwear and tie their hair up above their head if necessary. Prior to commencement of the scan, participants were required to hold two handles allowing for an anatomical position to be maintained. Participants were asked to stand still and look forward for the 40-second scan duration.

Body composition analyses were conducted at baseline, immediately prior to delivery of the nutrition support intervention and the final week of the intervention period. Baseline and pre-intervention scans were completed in the morning (05.00-06.00) in a fasted state prior to training. Due to a change in the athletes' schedules, post-intervention scans were completed between 12-14.00. Coefficient of variation range for between-day reliability of the device used for lean mass and fat mass are 0.0-1.8% and 0.3-6.4%. FIT3D® scanners have previously demonstrated equivalence to a 4-Compartment model for lean mass and fat mass measurements (Tinsley et al., 2020).

Figure 20. FIT3D® optical scanning device set-up

Dietary Intake

Dietary intake was monitored using a RFPM mobile phone application (MealLogger, Wellness Foundry, Ashburn, VA). MealLogger was chosen as it allows for users to upload photographs with descriptions to assist with the identification and analysis of foods or items. Additionally, the application is preferred to traditional dietary analysis methods in athletes (Simpson et al., 2017).

Participants were instructed to take a clear photo of all meals, food item or beverage consumed and including a hand, pen, or cutlery in the picture to act as a size reference. Multiple pictures were encouraged if participants were preparing complex meals. Participants were encouraged to provide as much detail in the description box as possible to assist with the analysis, including using weighing scales if available, detailing other common house-hold measures, including brand names and portion sizes and detailing cooking methods, condiments, or beverages.

Participants were contacted for any clarifications regarding logged items or meals if the quality of either photographs or descriptions was inadequate using WhatsApp. Additionally, each participant was contacted the morning following each monitoring day to both provide clarification on uploads if required and to recall the previous days intake and tease out unlogged items if appropriate.

Dietary intake was analysed using FoodWorks 10 (Version 10.0.4266, Xyris Software, Australia) as it contains a comprehensive database of food items in both Australia and New Zealand. If a food item was not present in FoodWorks, energy and macronutrient information was collected from food labels or the company website. Analysis was conducted by a registered Associate Nutritionist with the Nutrition Society of New Zealand for consistency.

Daily dietary intake was analysed for energy intake, energy intake relative to lean body mass, total and relative to bodyweight macronutrient intake (protein, carbohydrate, and fat). Additionally, per-meal dietary protein intake was calculated for high-volume day and combined low-volume/off day. This was to account for participants attending an academy training session at 05.30 on high-volume days which may influence the consumption of meals in the morning. Meals were separated into 6 eating occasions as described previously

(Anderson et al., 2017; Gillen et al., 2017): breakfast, AM snack, lunch, PM snack, dinner, evening snack.

Nutrition Knowledge

Nutrition knowledge was measured using the thirty-five item ANSKQ. The ANSKQ is validated for use in young athletic populations (Trakman et al., 2018) which includes demographic, general nutrition and sports nutrition knowledge questions. Slight modifications were made to some questions to better reflect the current study population – for example, "Do you think 100g of chicken breast has enough protein to promote muscle growth after a bout of resistance exercise?" was changed to "Do you think 150g of chicken breast has enough protein to promote muscle growth after a bout of resistance exercise?" due the anthropometric heterogeneity of the participants in the present study.

Participants completed the baseline ANSKQ immediately prior to receiving the initial nutrition education group session and a second time following the four-week intervention block. Both occurrences were completed in the presence of the lead researcher in exam-type conditions, with the questionnaires completed in a room in silence under the observation of a researcher. Questionnaires were either completed on an online survey software (Qualtrics, Provo, UT, USA) or hard copies were available if required.

Subjective Wellbeing

Participants completed a short 5-point wellbeing questionnaire previously used in rugby athletes (McLean et al., 2010) to measure subjective fatigue, sleep quality, upper and lower body muscle soreness, stress levels and mood. The questionnaires were completed on a weekly basis following a Monday morning gym session (07.00-07.30). Weekly questionnaires were distributed using an online form (Google Forms, Google, CA, USA) and completed on a personal mobile phone at the end of the gym session.

Statistical Analysis

Statistical analysis was conducted using SPSS (Version 27, IBM corp, Armonk, NY, USA) with significance set at $p < 0.05$. Shapiro-Wilk testing was applied to determine normality, with energy and macronutrient intake deemed non-parametric. Descriptive statistics are displayed as means ± SD.

To account for data on days where nutrient intake could not be determined due to missing or incomplete information, data were cleaned using ‘replace missing values’, whereby new values were added to reach the same mean and SD and allow for analysis. Wilcoxon-Signed Rank Sums Test were applied to analyse changes in total nutrient intake. Distribution of nutrient intakes between meals were analysed using Related-Samples Friedman’s Two-Way Analysis of Variance by Ranks, with Wilcoxon-Signed Rank Sums Test applied to compare changes between meals in response to the intervention. Changes in body composition variables were analysed using a repeated- measures ANOVA whilst ANSKQ scores and change in total wellbeing scores across the 4- week blocks were analysed using paired-samples t-test.

Results

Participants

Of the original participants, two were excluded due to injury and illness, three were excluded due to inadequate adherence to the study procedures and one was excluded due to leaving the academy. Dietary analysis was conducted on ten participants and body composition analysis was conducted on 11 participants. Fourteen participants were included in the group seminar and completed the ANSKQ with body mass (104.2 ± 17.2 kg) and height (186.3 ± 9.0 cm) recorded prior to baseline body composition analysis.

Participants represented a variety of positions: prop (n=2), lock (n=3), flanker (n=3), half-back (n=3), centre (n=1), wing (n=1) and full-back (n=1). Living situations were reported as living in house-shares (50%), with family or other caregivers (29%), alone (14%) and with a partner (6%). One participant followed a pescatarian dietary pattern. Of a potential 90 days dietary analysis, 57% and 46% of days were sufficiently logged for analysis during the monitoring and intervention periods, respectively.

Total Nutrient Intake

Changes in total nutrient intake between pre- and post-intervention are displayed in Table 7. Relative ($p=0.032$) energy intake were greater post-intervention. Additionally, total, and relative protein intake significantly increased post-intervention ($p<0.001$). No significant difference was observed between all other nutrients.

Table 7. Total and relative energy and macronutrient intake. * denotes significance ≤ 0.05

	Energy (kcal)	Energy (kcal.kg)	Protein (g)	Protein (g.kg)	Carbohydrate (g)	Carbohydrate (g.kg)	Fat (g)	Fat (g.kg)
Pre-Intervention	2511 ± 906	24.6 ± 8.9	131.1 ± 50.9	1.3 ± 0.5	265.2 ± 119.7	2.6 ± 1.2	96.3 ± 41.8	0.9 ± 0.4
Post-Intervention	2605 ± 840	25.8 ± 8.3 *	155.2 ± 51.5 *	1.5 ± 0.5 *	260.4 ± 100.0	2.6 ± 1.0	97.5 ± 43.6	1.0 ± 0.4

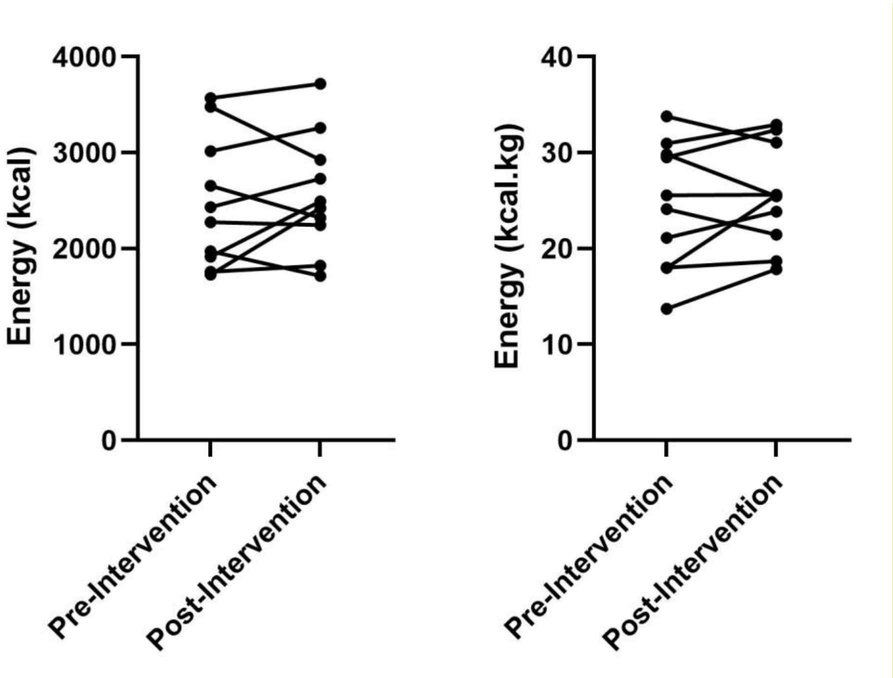

Figure 21. Individual change in absolute and relative energy intake following intervention

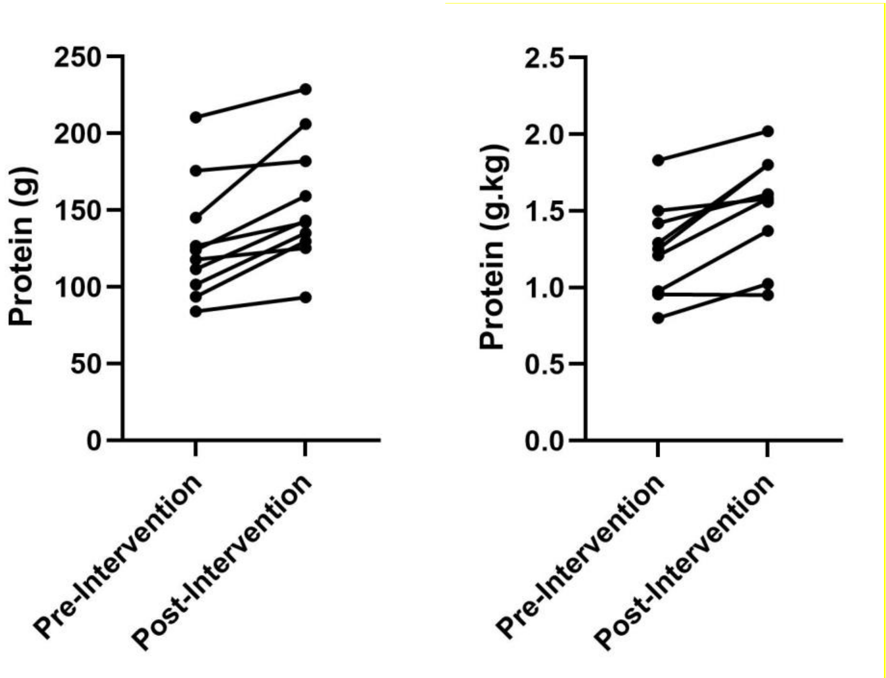

Figure 22. Individual change in absolute and relative protein intake following intervention

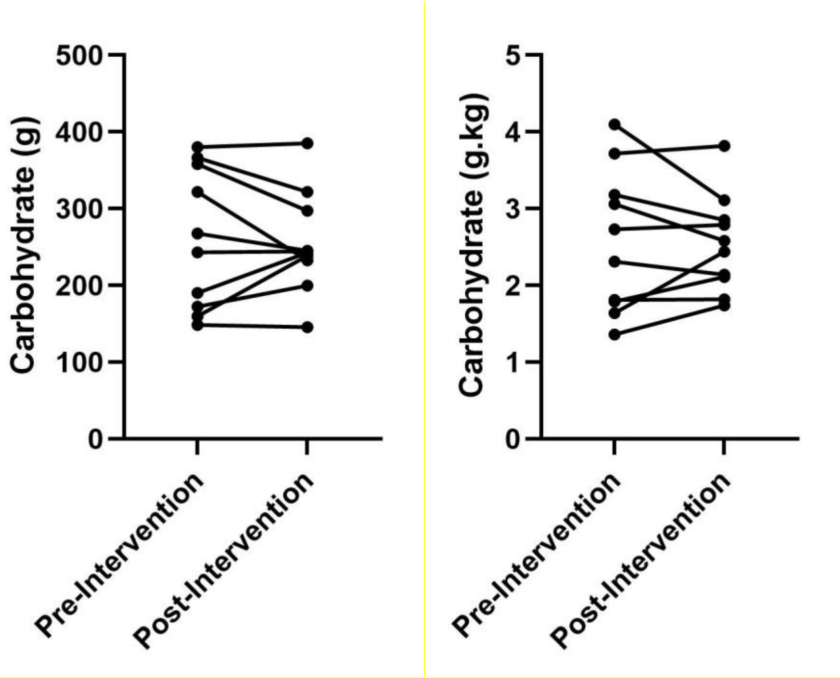

Figure 23. Individual change in absolute and relative carbohydrate intake following intervention

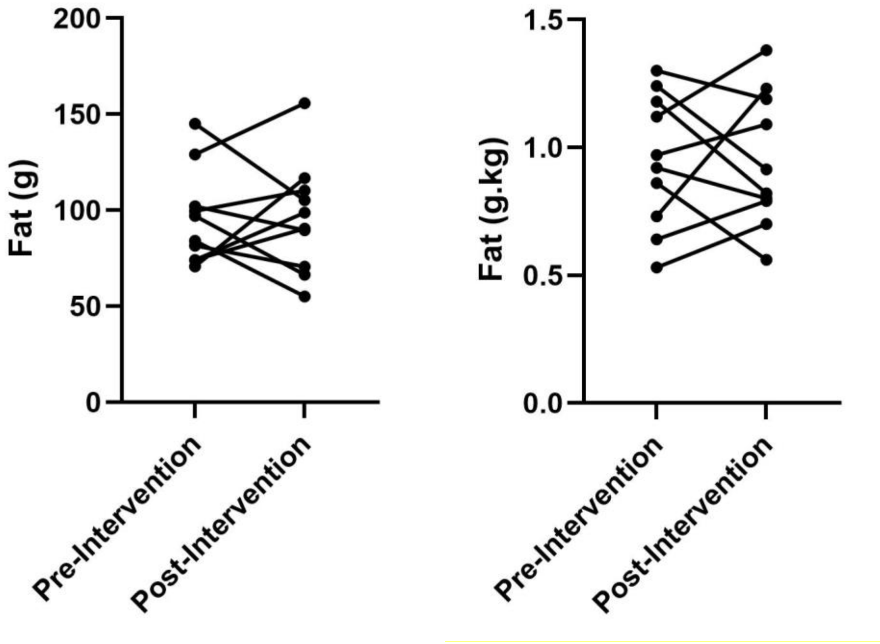

Figure 24. Individual change in absolute and relative fat intake following intervention

Meal Distribution of Nutrient Intake

Absolute and relative protein and carbohydrate intakes are displayed in Figures 1-4. On low-volume training days, both absolute and relative protein intake were greater at 'breakfast' (absolute: $p < 0.001$, relative: $p < 0.001$), 'AM snack' (absolute: $p = 0.001$, relative: $p < 0.001$), and 'evening snack' (absolute: $p < 0.001$, relative: $p < 0.001$) in response to the intervention. Additionally, relative 'lunch' protein intake was greater following the intervention ($p = 0.044$). A significant increase in absolute carbohydrate intake was observed ($p = 0.043$), with no significant changes in between-meal relative carbohydrate intake.

On high-volume training days, both absolute and relative protein intake were greater following intervention at 'post-gym' (absolute: $p < 0.001$, relative: $p < 0.001$), 'AM snack' (absolute: $p < 0.001$, relative: $p < 0.001$), and 'evening snack' (absolute: $p < 0.001$, relative: $p < 0.001$), time-points. Significantly greater relative protein intake was recorded at 'lunch' ($p = 0.026$) whilst a reduction in absolute ($p = 0.008$) and relative ($p = 0.031$) protein intake was observed at 'dinner' following the intervention. Absolute and relative carbohydrate intake were greater at ' pre-gym' (absolute: $p = 0.030$, relative: $p = 0.018$), 'AM snack' (absolute: $p = 0.028$, relative: $p = 0.048$), 'lunch' (absolute: $p < 0.001$, relative: $p < 0.001$), and 'evening snack' (absolute: $p = 0.042$, relative: $p = 0.047$). Absolute ($p < 0.001$) and relative ($p < 0.001$) 'PM snack' carbohydrate intakes were significantly lower and relative 'dinner' ($p = 0.049$) carbohydrate intake was reduced during the intervention period

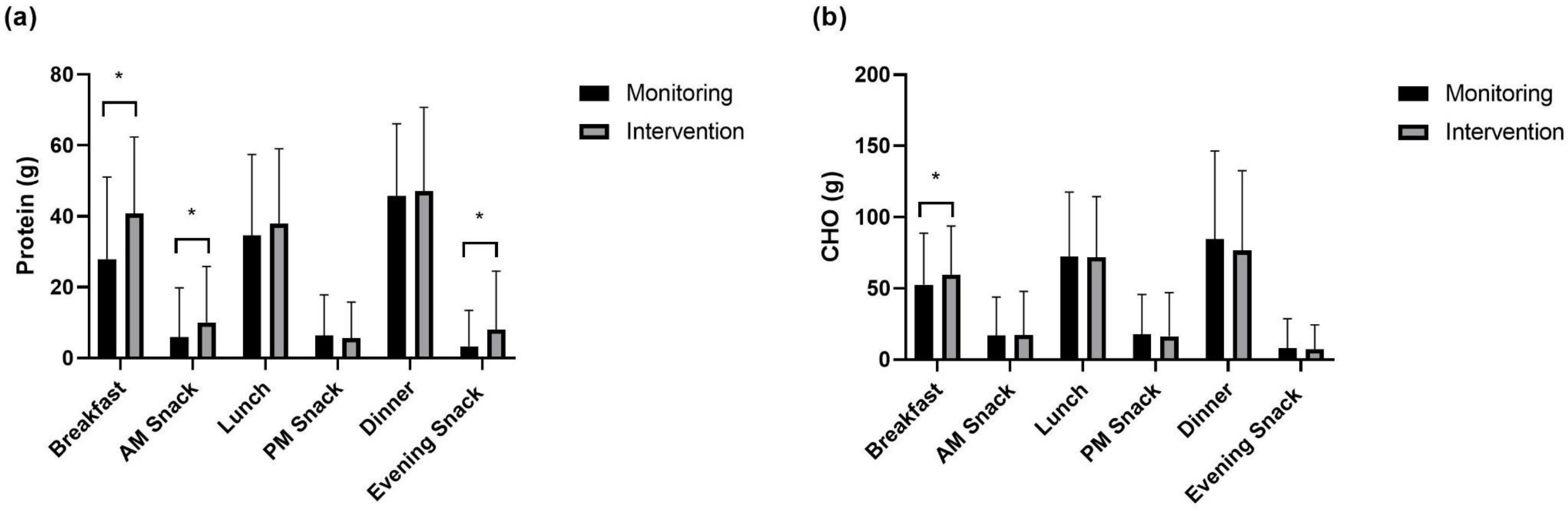

Figure 25. Absolute between-meal intake on low-volume training days of (a) protein and (b) carbohydrate. * signifies a difference in intake between monitoring and intervention periods.

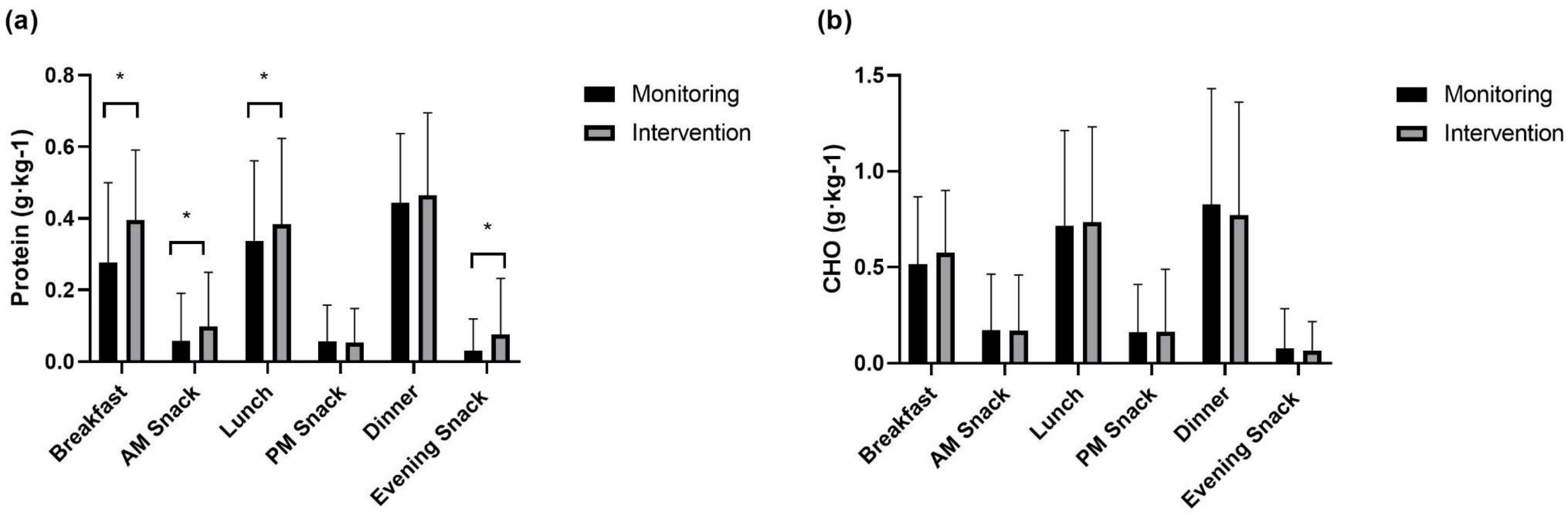

Figure 26. Relative between-meal intake on low-volume training days of (a) protein and (b) carbohydrate. * signifies a significant difference in intake between monitoring and intervention periods.

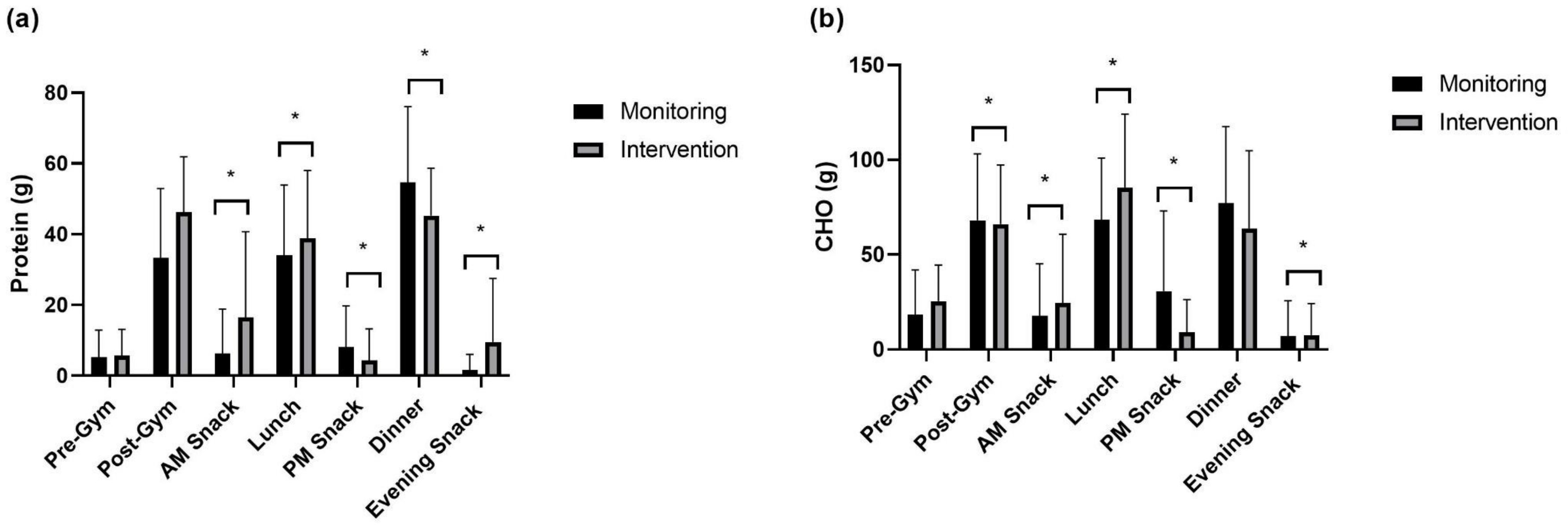

Figure 27. Absolute between-meal intake on high-volume training days of (a) protein and (b) carbohydrate. * signifies a significant difference in intake between monitoring and intervention periods.

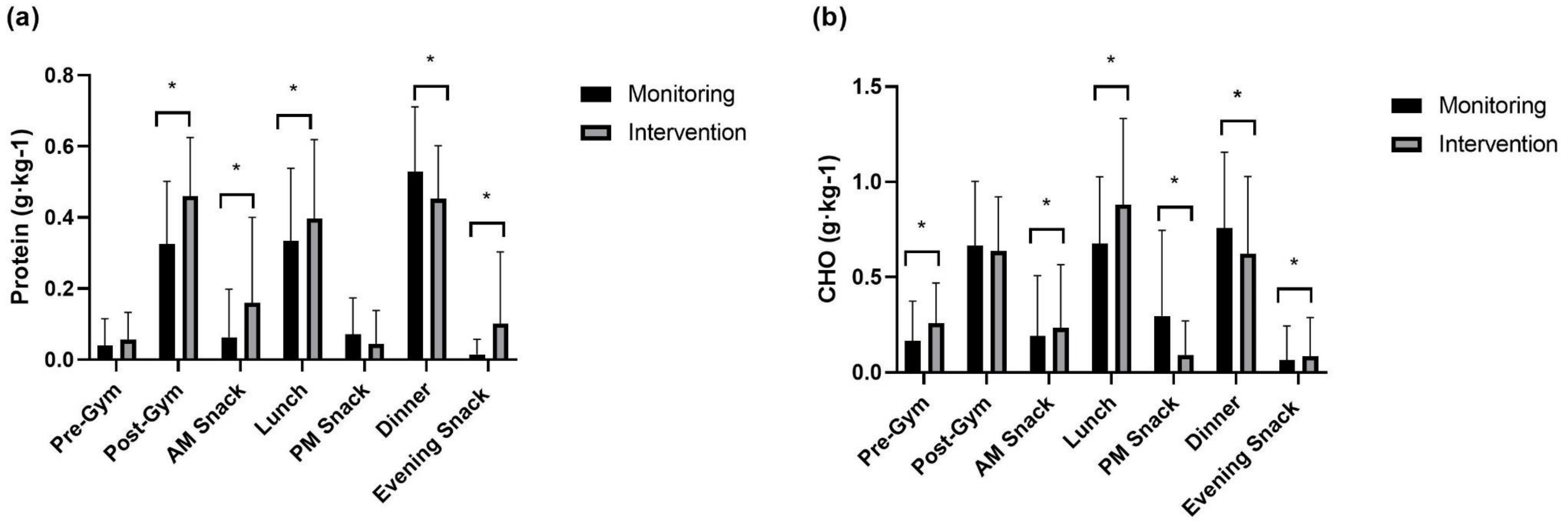

Figure 28. Relative between-meal intake on high-volume training days of (a) protein and (b) carbohydrate. * signifies a significant difference in intake between monitoring and intervention periods.

Body Composition

Body composition values are displayed in Table 8. There was no significant difference between measurements for body mass (*p*=0.29), lean mass (*p*=0.83) or fat mass (*p*=0.38) between baseline, pre-intervention, or post-intervention.

Table 8. Body composition measurements at baseline (pre-monitoring), pre-intervention and post-intervention

	Baseline			Pre-Intervention			Post-intervention		
	Body Mass (kg)	**Lean Mass (kg)**	**Fat Mass (kg)**	**Body Mass (kg)**	**Lean Mass (kg)**	**Fat Mass (kg)**	**Body Mass (kg)**	**Lean Mass (kg)**	**Fat Mass (kg)**
Mean	102.4	82.7	19.7	102.1	82.4	19.7	102.8	82.4	20.4
SD	18.2	12.0	7.3	19.0	11.7	8.1	19.6	11.4	9.0
Range	77.7 – 138.0	64.1 – 103.4	11.8 – 34.9	74.8 – 139.6	62.6 – 102.8	11.6 – 37.1	75.7 – 141.8	66.1 – 104.3	9.8 – 37.8

Nutrition Knowledge

No significant difference was observed between pre-intervention (38.9 ± 14.4%) and post- intervention (42.0 ± 12.6%) SNKQ scores (p=0.26). Individual changes in SNKQ scores are displayed in Figure 3. Five individual scores decreased and seven increased post-intervention, with two remaining the same.

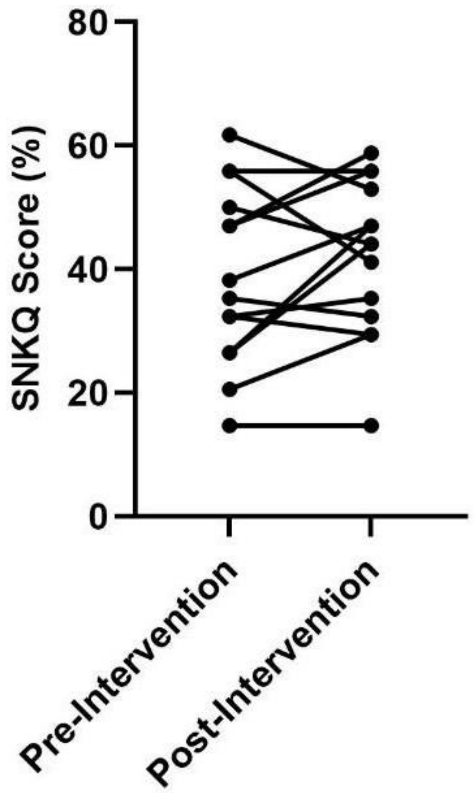

Figure 29. Individual changes to SNKQ scores (%) in response to intervention

Wellbeing

Changes in wellbeing scores across monitoring and intervention weeks are displayed in Figure 4. Significant improvements between pre- and post-intervention were observed for sleep quality, stress and mood. A significant increase between pre- and post-intervention was observed for upper body muscle soreness. No differences between time-points were observed for fatigue or lower body muscle soreness.

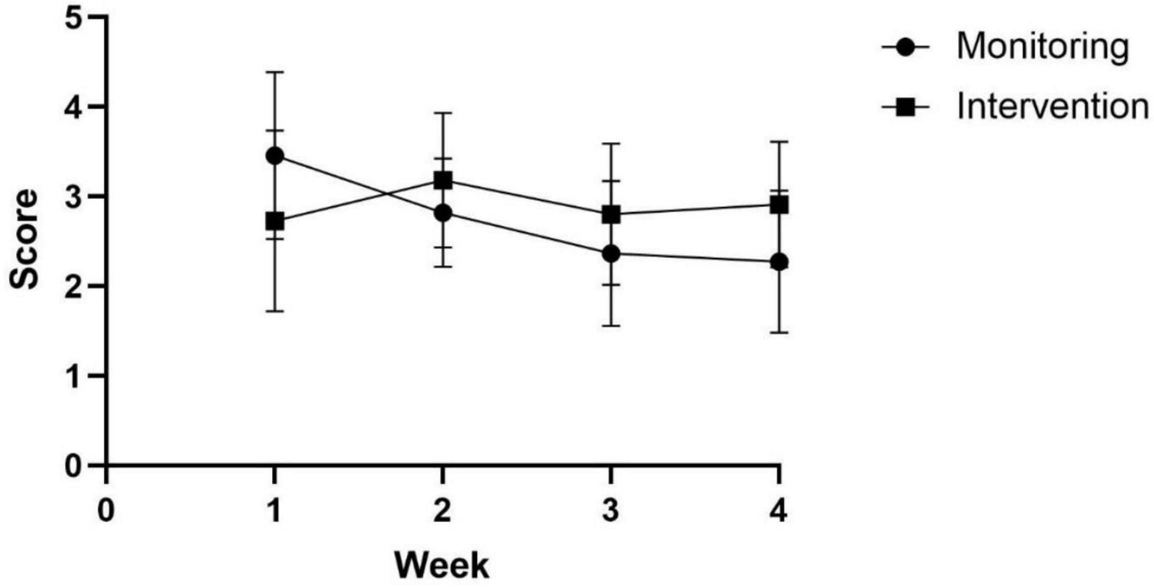

Figure 30. Subjective change in fatigue during monitoring and intervention periods

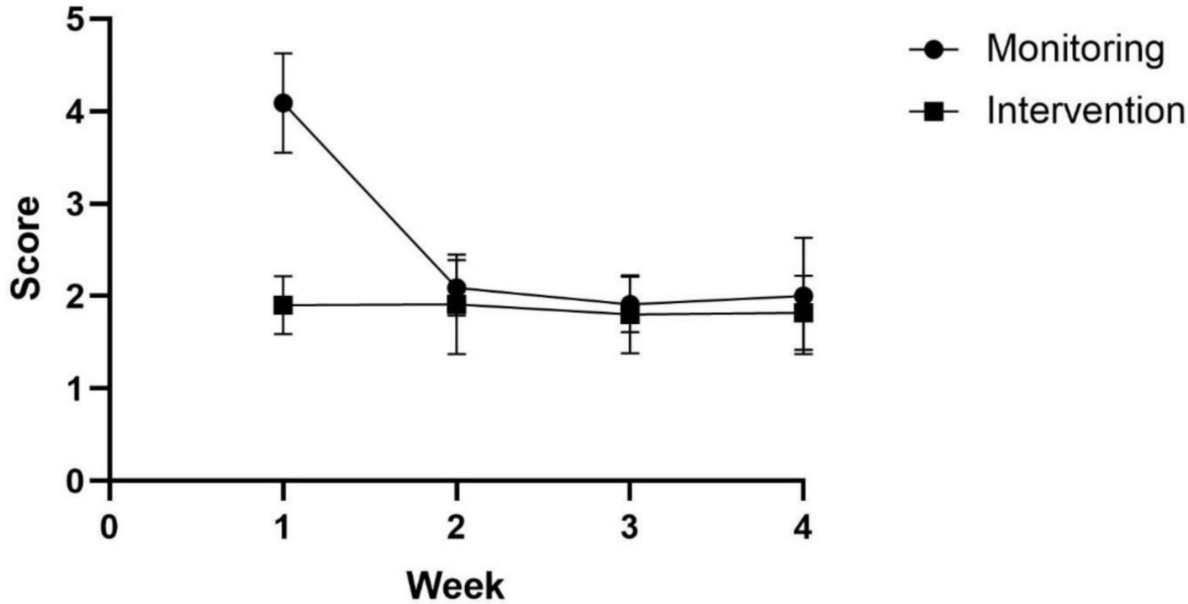

Figure 31. Subjective change in mood during monitoring and intervention periods

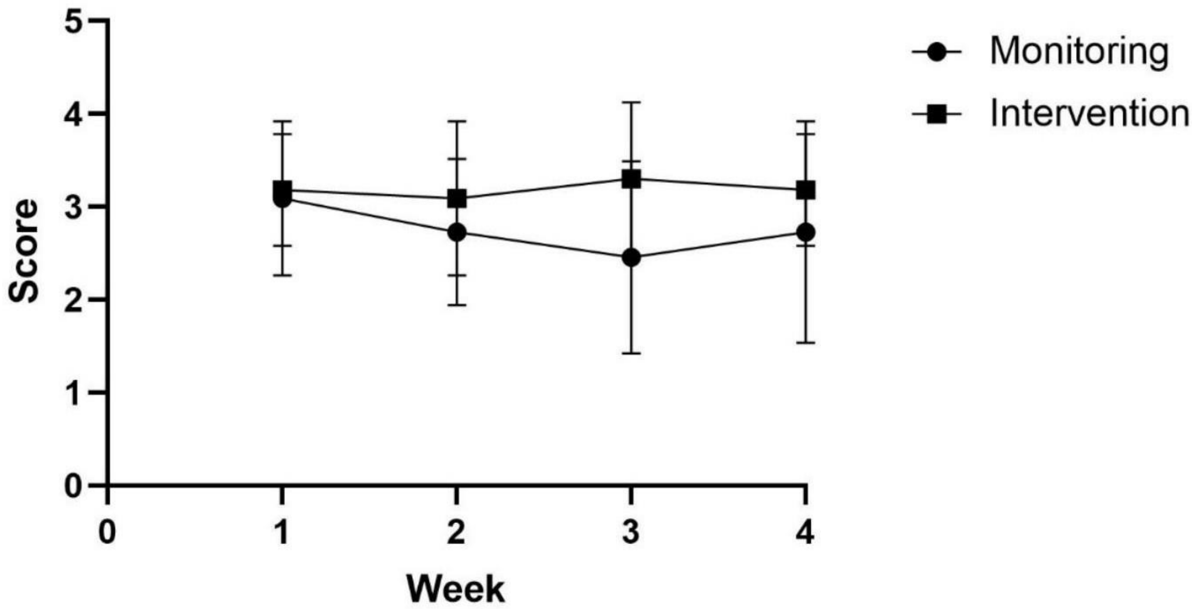

Figure 32. Subjective change in lower body muscle soreness during monitoring and intervention periods

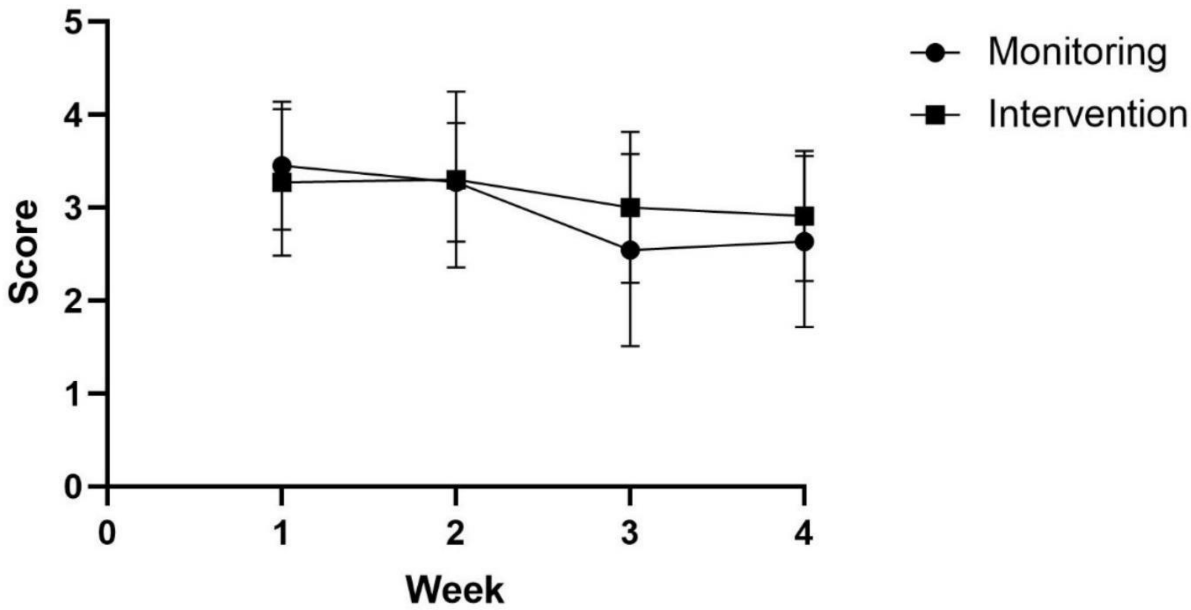

Figure 33. Subjective change in upper body during monitoring and intervention periods

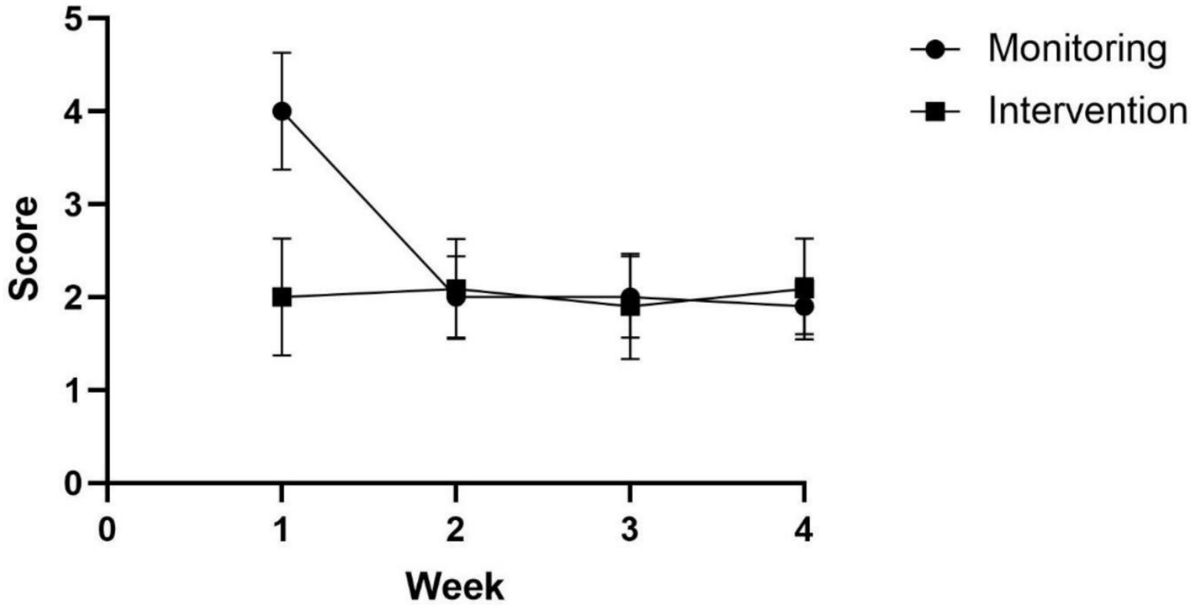

Figure 34. Subjective change in sleep quality during monitoring and intervention periods

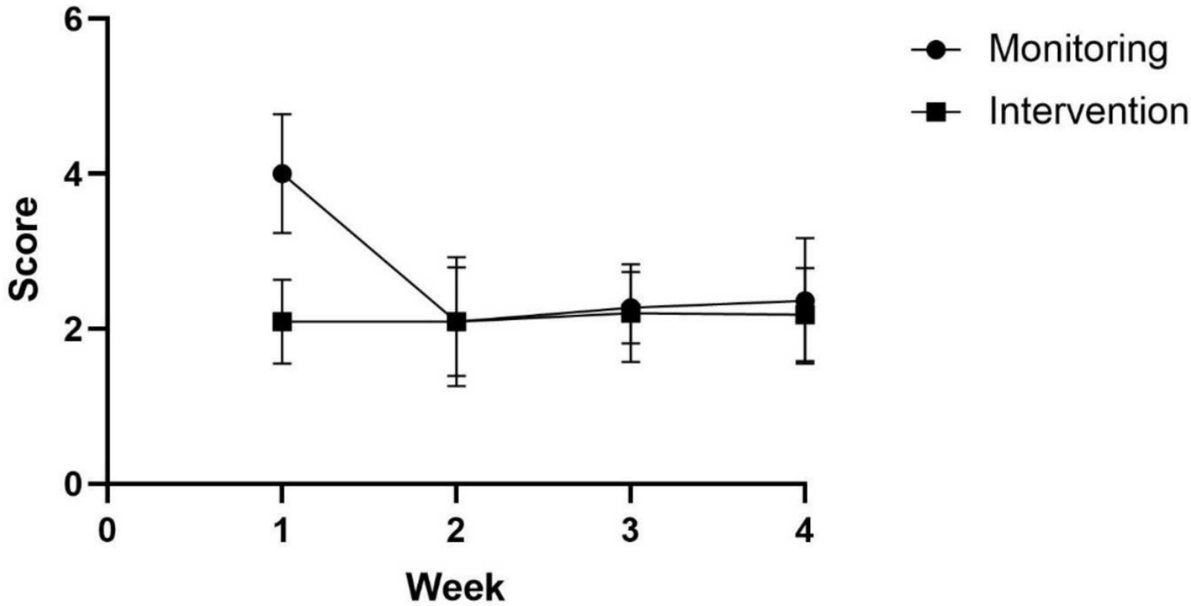

Figure 35. Subjective change in stress during monitoring and intervention periods

Discussion

The aim of the study was to explore the impact of complete nutrition support on nutrient intake, nutrition knowledge, body composition and subjective well-being in academy rugby union players. Both total absolute and relative to body weight protein intake increased following the intervention. Dietary protein intake throughout the day on both low-volume and high-volume training days improved, with greater intakes at snacking occasions and post-gym. Furthermore, dietary carbohydrate intake prior to morning training sessions on high-volume days was greater following the intervention.

Energy Intake

A significant difference was observed in total energy intake or energy intake relative to body mass in response to the nutrition support intervention. Whilst expressed against total body weight as opposed to FFM, energy intakes likely do not meet the threshold required to suggest energy sufficiency in exercising males (40kcal·kg FFM.day) (Melin et al., 2019). Furthermore, the energy intakes observed in the present study overall (Pre: 2492 ± 762 kcal, Post: 2614 ± 625 kcal) and an absolute level (Pre: 24.4 ± 7.5 kcal·kg, Post: 25.5 ± 6.0 kcal·kg) are lower than values reported in English U19 elite rugby academy players (3412 ± 670 kcal, 38.2 ± 9.8 kcal·kg, Smith et al, 2016). Additionally, large variability in individual energy intake was apparent but not unexpected due to the variability in total and lean body mass, of which influences individual energy requirements (Westerterp, 2017a).

Previous research has demonstrated that rugby players expend considerable energy on a daily basis. Using DLW, (Smith et al., 2018) observed daily energy expenditures of 4010 ± 744 (U16), 4414 ± 1523 (U20) and 4761 ± 1523 (U24). Due to three different age cohorts being represented considerable variability existed in both the number of heavy and light training days and matches during the period athletes were monitored. Due to the observed energy intake being lower than both intakes and expenditures seem previously (Smith et al., 2018, 2016) it is possible the current athletes were not meeting energy requirements. Low energy availability can impair athletic performance in the form of a decreased neuromuscular function, impaired cognitive function, endocrine dysregulation, and increased irritability (Ackerman et al., 2019; Logue et al., 2020); male athletes are particularly susceptible to decreased testosterone levels and sub-optimal bone mineral density (Melin et al., 2019), which can negatively influence performance and recovery, injury risk and health. Despite lower energy intakes than those previously reported body mass remained stable indicating that energy balance was maintained throughout the duration of the study. Numerous reasons may account for this.

First, eating and drinking habits on non-observation days may have resulted in a meeting of total weekly energy requirements. Alcohol ingestion may be problematic in rugby players, with a high prevalence of weekly binge-drinking sessions (defined as ≥5 drinks per session) (Quarrie et al., 1996; Sekulic et al., 2014) and 22% of a 595 professional cohort reporting adverse alcohol intake (Gouttebarge et al., 2018). Irrespective of excessive intake, consumption of alcohol is not typically compensated for with a reduction in energy intake and may result in a greater food energy intake than non-consumption (Kwok et al., 2019). During the study, no players reported consuming alcohol however data collection did not occur on Friday or Saturdays when drinking is most likely to occur due to a lack of responsibility over the weekend (Thrul and Kuntsche, 2015) or following matches (Prentice et al., 2014).

Second, the schedule of the present athletes may present multiple differing challenges to meeting energy requirements. Time, convenience, and knowledge are described as components of the food choice process (Furst et al., 1996) and an athlete with multiple obligations may favour convenience over appropriate food choices for health and performance. Intense exercise may delay feeding (King et al., 1994), a response which may be of particular importance for the present population as balancing multiple obligations may leave inadequate time to appropriately consume food.

Third, athletes are often required to alter their body composition to optimise performance via lean mass gain, adipose tissue reduction or a combination of both (Black et al., 2019). If athletes had been undergoing a weight loss regimen, adaptive thermogenesis may cause a reduction in total energy expenditure such that is lower than would be expected (Rosenbaum et al., 2008).

Fourth, body image concerns and disordered eating may be significant factor in athletes not meeting energy requirements. Disordered eating can present in behaviours such as skipping meals and restricting eating (Wells et al., 2020) which can negatively influence overall energy and nutrient intake. Disordered eating can develop in response to various sociological factors such as culture, education, family, team-mates, and coaching staff and can play a role in the development of low-energy availability and the adverse physiological and psychological outcomes (Melin et al., 2019).

Current data regarding the prevalence of disordered eating in male athletes is mixed (Abbott et al., 2021). Nonetheless, (Gibson et al., 2019) reported that 30% of Super Rugby players who completed an Eating Behaviour Questionnaire were classified as 'medium risk' for developing an eating disorder. Despite the limited data in rugby union athletes, it is prudent for practitioners and coaching staff to be aware of risk factors of disordered eating and monitor the athletes in their care accordingly.

Macronutrient Intake

Total protein intake significantly increased following the nutrition education protocol. Despite the increase, post-intervention (153.8 ± 37.1 g, 1.5 ± 0.3 g·kg) absolute and relative protein intake in the present study was lower than previous work in male academy rugby union players (210.7 ± 46.7 g, 2.3 ± 0.5 g·kg) (Smith et al., 2016). A possible reason for this was the incorporation of BCT's in the intervention, specifically adding objects to the environment in the form of providing supplemental protein to each participant. Ingesting adequate protein has long been recognised as a crucial consideration of dietary intake for athletes, with those engaging in team sports requiring substrates for training-induced protein re-modelling resulting in adaptations and to replace oxidised amino acids during prolonged exercise bouts Ingesting adequate protein has long been recognised as a crucial consideration of dietary intake for athletes, with those engaging in team sports requiring substrates for training-induced protein re-modelling resulting in adaptations and to replace oxidised amino acids during prolonged exercise bouts (Phillips, 2012; Phillips and van Loon, 2011; Phillips et al., 2007).

Despite the average protein intake meeting requirements, large variability between individuals was apparent. During the monitoring period, two participants did not meet the 1.2 g·kg minimum threshold set by the International Society for Sports Nutrition and American College of Sports Medicine (Jäger et al., 2017; Thomas et al., 2016) and only three exceeded 1.6g·kg·d, with greater protein intakes recommended for individuals when energy availability is low (Longland et al., 2016; Helms et al., 2014) These findings highlight the importance of both working with athletes individually to ensure protein requirements are met and the reporting of individual values in future studies.

Carbohydrate intake during both the monitoring and intervention periods did not meet the best-practice recommendations of 6-10 g·kg·d (Rodriguez, DiMarco & Langley, 2009;

Burke et al., 2011). Consumption of carbohydrates in the present study was greater than those reported in professional Australian Football Players (Jenner et al., 2018) however lower than professional (Bradley et al., 2015b, 2015a; Posthumus et al., 2021; MacKenzie et al., 2015) and academy Rugby Union players (Smith et al., 2016).

Inadequate carbohydrate intake may impair a rugby athletes' ability to perform optimally due to the repeated bouts of anaerobic movement patterns (Williams and Rollo, 2015), with (Bradley et al., 2016) demonstrating a significant reduction in *vastus lateralis* muscle glycogen content following a rugby league match. The authors note that pre-match glycogen levels were not different when 3 g·kg·d carbohydrate were consumed in the 36-hour lead into the match compared to 6 g·kg·d; despite reliance on endogenous carbohydrates during match-play, this may indicate that requirements may not be as high as those values reported in best-practice sports nutrition recommendations (Burke et al., 2011; Thomas et al., 2016).

Observation of the individual data indicates that some participants experienced a decrease in carbohydrate intake post-intervention. An improvement in food choices may facilitate a reduction in carbohydrate intake; ultra-processed foods may appeal to the rugby academy athlete due to the cost and convenience of such items, however they are typically high in calories, sugar, and fat (Hall et al., 2019). Whilst this may appear sub-optimal, ensuring athletes consume a nutrient sufficient diet along with meeting macronutrient requirements is essential for promoting good health and wellbeing (Wirt and Collins, 2009) and maintaining function of metabolic pathways in which micronutrients are required (Thomas et al., 2016).

Meal Distribution

Protein

Following a bout of unilateral lower body resistance exercise, protein doses of 40 g have exhibited a similar stimulation of muscle protein synthesis to 20 g, but with an increase in amino acid oxidation and urea production (Moore et al., 2009a; Witard et al., 2014). Full- body resistance training appears to increase skeletal muscle sensitivity to ingested protein with 40 g inducing a greater anabolic response than 20 g, however greater amino acid oxidation is still observed (Macnaughton et al., 2016). Accordingly, distribution of adequately dosed protein (Morton et al., 2015; Schoenfeld and Aragon, 2018) throughout the day has been postulated as a factor in the stimulation of muscle protein synthesis (Areta et al., 2013) and thus potentially the optimal development and/or retention of lean mass (Schoenfeld and Aragon, 2018). As increased lean mass can amplify speed, strength, and power (Duthie et al., 2003; Duthie et al., 2006) rugby players can benefit from increased levels to support optimal match-play demands.

Dietary protein intake significantly increased at the post-gym eating occasion on high-volume days (usually corresponding with breakfast due to the timing of morning training) and at breakfast on the low-volume days, towards the proposed 0.4 g·kg per meal threshold (Morton et al., 2015; Schoenfeld and Aragon, 2018). Despite MacKenzie et al. (2015) reporting no influence of increasing dietary protein distribution on lean mass development in rugby union players, aiming for the optimal threshold at multiple eating occasions will increase total daily protein intake and whole-body protein balance, which may accumulate to chronic lean mass and metabolic adaptations beneficial to the rugby athlete (Duthie et al., 2006).

Increased amino acid availability due to pre-sleep protein ingestion has been proposed as a strategy to amplify acute overnight muscle protein synthesis (Res et al., 2012) and thus chronic resistance training adaptations (Snijders et al., 2015) A greater intake may be required at this time to optimally support positive muscle turnover, with 40g suggested to account for due to the greater post-absorptive period experienced during sleep than during a typical day (Trommelen and van Loon, 2016). In the present study, both pre- and post-intervention protein intakes for both high-volume and low-volume training days were below 10 g; sub-optimal protein intake at this feeding occasion was observed previously in rugby (CHAPTER 4), soccer (Anderson et al., 2017) and mixed athletes (Gillen et al., 2017).

Carbohydrate

Carbohydrates are a major fuel for rugby players due to the intermittent style of play, distance covered during matches and high-intensity events such as scrummaging and jumping (Bradley et al., 2016). In the present study, carbohydrate intake was measured both pre- and post-training during the morning sessions on a double training day. Following guidelines for carbohydrate intake (Burke et al., 2011) both pre- and post-training carbohydrate intake may have been inadequate to support optimal performance, adaptation and recovery for the participants evening training session.

Despite specific pre-exercise carbohydrate recommendations being made for prolonged endurance exercise exceeding 90 minutes (Burke et al., 2011) muscle glycogen depletion is observed in response to a resistance training protocol (Camera et al., 2010) with the degree of depletion dependent on training intensity, duration and work accomplished (Slater and Phillips, 2011). Additionally, a lack of upregulation of cell signalling pathways that promote glycogen synthesis may be observed following resistance exercise (Glover and Phillips, 2010; Camera et al., 2010) which can present a challenge for those with congested schedules and multiple training sessions in the day. In the present study, morning resistance training sessions were succeeded by evening field-based training sessions consisting of intermittent movement patterns and skill-based activities which may be impaired by carbohydrate insufficiency.

Body Composition

No significant change in all body composition measures was observed in response to the nutrition education protocol. Contrary to our observations, small positive changes to fat mass and fat-free mass have previously been reported in both professional (Argus et al., 2010) and semi-professional (Crewther et al., 2016) New Zealand rugby players. Whilst the professional players engaged in a higher-volume training programme (Argus et al., 2010), the involvement in both resistance-training and skill-based club training sessions was similar in the semi-professional players (Crewther et al., 2016) to the participants in the present study. Greater lean mass levels are beneficial for improving the effectiveness of contact events of which is beneficial to the rugby player (Bell, 1979). Furthermore, speed, strength and power can be enhanced via lean mass accretion, qualities of which benefit rugby performance (Duthie et al., 2006). Ensuring rugby players possess appropriate levels of fat mass to complement their playing position (Duthie et al., 2003) and maintain endocrine homeostasis (Ackland et al., 2012) whilst not impairing exercise performance (Bell, 1979; Duthie et al., 2003; Zemski, Keating, Broad, & Slater, 2019) is an important consideration for the sports nutrition practitioner.

Nutrition Knowledge

Nutrition knowledge did not change in response to the delivery of a nutrition support intervention in the present study. Nutrition knowledge scores were lower than those previously observed in elite and non-elite male and female Gaelic Footballers (Mitchell et al., 2021) and mixed NCAA athletes when the same assessment tool was applied. Furthermore, many participants reported that they received nutrition information from sources other than a dietician or nutritionist, such as family and friends (35.7%) (Jagim et al., 2021) and coaching staff (78.6%). New Zealand premier rugby coaches have previously been described as considerable disseminators of nutrition information to players, with 83.8% of 168 respondents reporting providing information on nutrients, fluids, recovery, supplements and weight control (Zinn et al., 2006). Despite this, the authors note that coaches possessed inadequate nutrition knowledge themselves (Zinn et al., 2006). As the athletes in the present study attended both academy and club training sessions, variable information regarding nutrition may have been provided. Athletes should be aware of the potential that conflicting and incorrect information can be disseminated and consult with a nutrition professional accordingly.

High intra-individual variability in nutrition knowledge scores was observed (PRE:38.9 ± 14.4%; POST:42.0 ± 12.6%) similar to a mixed Australian athletic cohort during the creation and validation of the instrument (Trakman et al., 2018). Greater nutrition knowledge has previously been demonstrated in older individuals and those with greater education levels in both general (Wardle et al., 2000) and athletic populations (Mitchell et al., 2021) particularly when nutrition education was included (Trakman et al., 2018).

Previous systematic review data supports that the implementation of nutrition education protocols can significantly improve nutrition knowledge (Tam et al., 2019); this can then positively influence nutrition and food choices. In the present study, no significant improvement in nutrition knowledge was observed, however nutrition education was only a small component of the research design. A greater emphasis was placed on assuming the role of a full-time nutrition practitioner and providing support, with the education provided representing a 45-minute presentation and short individual consultation. In the systematic review, most studies applied weekly 60-minute sessions with the aim of delivering specific nutrition information at a greater depth than the present study. Future research exploring the influence of targeted nutrition education sessions on nutrition knowledge and nutrition habits over a greater period in the same population would be beneficial.

Whilst nutrition knowledge can be modified by the practitioner, many other factors may contribute to poor food choices made by athletes. Making decisions for food intake is multi-factorial and influenced by resource availability and personal and social factors (Sobal and Bisogni, 2009). Satiety and hunger regulation via the brain, gastric distention (Wang et al., 2008) and gastrointestinal appetite hormone release altered by feeding (Suzuki et al., 2010) and exercise (Stensel, 2011) may all influence an athletes' food choices and meal timings.

In the present study, athletes were not in a professional contract and thus were either working or studying. Additionally, 50% and 29% of participants reported living in a house-share and with family, respectively. These environments may present limitations to both tangible and intangible resources regarding food choices (Furst et al., 1996) with lack of money, space to prepare meals and time especially challenged. The resulting food insecurity, in that higher costs associated with nutrient-dense items (Drewnowski, 2004), may be prohibitive to the athlete making appropriate decisions for health and performance. The nutrition practitioner should be aware of challenges faced by individual athletes and devise strategies that can be utilised considering environmental factors.

Wellbeing

Participation in competitive rugby union can support and facilitate a range of positive wellbeing outcomes; participants from an experienced amateur US cohort reported that involvement in rugby created their identity and benefited making friends, improving mental growth and psychological fulfilment (Dong et al., 2013). Despite this, young male rugby union athletes reported greater stress on training days (Nicholls et al., 2009). Such stressors relate to diet (e.g weight and general weakness), sleep (e.g getting enough sleep) and health (e.g muscle pain and unexplained aches) (Leduc et al., 2022; Nicholls et al., 2009). This may be particularly relevant to the present population, who engaged in six weekly training sessions across four days during the study period, however such perceptions were not supported in the present cohort, with significant improvements observed following the intervention for subjective feelings of stress, mood, and sleep quality.

Upper body muscle soreness increased from pre to post intervention. Whilst perceptual, this has important implications for rugby players engaging in congested training and play schedules. Muscle soreness may persist for four days following match-play (Fletcher et al., 2016) and significant correlations between the number of contacts endured during a match, muscle soreness in forwards (r=0.62) and fatigue in both forwards and backs (r=0.44) were observed in rugby league players (Twist et al., 2012). Cumulative consecutive day training has previously demonstrated a negative effect on neuromuscular function and perceived muscle soreness in elite rugby players (Tavares et al., 2018). In contrast to the present study, the authors only observed adverse perceived muscle soreness in the lower body.

Practical challenges and limitations

Practically, data collection during the short period available was difficult due to numerous factors. First, significant changes to nutrient intake are unlikely to occur in such a short timeframe. An initial barrier identified in the present study was the incorporation of the sports nutrition practitioner, who was previously unknown to the players, into the team and for the athletes to be receptive to the information and advice provided by the practitioner. This initial development of rapport between the practitioner and the athletes likely delayed the spped at which suggestions were taken on board, prior to implementation. Additionally, Lally et al (2010) modelled the time to automatic performance of a healthy habit in participants by asking for repetition of the habit, logging whether the habit was completed daily over 84 days and completing a self-report habit index (Verplanken and Orbell, 2003) to calculate automaticity of said habit. The authors suggest habit formation takes an average of 66 days, with significant variability between participants (18-254 days). The eating habits promoted by the researchers were simple tasks, including eating a piece of fruit at lunch; complex tasks such as meeting best practice sports nutrition recommendations for multiple nutrients and meals when faced with previously mentioned barriers to resources for optimal food choices may take longer to promote and enforce. Second, two participants were away for a 1-week period for recreational purposes. Third, nine participants were not always available due to travel or overseas game commitments. These highlight the complexities of promoting optimal nutrition practices in these athletes, particularly when limited practitioner support is provided and athletes are regularly travelling.

Baseline and pre-intervention body composition analysis were conducted during early morning training sessions whereas post-intervention was collected at mid-day. This was due to a change in the participants training schedules which made early morning data collection unattainable and thus complete standardisation before tests was not practically feasible. Factors such as hydration status (Bonilla et al., 2022) and intestinal faecal mass (Cheuvront et al., 2004) can influence the body composition values obtained both within and between-day (Bonilla et al., 2022). Additionally, different body composition estimation equations may be required for individuals who aren't of Caucasian ethnicity (Tinsley et al., 2020). As such, the values presented from the present study should be interpreted with caution.

The analysis of dietary intake is prone to error and therefore the results must be represented and interpreted with caution. To reduce the likelihood of random error we aimed to measure dietary intake on 12 days during both the monitoring and intervention blocks (Rutishauser, 2005); extended periods of dietary analysis can reduce the magnitude of inter-practitioner variance (Braakhuis et al., 2003). Furthermore, analysis over an extended period may represent more habitual patterns than observation across a single week. However, all participants failed to fully record dietary intake across all possible eating occasions and days.

Other than protein intake, nutrient intake following the nutrition support intervention was unchanged. Despite this, anecdotal observations indicate that better food choices were made by many participants. As diet quality was not a measured variable in the present study, these changes are not quantified. Future research observing changes in both dietary intake and diet quality in response to nutrition education in athletes would be beneficial to identify strategies which may be best applied in a practical setting. As a multifaceted problem, improved diet quality may produce unfavourable effects in that participants are unable to meet energy and carbohydrate requirements due to the additional food volume causing gastric distention (Wang et al., 2008) and thus inducing satiety before energy requirements can be met. The long-term benefits of athletes making better food choices will allow for the athlete to experience enhanced health, well-being, and performance (Wirt and Collins, 2009; Thomas et al., 2016).

Novelty & directions for future research

To the authors' knowledge, this study was the first to report energy and macronutrient intake, nutrition knowledge, body composition and well-being in New Zealand provincial academy rugby players. Dietary intake is also reported over greater periods, encompassing various days over four-week periods. This is likely to be more reflective of an athletes typical eating patterns and provide greater precision when compared to data collection of less days, over a shorter period (Black, 2001). By spreading the data collection out across multiple days, the likelihood of measurement fatigue was reduced. Additionally, we demonstrate the application of a nutrition support intervention informed by behaviour change techniques and how this influenced dietary energy and protein intake. Whilst no positive change was observed for other nutrients and nutrition knowledge, the application of a structured nutrition support protocol over a longer duration in athletes not currently receiving such support may be beneficial to enhance nutrient intake and thus performance, recovery, and well-being.

Future research should seek to incorporate a mixed-methods approach to analysing nutrient intake and the role of sports nutrition practitioners working with professional and semi-professional teams. Whilst the analysis of nutrient intake, body composition and subjective well-being has provided insight into how well-received the short-duration nutrition support protocol was, anecdotal conversations with the athletes during this time provided additional information from their perspective. Additionally, research observing changes in both dietary intake and diet quality in response to nutrition education in athletes would be beneficial to identify strategies which may be best applied in a practical setting. Whilst the current data may not demonstrate a large outcome regarding changes to individual nutrient intake, qualitative data and diet quality analysis would enhance our understanding of the protocols and address nutrition support provision in athletes from a holistic viewpoint.

Practical Recommendations

Nutrition practitioners are a valuable resource for rugby teams; the standardisation of information provided, the development of individual and team-based nutrition education and availability for support means investment by teams in a nutrition practitioner can facilitate performance and recovery, modulate injury risk, and ensure athletes are following dietary patterns that complement health and well-being.

- Athletes at the developmental level are typically required to navigate multiple commitments. Attending academy training sessions and games, club training and games and work and/or education may result in the athlete struggling to meet nutritional requirements. Additionally, personal considerations such as maintaining relationships with family, friends and partners should be factored. The practitioner and/or support staff should be aware of this on an individual level and put into place strategies to best support the athlete both physiologically and psychologically.
- Athletes engaging in rugby across multiple levels will be present in multiple seasonal cycles (Jenner et al., 2019) and therefore have contradictory training goals. For example, an athlete mid-competition season at club level will be training for competition outcomes whereas engagement in an academy will be pre-season for the provincial season and may command training goals for hypertrophy and adaptation. As such, practitioner should be aware of the variable goals and adjust nutrition recommendations accordingly.

- Sports such as rugby contain different positions with a variety of on-pitch, training and body composition demands (Duthie et al., 2003). Ensuring athletes receive tailored nutrition support is paramount to meeting energy and nutrient requirements. At the beginning of the present study, participants' body mass ranged from 78kg to 140kg and thus not only are individual requirements important to highlight but various strategies to implement these may be necessary due to the large variation in absolute food volume required.

- Athletes may live with parents, guardians, family members or friends who either contribute to or are solely responsible for the purchasing and/or preparation of food and meals. Strategies should be implemented by support staff and practitioners to include those involved in providing nutrition to athletes to assist with optimising these practices away from facilities. Such strategies may include guiding grocery shopping, cooking classes and tailoring portions to the individual athlete.

- Athletes may not possess the required level of nutrition knowledge to execute optimal nutrition practices. Ensuring that athletes and others in their lives such as family and friends who may influence nutrition habits receive appropriate education to promote appropriate food choices.

- In New Zealand, athletes engaging with a provincial academy would concurrently train and play for a local club. This presents challenges in that nutrition advice may not be standardised, with club coaches possibly providing information that contradicts what the athlete needs (Zinn et al., 2006). Additionally, multiple training obligations may result in difficulties with monitoring training load to promote adaptations and monitor injury risk.

- The culmination of factors mentioned may have resulted in the large intra-individual variability in nutrient intake, body composition and nutrition knowledge in the present study. Ensuring that practitioners work with athletes as individuals and provide support and resources on their level may result in greater engagement.

Chapter 7: Thesis summary, conclusions & direction for future research

This thesis has provided novel information about the subjective impact of the original COVID-19 lockdown restrictions in rugby athletes. Some key themes highlighted include that eating habits may have improved due to the closure of fast-food restaurants and that family and friends contributed significantly to the preparation of food and meals. This information highlights the importance of including the athletes' wider network in the nutrition support process as such individuals may have a major influence on their overall eating habits.

This thesis has determined that using a mobile phone-based application to collect dietary intake information and the subsequent interpretation of the photographs and descriptions is comparable to the weighed food diary for analysing energy and macronutrient intake in athletic individuals at a group level. Despite this, significant individual variability is apparent between nutrient interpretation, suggesting the practical application of a RFPM application lacks validity if the provision of specific nutrient intakes to athletes is required. Major practical challenges within the dietary analysis process have been highlighted, of which the sports nutrition practitioner should consider when determining a method to analyse an athletes' nutrient intake as it would be unwise to make specific recommendations based on data that can be interpreted with large inter-individual differences.

This thesis has highlighted that semi-professional and professional rugby athletes do not distribute their dietary protein intake between meals in accordance with mechanistic research and best practice guidelines to support an optimal anabolic response. Whilst the total dietary protein intakes were within best-practice sports nutrition guidelines, even distribution of 0.4g·kg across 4-6 meals may be more beneficial to supporting skeletal muscle re-modelling due to the short-lived response observed to single amino acid feedings. Whilst whole-food ingestion results in greater protein synthesis rates ≤5 hours post-ingestion (Burd et al., 2015) the distribution of dietary protein may be of greater importance from a holistic viewpoint. As highlighted in Chapter 6, rugby players often engage in congested training schedules, and promoting adequate per-meal protein intakes can assist athletes in meeting overall daily requirements.

It was determined that the implementation of a nutrition support protocol in provincial academy rugby athletes can positively influence energy and protein intake. Despite this, under-reporting in the cohort was likely prevalent, and energy intake may have been sub-optimal for male athletes to maintain energy sufficiency. The overall and per-meal energy and macronutrient intakes have been highlighted in this population, with intake measured across multiple days over a four-week period, a timeframe of which is more likely to reflect true habits. Further practical challenges surrounding the delivery of nutrition support in New Zealand provincial academy athletes have been highlighted. This population represents a unique level within the rugby structure in that they concurrently train with multiple teams and as such may transcend both a pre-season and competition season, are working towards professionalism but receive little to no financial support and thus may work, study, live with family or friends, and have limited access to nutrition practitioners. Whilst Chapter 6 aimed to address the influence of nutrition support in rugby players from a quantitative perspective, the experiences of the athletes, staff and practitioner were not addressed. During the study, anecdotal conversations between the practitioner and players suggest that the implementation of nutrition support was well-received, and future qualitative research should be conducted to further explore this. Such studies would allow for the sports nutrition practitioner to tailor their practice to best suit the athletes. Notably, sports nutritionist availability is often limited or completely lacking in academy environments, with this thesis re-enforcing the value such individuals can have in the development of the athletes.

This thesis also highlights significant inter-individual differences are observed in prior energy and macronutrient intake and nutrition knowledge, and subsequent responses of these variables to a nutrition support protocol. This is unsurprising, given the large variability in body composition values and on-pitch positional differences observed in rugby athletes. Sports nutrition practitioners working with athletes must be aware of this and allocate appropriate resources, if available, to providing personalised support and recommendations and these differences further highlight the importance of teams and organisations considering full-time practitioner support to best support the athletes in their care.

Additionally, identification of unique facilitators for food choices and nutrient intake in New Zealand provincial academy rugby athletes means further considerations must be made during the nutrition support process. As most individuals will receive little to no financial support for their engagement in the academy and will engage in multiple tiers of rugby, congested schedules are likely. Furthermore, Chapter 3 and Chapter 6 suggest that athletes may live with parents, caregivers, friends, partners, or children, all of whom may directly or indirectly influence food choices made by the individual. Collectively, this information highlights the importance of providing individual nutrition support to developing rugby athletes; a lack of resource provision for nutrition support may negatively influence performance, recovery, well-being, health, injury risk, and growth.

Collectively, it is noteworthy that investments in sports nutrition practitioner support and resources (e.g supplementary protein provision) can result in significant changes to nutrient intake in a short timeframe. Whilst research is required to understand how such services are received by athletes, staff, and practitioners to help shape the provision of service, this thesis highlights the importance of teams and organisations investing in these services to ensure developing rugby athletes are best supported in their nutrition habits.

Thesis limitations

Chapter 3

- The data for Chapter 3 was collected as an anonymous survey. As such, the information cannot be verified.
- Accurate information could not be gathered due to the ambiguous nature of the questions presented in the survey.
- Specific questions about food and macronutrient intake were minimal. As such, specific recommendations cannot be made for individuals in a lockdown or isolation situation such as may be encountered during a pandemic.
- Variation in the number of participants, the location of participants and the potential for different participants to have completed both surveys meant statistical analysis could not be applied to explore differences in during- and post-lockdown responses.

Chapter 4

- Validity of the RFPM mobile-phone application was determined against the weighed food diary. Whilst the weighed food diary is often considered the 'gold standard' of dietary assessment potential error arising from this method means true validation of the RFPM application cannot be fully determined.
- The recruitment of athletic individuals as opposed to recruiting rugby players specifically presents a limitation in the context of the present thesis.

Chapter 5

- Dietary analysis presents a major limitation throughout the thesis. Whilst an aim of the thesis was to assess the practical validity of a RFPM mobile phone application (Chapter 4), the practice is prone to error; as such, this must be considered when interpreting dietary intake data.
- Dietary analysis was conducted in variable numbers of grouped participants. Additionally, only two cohorts were investigated and as such the observations may not translate to other rugby teams.

Chapter 6

- The monitoring period following the provision of the nutrition support intervention was limited to 4-weeks. Whilst this was necessary due to the schedule of the team, this may not be reflective of a real-life situation as significant changes to eating habits may not be expected over such a limited timeframe.
- No qualitative data was included, which presents a major limitation in that anecdotal observations of participants during the study indicate improvements in diet quality following education and support may have resulted in subjective improvements in well-being and performance.

Areas for future research

The current thesis has addressed important considerations for sports nutrition practitioners working in both general and rugby-specific environments. Future research developing key areas could enhance our understanding of dietary analysis and nutrition support provision for athletes. The following research themes have been identified in response to the novel information provided in this thesis.

Chapter 3

- Qualitative data would improve our understanding of how rugby athletes were impacted in response to COVID-19 lockdown restrictions by identifying themes and greater subjective detail in how nutrition and training habits were influenced. Furthermore, information in different athletic populations from different countries would be beneficial. Whilst our initial survey was distributed in multiple countries, the extent of and relaxation of restrictions was different and as such, may have influenced an athletes' food choices. For example, a country whereby fast-food restaurants remained open during strict lockdowns may have led athletes to consume more of these foods than those in New Zealand, where L4 lockdown restrictions saw the complete closure of fast-food establishments. Similar themes to those found in our survey were identified using semi-structured interviews in semi-professional rugby players in Scotland. Such themes included potential improvement in nutrition choices due to more free time and difficulties training due to lacking access to equipment and facilities (Hitendre et al., 2022).

Chapter 4

- The practical validation of using a RFPM mobile phone application to determine energy and nutrient intake in athletes using biological markers to provide better objective assessment.
- The validation of RFPM mobile phone applications in specific populations. Whilst the practical validity was assessed in athletic individuals, uptake and use of such tools in athletes at greater levels of professionalism may be different and should be investigated.

Chapter 5

- The influence of optimal dietary protein distribution based on best practice guidelines in the literature on lean mass, recovery, and performance in rugby athletes. Whilst such guidelines are recommended to support anabolism and skeletal muscle re-modelling, the significance of the practical application of such a dietary approach still requires investigation to determine the importance of making recommendations to athletes.
- Whilst a per-serving dose of 0.4g·kg is proposed to optimise protein anabolism (Schoenfeld and Aragon, 2018), the determination of an optimal protein dose to support the re-modelling response following collision sport activity would allow for sport -specific recommendations to be made.

Chapter 6

- Future research should investigate the original aim of exploring the influence of an optimal dietary protein distribution, as reported in the literature, in rugby athletes on long-term body composition, performance, recovery and well-being outcomes.
- Qualitative data would allow for a greater understanding of how well-received nutrition support provision is in provincial academy rugby players.
- Quantification of diet quality alongside energy and macronutrient intake. Whilst meeting energy and macronutrient requirements is important for the rugby athlete, consumption of a nutrient-dense diet will allow for the optimal supporting of athleticism and health.
- The relationship between nutrition knowledge and dietary intake in developing athletes attending academies. In New Zealand, the food choices made by these individuals is more likely to be influenced by their knowledge levels as limited

nutrition support and sports nutrition practitioner interaction than those in professional environments with greater resource availability. Semi-professional rugby players in Scotland demonstrated greater nutrition knowledge scores correlated with overall total food intake; protein, carbohydrate, vegetable, wholemeal pasta, pizza, sweet and snack intake all demonstrated a positive relationship with nutrition knowledge scores (Hitendre et al., 2022). Further investigation into the factors influencing food choices in young developing athletes is warranted.

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Appendices

Appendix 1: Chapter 3 co-authorship form

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Co-Authorship Form

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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.

Roberts, C. J., Gill, N., & Sims, S. (2020). The Influence of COVID-19 Lockdown Restrictions on Perceived Nutrition Habits in Rugby Union Players. Frontiers in Nutrition. https://doi.org/10.3389/fnut.2020.589737

Nature of contribution by PhD candidate	Development of research question and tools, recruitment of and engagement with participants, data collection, extraction and analysis, preparation and review of manuscript, journal submission
Extent of contribution by PhD candidate (%)	90

CO-AUTHORS

Name	Nature of Contribution
Stacy Sims	Development of research question and tools, review of manuscript, primary supervision
Nicholas Gill	Recruitment of participants, review of manuscript, secondary supervision

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
Stacy Sims	[signature]	13/07/2022
Nicholas Gill	[signature]	11/07/2022

Appendix 2: Chapter 4 co-authorship form

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Ecological validation and practical challenges of conducting dietary analysis in athletic individuals using a novel remote food photographic method mobile phone application

Nature of contribution by PhD candidate	Development of research question, recruitment of and engagement with participants, data collection, extraction and analysis, preparation and review of manuscript, journal submission
Extent of contribution by PhD candidate (%)	85

CO-AUTHORS

Name	Nature of Contribution
Stacy Sims	Development of research question, review of manuscript, primary supervision
Nicholas Gill	Development of research question, review of manuscript, secondary supervision
Brett Baxter	Statistical analysis, review of 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
Stacy Sims		13/07/2022
Nicholas Gill		11/07/2022
Brett Baxter		13/07/2022

Appendix 3: Chapter 5 co-authorship form

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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.

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. https://doi.org/10.36905/jses.2022.01.05

Nature of contribution by PhD candidate	Development of research question, recruitment of and engagement with participants, data collection, extraction and analysis, preparation and review of manuscript, journal submission
Extent of contribution by PhD candidate (%)	80

CO-AUTHORS

Name	Nature of Contribution
Stacy Sims	Development of research question, review of manuscript, primary supervision
Nicholas Gill	Recruitment of participants, review of manuscript, secondary supervision
Logan Posthumus	Recruitment of participants, data analysis, review of manuscript
Katrina Darry	Recruitment of participants, data analysis, review of 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

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Logan Posthumus	[signature]	07/07/2022
Katrina Darry	[signature]	13/07/2022

Appendix 4: Chapter 6 co-authorship form

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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.

Roberts, C., Gill, N., Beaven, C., Posthumus, L., & Sims, S. 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. under review in the *International Journal of Sport Science and Coaching*

Nature of contribution by PhD candidate	Development of research question and protocols, recruitment of and engagement with participants, data collection, extraction and analysis, preparation and review of manuscript/research outputs, journal submission, delivery of conference presentations
Extent of contribution by PhD candidate (%)	80

CO-AUTHORS

Name	Nature of Contribution
Stacy Sims	Development of research question and protocols, review of manuscript, primary supervision
Nicholas Gill	Review of manuscript, secondary supervision
Logan Posthumus	Development of research question and protocols, recruitment of and engagement with participants, data collection, review of manuscript
Christopher Beaven	Technical support, data analysis, review of 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
Stacy Sims		13/07/2022
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Logan Posthumus		07/07/2022
Christopher Beaven		07/07/2022

July 2015

Appendix 5: Survey questions for Chapter 3

Question	Groups	During Lockdown N (%)	After Lockdown N (%)
How often do you consume breakfast?	Every day	63.2	72.6
	4-6 days per week	16.3	18.9
	1-3 days per week	15.1	5.7
	Never	5.4	2.8
How many meals do you eat per day?	0-1 per day	1.2	0.0
	2-3 per day	67.1	51.9
	≥ 4 per day	31.8	46.1

How often do you eat snacks?	≤ 1 per day	4.7	2.8
	1-2 per day	63.6	71.7
	3-4 per day	29.1	25.5
	≥ 5 per day	2.7	0.0
Who is most likely to prepare your food and meals?	Myself	44.6	71.7
	Partner	8.5	3.8
	Family Member	23.6	7.6
	Combination of people	23.3	17.0
Who is most likely to purchase your food?	Myself	38.0	67.0
	Partner	11.2	5.7
	Family Member	42.6	19.8
	Combination of people	8.1	7.6

My knowledge about nutrition comes from (choose all that apply)	Dietician/nutritionist associated with the club	61.6	68.9
	Dietician/nutritionist not associated with the club	17.4	21.7
	Coaching staff	25.2	26.4
	Teammates	27.1	33.0
	Friends not with team	16.7	16.0
	Family member	30.6	32.1
	Internet	34.5	31.1
	Social Media	24.4	22.6
	Television	5.8	2.8
	No nutrition knowledge		

	Other	4.3	1.9
		18.2	9.4
How would you rate your nutrition habits now compared to before lockdown? (SURVEY 1)			
How would you rate your nutrition habits now compared to during lockdown? (SURVEY 2)	Nutrition habits have been better	30.6	35.9
	Nutrition habits have been worse	26.0	13.2
	Nutrition habits have been the same	43.4	50.9

When reflecting on total food intake, how would you describe your current food habits compared to before lockdown? (SURVEY 1) **When reflecting on total food intake, how would you describe your current food habits compared to during lockdown? (SURVEY 2)**	Eaten more food	35.7	36.8
	Eaten less food	30.2	18.9
	Eaten the same amount of food	34.1	44.3
Fruit & vegetable intake: How has your intake changed since lockdown restrictions were implemented? (SURVEY 1) **Fruit & vegetable intake: How has your intake changed since the relaxation of lockdown restrictions? (SURVEY 2)**	Higher consumption during lockdown	36.4	33.0
	Lower consumption during lockdown	16.7	13.2
	Similar consumption during lockdown	46.9	53.8
Packaged/convenience food: How has your intake changed with since lockdown restrictions were implemented? These types of foods	Higher consumption during lockdown	26.4	22.6

may include ready meals, chocolate bars, cakes, crisps, processed meat products and fries(SURVEY 1)	Lower consumption during lockdown	41.9	32.1
	Similar consumption during lockdown	31.8	45.3
Packaged/convenience food: How has your intake changed with relaxation of the lockdown restrictions? (SURVEY 2)			
		1.2	0.9
How often did you consume alcohol DURING lockdown? (SURVEY 1 & 2)	Every day	12.0	4.7
	A few times per week	18.2	17.0
	About once per week	20.5	20.8
	A few times per month	19.0	24.5
	≤ once per month	29.1	32.1
	Never		
		0.4	0.0

How often did you consume alcohol BEFORE lockdown? (SURVEY 1)	Every day	5.4	4.7
	A few times per week	26.7	18.9
How often have you consumed alcohol AFTER lockdown? (SURVEY 2)	About once per week	29.5	32.1
	A few times per month	21.7	20.8
	≤ once per month	16.3	23.6
	Never		
		95.7	86.8
	White meat	93.8	91.5
	Red meat	65.5	53.8
Which of the following foods have you eaten during lockdown? (SURVEY 1)	White fish	34.1	30.2
	Oily fish	91.9	84.9
	Eggs	91.5	78.3
Which of the following foods have you eaten since lockdown restrictions were relaxed? (SURVEY 2)	Low-fat dairy products	39.2	38.7

	Legumes	7.8	5.7
	Tofu		
		11.6	8.5
How often have you eaten ANY of the above during lockdown? (SURVEY 1)	> 3 times per day	37.6	40.6
	2-3 times per day	18.2	17.0
	Once per day	26.7	24.5
How often have you eaten ANY of the above since lockdown restrictions were relaxed? (SURVEY 2)	Most days per week	4.7	6.6
	A few days per week	0.8	2.8
	≤ Once per week	0.4	0.0
	Never		
How often are you consuming dietary supplements?			
		10.1	11.3

	> Once per day	14.7	22.6
	Once per day	5.8	14.2
	Most days per week	7.4	8.5
	A few times per week	8.9	11.3
	Rarely	53.1	32.1
	Never		
How would you describe your motivation to exercise and train during lockdown compared to before? (SURVEY 1)			
		28.3	58.5
How would you describe your motivation to exercise and train since lockdown restrictions were relaxed compared to during lockdown? (SURVEY 2)	More motivated to train	39.2	11.3
	Less motivated to train	32.6	30.2
	No change in motivation levels		

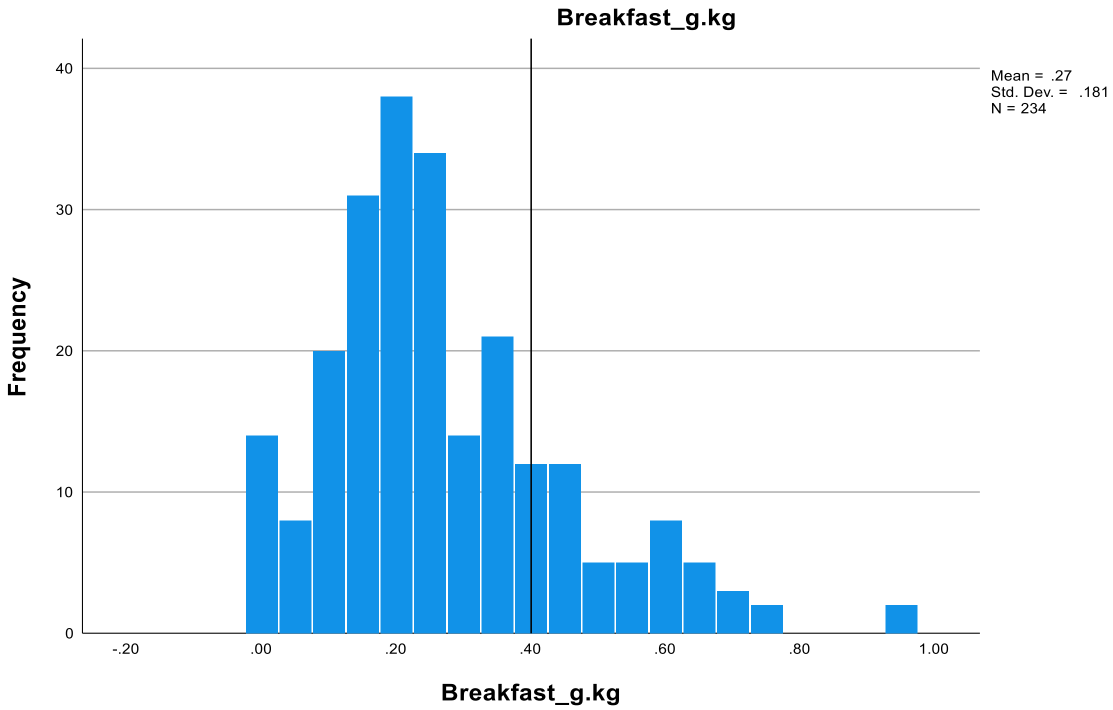
How many training sessions did you have BEFORE lockdown? (SURVEY 1)		1.6	0.0
	None	7.4	8.5
How many training sessions did you have DURING lockdown? (SURVEY 2)	1-2 per week	20.9	24.5
	3-4 per week	44.6	45.3
	5-6 per week	25.6	21.7
	> 6 per week		
How many training sessions have you had DURING lockdown? (SURVEY 1)		5.0	0.0
	None	5.4	4.7
	1-2 per week	29.1	23.6
How many training sessions have you had since lockdown restrictions were relaxed? (SURVEY 2)	3-4 per week	35.3	45.3
	5-6 per week	25.2	26.4

> 6 per week

Participant	Energy (kcal)				Protein (g)				Carbohydrate (g)				Fat (g)			
	RFPM	WFD	Δ%	CV	RFPM	WFD	Δ%	CV	RFPM	WFD	Δ%	CV	RFPM	WFD	Δ%	CV
1	1437	1289	10.3	7.7	95.0	94.0	1.1	0.7	131.3	95.7	27.2	22.2	54.7	55.0	-0.6	0.4
2	1533	1627	-6.1	4.2	71.3	93.0	-30.4	18.7	170.7	168.0	1.6	1.1	58.3	58.3	0.0	0.0
3	2143	1906	11.1	8.3	146.3	93.3	36.2	31.3	222.7	211.0	5.2	3.8	68.3	73.7	-7.8	5.3
4	3155	3438	-9.0	6.1	142.7	169.3	-18.7	12.1	310.7	392.3	-26.3	16.4	136.3	119.3	12.5	9.4
5	3015	2263	24.9	20.1	243.7	176.7	27.5	22.5	258.7	221.7	14.3	10.9	107.3	67.7	37.0	32.1
6	1696	2709	-59.7	32.5	116.3	193.7	-66.5	35.3	158.3	218.0	-37.7	22.4	60.7	111.0	-83.0	41.5
7	1746	1700	2.6	1.9	113.0	101.3	10.4	7.7	149.0	155.3	-4.3	2.9	65.7	61.7	6.1	4.4
8	2344	2458	-4.8	3.3	131.5	137.5	-4.6	3.2	173.5	201.0	-15.9	10.4	112.0	145.5	-29.9	18.4
9	1566	1561	0.3	0.2	62.0	70.3	-13.4	8.9	132.7	157.0	-18.3	11.9	85.3	69.7	18.4	14.3
10	2576	2747	-6.6	4.5	184.0	172.7	6.1	4.5	302.0	292.3	3.2	2.3	69.0	98.3	-42.5	24.8
11	1869	2514	-34.6	20.8	95.0	123.0	-29.5	18.2	187.3	274.7	-46.6	26.7	71.7	90.3	-26.0	16.3
12	1387	1438	-3.7	2.5	53.0	54.0	-1.9	1.3	201.0	193.7	3.6	2.6	39.0	45.0	-15.4	10.1
13	3528	2956	16.2	12.5	210.3	221.3	-5.2	3.6	374.0	279.3	25.3	20.5	112.7	89.3	20.7	16.3
14	2942	2249	23.6	18.9	186.3	165.0	11.4	8.6	135.3	136.3	-0.7	0.5	179.7	114.7	36.2	31.2
15	2095	1882	10.2	7.6	110.0	93.7	14.8	11.3	203.0	194.0	4.4	3.2	95.7	82.3	13.9	10.6
16	3020	2765	8.4	6.2	169.3	149.3	11.8	8.9	315.7	322.3	-2.1	1.5	113.7	90.3	20.5	16.2
17	2455	3255	-32.6	19.8	109.0	138.7	-27.2	17.0	274.3	406.3	-48.1	27.4	75.7	105.0	-38.8	23.0
18	1690	2068	-22.3	14.2	120.0	190.0	-58.3	31.9	157.7	168.3	-6.8	4.6	57.7	62.0	-7.5	5.1
19	2768	2668	3.6	2.6	110.7	102.0	7.8	5.8	240.0	262.7	-9.4	6.4	135.7	119.3	12.0	9.1

20	2346	2219	5.4	3.9	119.7	108.0	9.7	7.3	181.7	178.0	2.0	1.4	121.7	116.3	4.4	3.2
Mean	2266	2286	-3.1	9.9	129.5	132.3	-5.9	12.9	214.0	226.4	-6.5	10.0	91.0	88.7	3.5	14.6
SD	648	604	20.8	8.5	49.1	45.9	26.3	10.4	70.8	81.8	20.7	9.3	35.5	27.0	29.3	14.1

Abbreviations: RFPM, Remote Food Photography Method. WFD, weighed food diary. Δ, difference. CV, coefficient of variation. SD, standard deviation.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Std. Dev. = .181
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30
40
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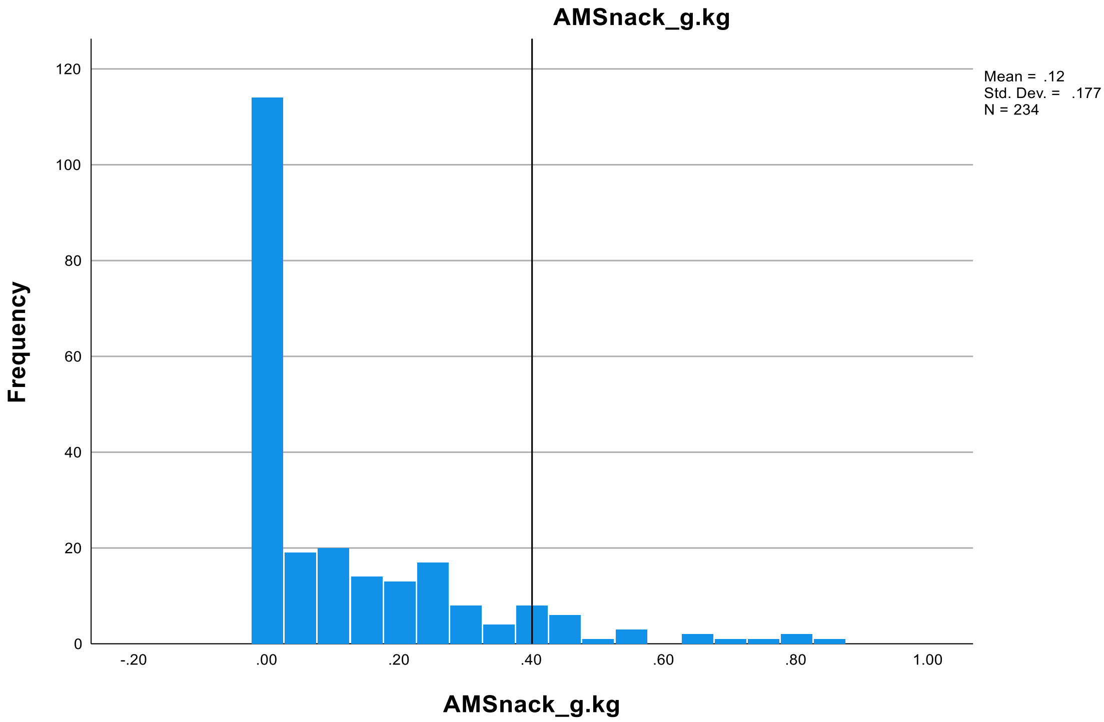
.00
.20
.40
.60
.80
1.00
Breakfast_g.kg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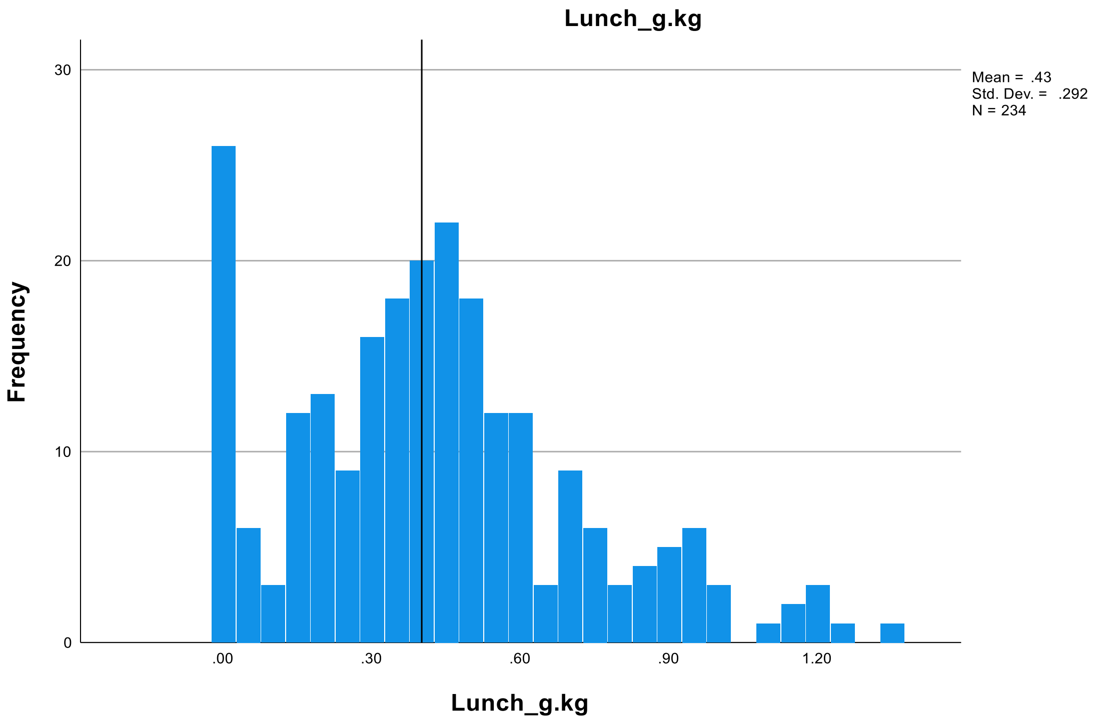
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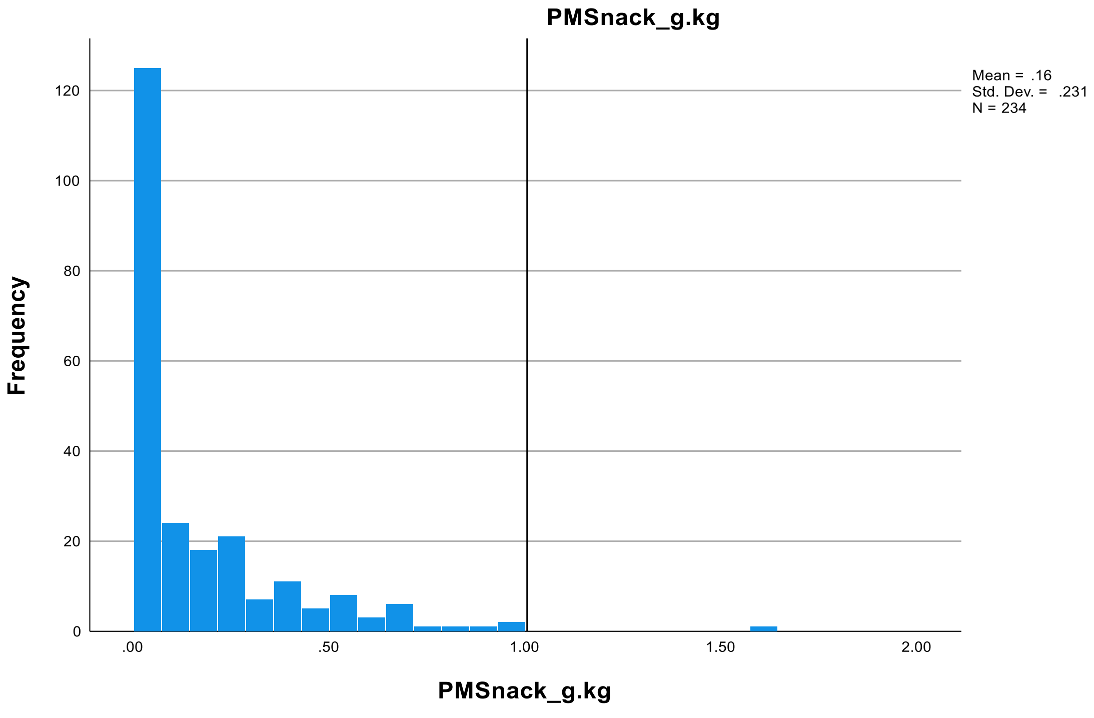
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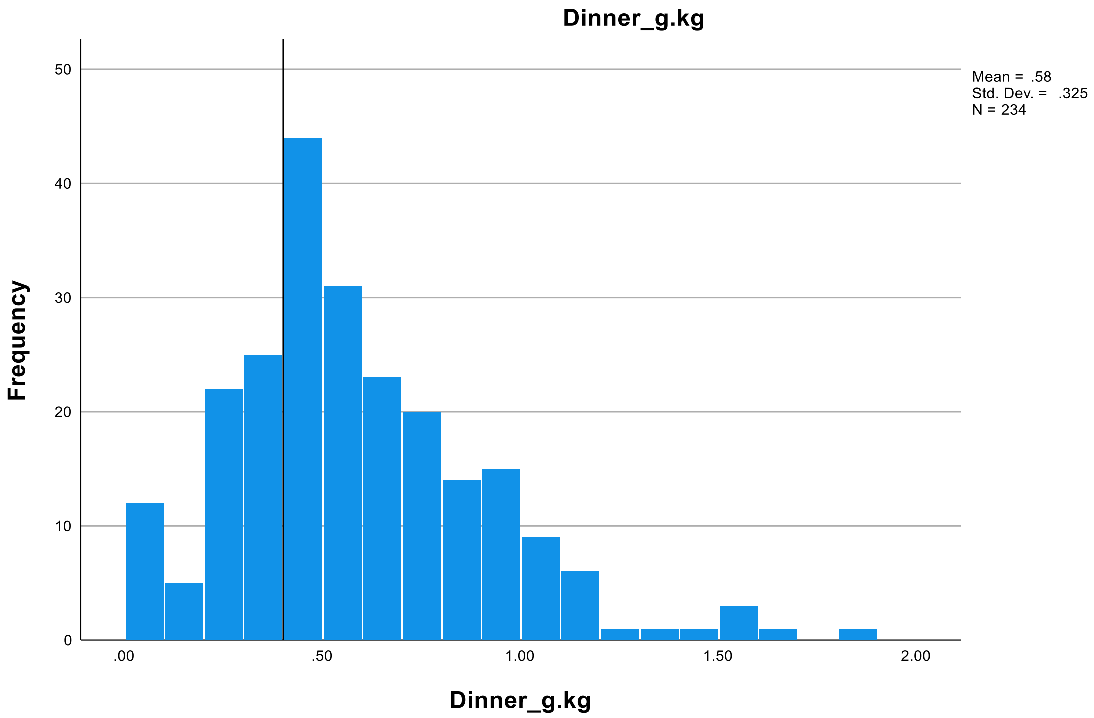

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40
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.00
.50
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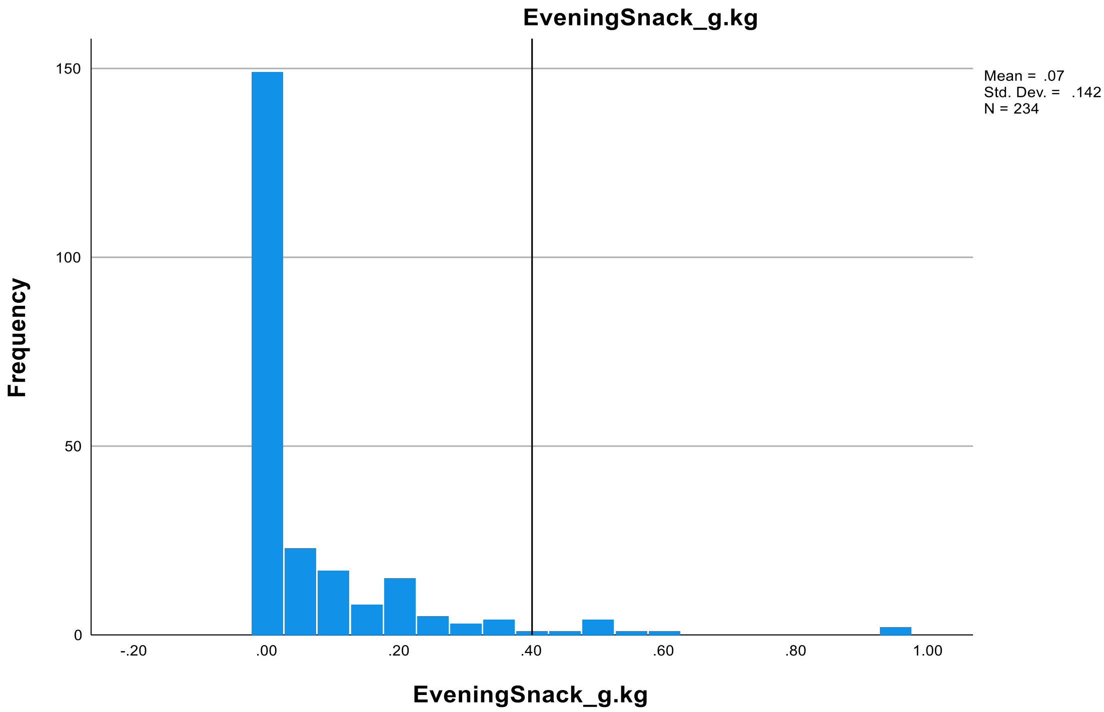
2.00
Dinner_g.kg



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100
150
-.20
.00
.20
.40
.60
.80
1.00
EveningSnack_g.kg

	5	4	3	2	1	Record Score
FATIGUE	Very fresh	Fresh	Normal	More tired than normal	Always tired	
SLEEP QUALITY	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
MUSCLE SORENESS – UPPER BODY	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	

MUSCLE SORENESS – LOWER BODY	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
STRESS LEVELS	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
MOOD	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at teammates, family and co-workers	Highly annoyed/irritable/down	

SNKQ

Start of Block: Demographic Block

Q1 What is your name?

____

Q2 What country were you born in?

____

Q3 What is your current living situation?

- ○ Alone (1)
- ○ With parents (2)
- ○ With partner (3)
- ○ With other players/athletes (4)
- ○ With flatmates who aren't athletes (5)
- ○ Other (6)

Q60 Who **PURCHASES** your food? Please select all that apply:

- ☐ Myself (1)
- ☐ Partner (2)
- ☐ Parent or guardian (3)
- ☐ Other family member (4)
- ☐ Friends (5)
- ☐ Team-mates (6)
- ☐ Club (e.g steamers)(please explain what is provided) (7) ____________________

Q61 Who **PREPARES** your food? Please select all that apply:

- ☐ Myself (1)
- ☐ Partner (2)
- ☐ Parent or guardian (3)
- ☐ Other family member (4)
- ☐ Friends (5)
- ☐ Team-mates (6)
- ☐ Club (e.g steamers)(please explain what is provided) (7) ____

Q6 What position do you play in your main sport?

____

Q11 Have any of these individuals ever given you advice regarding your diet? Tick all that apply

- ▢ Athletic trainer (1)
- ▢ Coach (2)
- ▢ Dietitian (3)
- ▢ Doctor (4)
- ▢ Friends (5)
- ▢ Family (6)
- ▢ Nutritionist (7)
- ▢ Team-mates (8)

Q12 Rank the top 3 sources of information you rely on regarding nutrition by placing 1, 2 and 3 in the relevant boxes

_______Academic journal (1)

_______Athletic trainer/strength & conditioning coach (2)

_______Coach (3)

_______Dietitian (4)

_______Nutritionist - Team (5)

_______Nutritionist - External (6)

_______Doctor (7)

_______Family (8)

_______Friends (9)

_______Internet search (please specify websites used) (10)

_______Mass media (magazine, radio, TV) (11)

_______Social media (Facebook, Twitter, Instagram) (12)

_______Team-mates (13)

Q13 Does the sporting organization you are part of provide you with access to nutrition information or nutritionists/dietitians?

- ○ Nutrition information only (1)
- ○ Mandatory access to nutritionist/dietician (2)
- ○ Voluntary access to nutritionist/dietician (3)
- ○ Nutrition information and mandatory access to nutritionist/dietician (4)
- ○ Neither of the above (5)

Q15 What type of support **IS CURRENTLY PROVIDED**? SELECT ALL THAT APPLY

- ▢ Access to nutrition information relevant to healthy eating (1)
- ▢ Access to nutrition information relevant to sports/training nutrition (2)
- ▢ Access to group presentations by nutritionists/dietitians (3)
- ▢ Individual consultations by nutritionists/dietitians (4)
- ▢ Cooking classes (5)
- ▢ Handouts (6)

Q18 What type of support **WOULD YOU FIND USEFUL BUT ISN'T CURRENTLY PROVIDED**? SELECT ALL THAT APPLY

- ▢ Access to nutrition information relevant to healthy eating (1)
- ▢ Access to nutrition information relevant to sports/training nutrition (2)
- ▢ Access to group presentations by nutritionists/dietitians (3)
- ▢ Individual consultations by nutritionists/dietitians (4)
- ▢ Cooking classes (5)
- ▢ Handouts (6)

Q14 If access to a nutritionist/dietitian is provided, how long, per week, are services provided/used by yourself?

- ◯ 0 minutes (1)
- ◯ 1-15 minutes (2)
- ◯ 16-30 minutes (3)
- ◯ 31-45 minutes (4)
- ◯ 46-60 minutes (5)
- ◯ 1-2 hours (6)
- ◯ 2-3 hours (7)
- ◯ 3-4 hours (8)
- ◯ 4-5 hours (9)
- ◯ Greater than 5 hours (10)

Q20 Are you satisfied with the level of nutrition support provided by the sporting organization? Please explain your answer in as much detail as possible:

- ◯ Yes (1) ____________________
- ◯ No (2) ____________________

Q19 Do you think that the sporting organizations should provide members with access to nutrition information or nutritionists/dieticians? Please explain your answer

- ◯ Yes, nutrition information only (1) ____________________
- ◯ Yes, nutrition information and access to nutritionist/dietician (2) ____________________
- ◯ No, not a role of sporting organizations (3) ____________________

Q21 Do you regularly take supplements? (e.g multivitamin, creatine)

○ Yes (please specify) (1) ____

○ No (2)

Q22 How would you rate your own nutrition knowledge?

○ Outstanding (1)

○ Above average (2)

○ Average (3)

○ Below average (4)

○ Poor (5)

Q23 Adhering to a healthy diet is important for athletic performance

- ○ Strongly agree (1)
- ○ Agree (2)
- ○ Neither agree nor disagree (3)
- ○ Disagree (4)
- ○ Strongly disagree (5)

Q24 Please explain your employment status

○ Work - full time (please explain your job) (1)
____

○ Work - part time (please explain your job) (2)
____

○ Student - full time (please explain what type of student you are e.g university, college etc) (3) ____

○ Student - part time (please explain what type of student you are e.g university, college etc) (4) ____

○ Paid athlete (5)

End of Block: Demographic Block

Start of Block: General Nutrition Knowledge Block

Q25 Eating more energy from protein than you need can make you put on fat.

◯ Agree (1)

◯ Disagree (2)

◯ Not sure (3)

Q26 The body needs fat to fight off sickness.

◯ Agree (1)

◯ Disagree (2)

◯ Not sure (3)

Q27 Do you think cheddar cheese is high or low in fat?

- High (1)
- Low (2)
- Not sure (3)

Q28 Do you think margarine is high or low in fat?

- High (1)
- Low (2)
- Not sure (3)

Q29 Do you think honey is high or low in fat?

○ High (1)

○ Low (2)

○ Not sure (3)

Q31 The body has a limited ability to use protein for muscle protein synthesis.

○ Agree (1)

○ Disagree (2)

○ Not sure (3)

Q32 Eggs contain all the essential amino acids needed by the body.

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q33 Thiamine (B1) is needed to take oxygen to muscles.

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q34 Vitamins contain energy (kilojoules/calories).

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q35 Do you think alcohol can make you put on weight?

- ○ Yes (1)
- ○ No (2)
- ○ Not sure (3)

Q36 "Binge drinking" (also referred to as heavy episodic drinking) is generally defined as:

○ Having two or more standard alcoholic drinks on the same occasion (1)

○ Having four to five or more standard alcoholic drinks on the same occasion (2)

○ Having seven to eight or more standard alcoholic drinks on the same occasion (3)

○ Not sure (4)

End of Block: General Nutrition Knowledge Block

Start of Block: Sport Nutrition Knowledge

Q37 Do you think 1 medium banana has enough carbohydrate for recovery from intense exercise? Assume the athlete weighs about 70kg and has an important training session again tomorrow.

○ Enough (1)

○ Not enough (2)

○ Not sure (3)

Q38 Do you think 1 cup of cooked quinoa and 1 tin of tuna has enough carbohydrate for recovery from intense exercise? Assume the athlete weighs about 70kg and has an important training session again tomorrow.

- ○ Enough (1)
- ○ Not enough (2)
- ○ Not sure (3)

Q40 Do you think 150g of chicken breast has enough protein to promote muscle growth after a bout of resistance exercise?

- ○ Yes (1)
- ○ No (2)
- ○ Not sure (3)

Q39 Do you think 1 cup of of baked beans has enough protein to promote muscle growth after a bout of resistance exercise?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Not sure (3)

Q41 Do you think 1/2 cup of cooked quinoa has enough protein to promote muscle growth after a bout of resistance exercise?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Not sure (3)

Q42 Which is a better recovery meal option for an athlete who wants to put on muscle?

- A 'mass gainer' protein shake and 3-4 scrambled eggs (1)
- Pasta with lean beef and vegetable sauce, plus a dessert of fruit, yoghurt and nuts (2)
- A large piece of grilled chicken with a side salad (lettuce, cucumber, tomato) (3)
- Not sure (4)

Q43 When we exercise at a low intensity, our body mostly uses fat as a fuel

- Agree (1)
- Disagree (2)
- Not sure (3)

Q44 Vegetarian athletes can meet their protein requirements without the use of protein supplements.

- ◯ Agree (1)
- ◯ Disagree (2)
- ◯ Not sure (3)

Q45 The daily protein needs of a 100kg (220lb) well trained resistance athlete are closest to:

- ◯ 100g (1g/kg bodyweight) (1)
- ◯ 150g (1.5g/kg bodyweight) (2)
- ◯ 500g (5g/kg bodyweight) (3)
- ◯ They should eat as much protein as possible (4)
- ◯ Not sure (5)

Q46 The optimal calcium intake for athletes aged 15 to 24 years is 500mg/day.

○ Agree (1)

○ Disagree (2)

○ Not sure (3)

Q47 A fit person eating a balanced diet can improve their athletic performance by eating more vitamins and minerals from food.

○ Agree (1)

○ Disagree (2)

○ Not sure (3)

Q48 Vitamin C should always be taken by athletes.

○ Agree (1)

○ Disagree (2)

○ Not sure (3)

Q49 Athletes should drink water to:

○ Keep plasma (blood) volume stable (1)

○ Stop dry mouth (2)

○ All of the above (3)

○ Not sure (4)

Q50 Experts think that athletes should:

- ◯ Drink 50 - 100ml (1.7 - 3.3 fluid ounces) every 15 - 20 minutes (1)
- ◯ Suck on ice cubes rather than drinking during practice (2)
- ◯ Drink to a plan, based on body weight changes during training sessions performed in a similar climate (3)
- ◯ Drink sports drinks (e.g Powerade) rather than water during intense sessions (4)
- ◯ Not sure (5)

Q51 Before competition, athletes should eat foods that are high in:

- ◯ Fluids, fat and carbohydrate (1)
- ◯ Fluids, fibre and carbohydrate (2)
- ◯ Fluids and carbohydrate (3)
- ◯ Not sure (4)

Q52 In events lasting 60 - 90 minutes, 30 - 60g (1.0 - 2.0 ounces) of carbohydrate should be consumed per hour.

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q53 Eating carbohydrates when you exercise will help keep blood sugar levels stable.

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q54 Which is the best snack to have during an intense 90-minute training session?

◯ A protein shake (1)

◯ A ripe banana (2)

◯ Boiled eggs (3)

◯ A handful of nuts (4)

◯ Not sure (5)

Q55 How much protein do you think experts say athletes should have after completing a resistance exercise session?

◯ 1.5g/kg body weight (120 - 210g) (1)

◯ 1.0g/kg body weight (75 - 140g) (2)

◯ 0.3g/kg body weight (25 - 40g) (3)

◯ Not sure (4)

Q56 Supplement labels may sometimes say things that are not true.

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q57 All supplements are tested to make sure they are safe and don't have any contamination.

- ○ Agree (1)
- ○ Disagree (2)
- ○ Not sure (3)

Q58 Which supplement does not have enough evidence in relation to improving body composition and sporting performance?

- ○ Caffeine (1)
- ○ Ferulic acid (2)
- ○ Bicarbonate (3)
- ○ Leucine (4)
- ○ Not sure (5)

Q59 The WORLD ANTI-DOPING AGENCY (WADA) bans the use of:

- ○ Caffeine (1)
- ○ Bicarbonate (2)
- ○ Carnitine (3)
- ○ Testosterone (4)
- ○ Not sure (5)

End of Block: Sport Nutrition Knowledge

Protein distribution table

Co-authorship form

5 MINUTE BREAKFAST

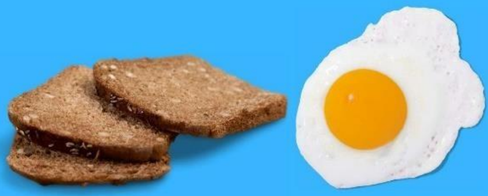
PROTEIN OATS

- 1-2 cups oats
- 1-2 scoops whey protein
- nuts, fruits, milk - toppings of choice

Cook oats in microwave or boiling water for 3-4 mins. Stir in whey protein. Add toppings.

EGGS ON TOAST

- 3-6 eggs - prepared poached, fried, boiled, scrambled or omelette
- 2-3 slices wholemeal toast
- handful of spinach, avo, tomato, onions etc.



SMOOTHIE

- 1 banana
- 1-2 cups milk
- 1-2 scoops whey protein
- handful frozen mixed berries
- tablespoon peanut butter
- 1 cup oats

OVERNIGHT OATS

- 1-2 cups oats
- 1-2 scoops whey protein
- nuts, fruits, milk - toppings of choice

prepare ingredients in water and leave in the fridge overnight

GRAB & GO IF YOU DON'T HAVE MUCH TIME IN THE MORNING!


EASY LUNCH IDEAS
BAY OF PLENTY RUGBY UNION
WRAPS OR SANDWICHES
1-2 multigrain wrap OR 4-6 slices wholemeal bread
1-2 fist-sized portions protein
2-3 veggies of choice
Sauce & seasoning to taste
TUNA, RICE & VEGGIES
1-2 large tin tuna (185g)
Packet microwave rice
Handful of spinach, other veggies of choice
LUNCH PRO TIP!
Make a double serving of dinner and put into a container so you've already got a prepped lunch for the following day!

PERFORMANCE DINNER

STIR-FRY

- 1-2 fistfuls protein source
- 1-2 cups cooked rice/noodles
- Veggies (onion, capsicum, spinach, broccoli, beansprouts, frozen veg go great in stir-fries!)
- Stir-fry sauce (mix & match packets for variety)
- Handful of crushed nuts

BURRITO

- 1-2 fistfuls protein source
- 1 large multi-grain wrap
- 1 cup rice
- Half can of kidney beans
- handful of spinach
- 1/2 onion & capsicum
- Avocado
- Salsa

HOME-MADE BURGERS

- 1-2 fistfuls prime mince
- 1/2 cup breadcrumbs
- 2 eggs
- Herbs & spices of choice
- Flour
- Veggies - spiach/lettuce, onion, tomato, beetroot
- Avocado
- Burger buns
- Sauce

MEAT/FISH & VEGGIES

- 1-2 handfuls of meat/fish (try and eat oily fish like salmon or mackerel 1-2 times per week)
- 1-2 cups of rice
- Half plate of veggies

STIR-FRY RECIPE

INGREDIENTS

- 1-2 fistfuls protein source (chicken, beef, fish, pork, tofu, beans all go perfectly in a stir-fry)
- 1-2 cups cooked rice/noodles
- Veggies (onion, capsicum, spinach, broccoli, beansprouts, frozen veg all taste delicious in stir-fry dishes!)
- Stir-fry sauce (mix & match packets for variety - teriyaki, pad thai and sweet chilli all completely change the meal)
- Handful of crushed nuts - add some crunch & healthy fats

DIRECTIONS

- Boil rice or noodles and allow to cool - this prevents them from clumping
- Add 2-3 tablespoons olive oil to a pan or wok and set to medium heat
- Add the protein and stir-often until cooked through
- Boil any veggies that require it
- Throw in the onions and cook until lightly browned
- Add the other veggies and cook to preference
- Add sauce to taste and finish with a handful of nuts sprinkled on top

PRO TIPS!

- Add 1-2 scrambled eggs for extra protein and good fats!
- Cook in bulk and put into containers for multiple lunches & dinners

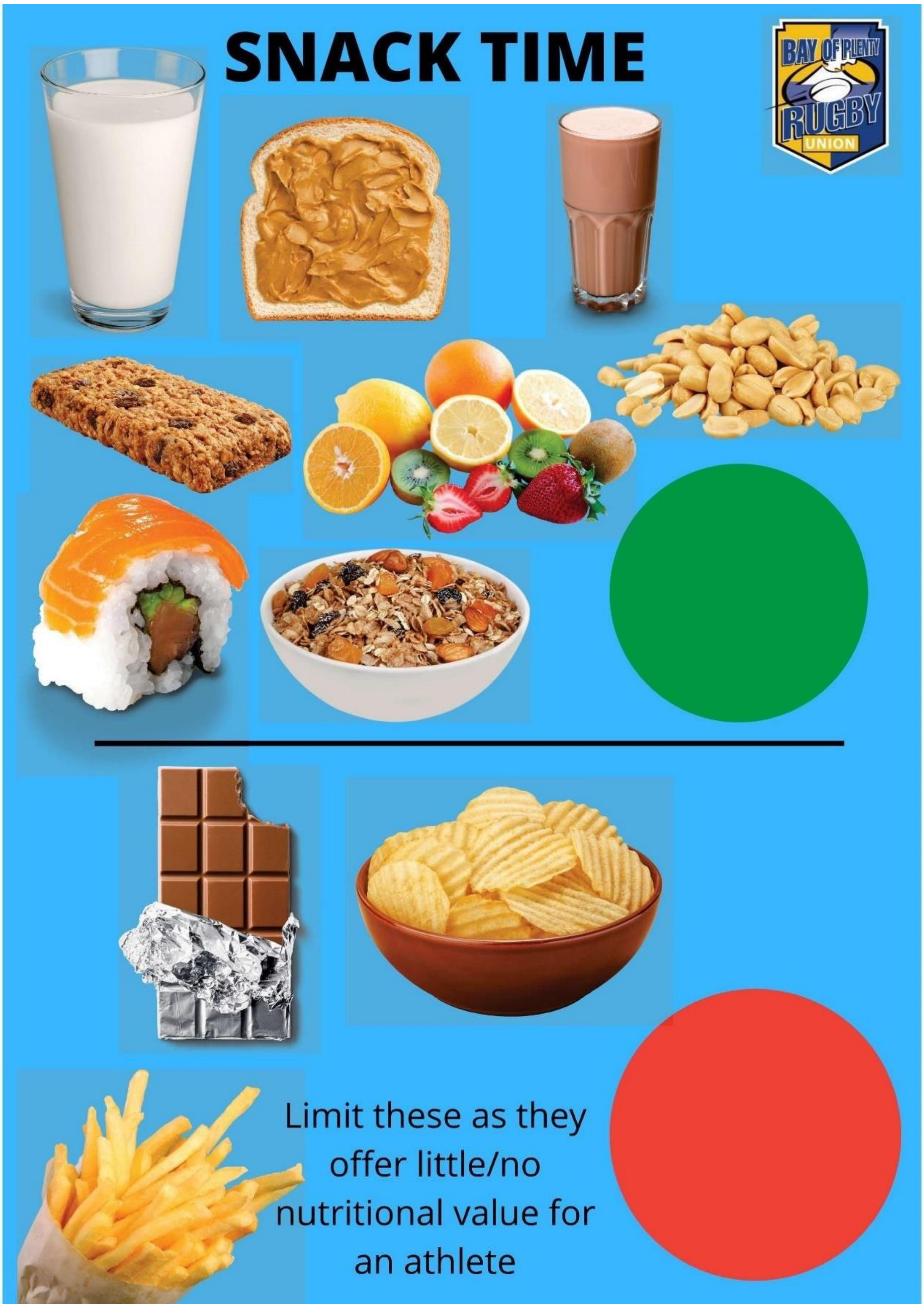
HOME-MADE BURGERS RECIPE

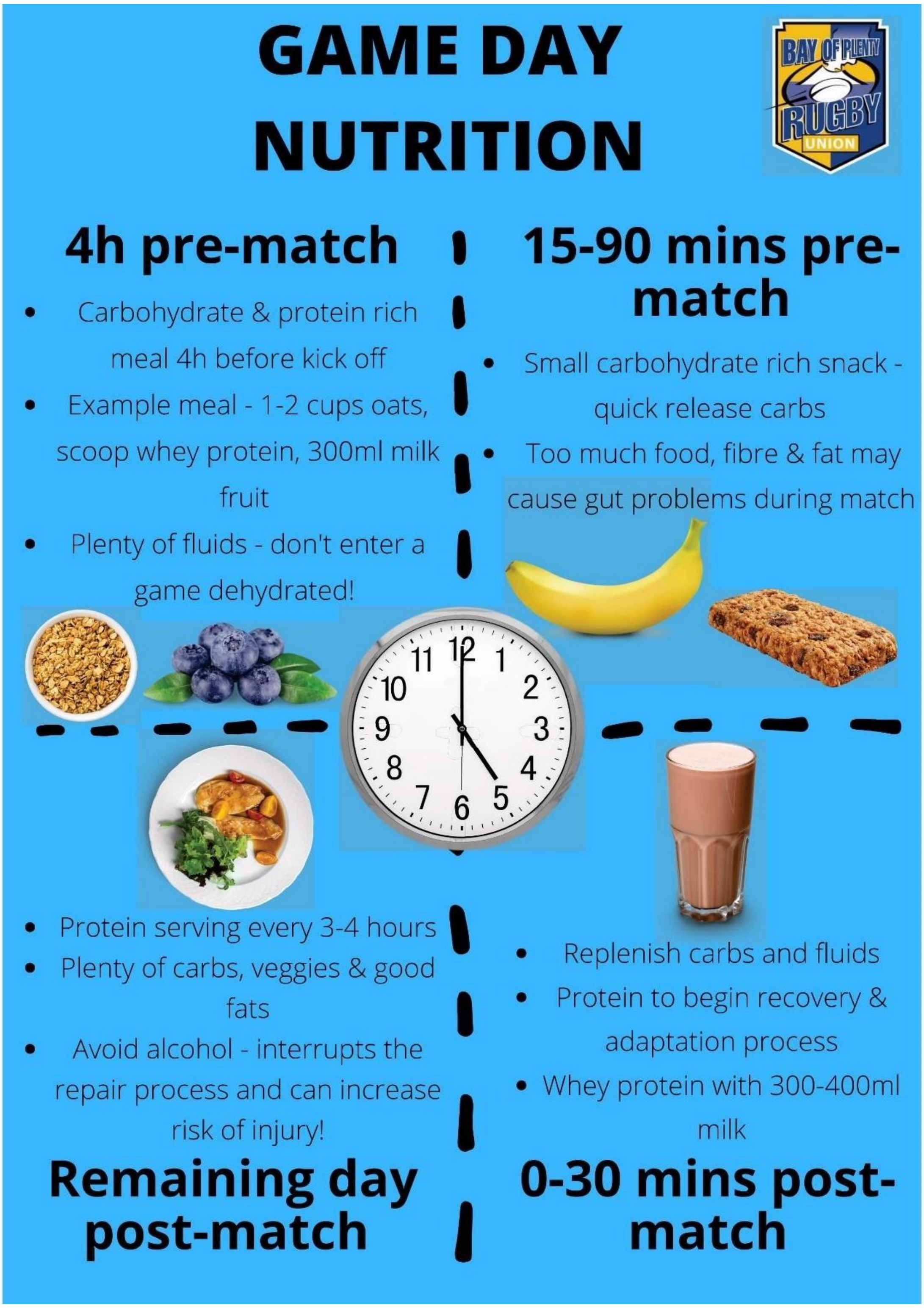
INGREDIENTS

- 1-2 fistfuls prime mince
- 1/2 cup breadcrumbs
- 2 eggs
- Herbs & spices of choice
- Flour
- Veggies - spiach/lettuce, onion, tomato, beetroot
- Avocado
- Burger buns
- Sauce

DIRECTIONS

- Mix the eggs, breadcrumbs and herbs & spices in a bowl
- Add in the mince - get your hands stuck in and mix, then shape into even sized patties
- Coat each patty in flour then place on tray
- Place in the freezer for 20 minutes to firm the pattys up
- Once firm, place on a pre-heated pan with 2-3 tablespoons of olive oil
- Cook for 7-8 minutes on either side
- Prepare buns with salad of choice - spinach/lettuce for the underside, onions, tomato, avocado .. get creative on top!
- Add sauce of choice and enjoy!


SNACK TIME
BAY OF PLENTY
RUGBY
UNION
Limit these as they offer little/no nutritional value for an athlete


GAME DAY NUTRITION
BAY OF PLENTY RUGBY UNION
4h pre-match
Carbohydrate & protein rich meal 4h before kick off
Example meal - 1-2 cups oats, scoop whey protein, 300ml milk fruit
Plenty of fluids - don't enter a game dehydrated!
15-90 mins pre-match
Small carbohydrate rich snack - quick release carbs
Too much food, fibre & fat may cause gut problems during match
Protein serving every 3-4 hours
Plenty of carbs, veggies & good fats
Avoid alcohol - interrupts the repair process and can increase risk of injury!
Remaining day post-match
Replenish carbs and fluids
Protein to begin recovery & adaptation process
Whey protein with 300-400ml milk
0-30 mins post-match

GROCERY LIST

PROTEIN

- Chicken breast/thigh
- Prime/premium mince
- Tinned tuna/salmon/chicken
- Eggs &/or egg whites
- Whole milk
- Cheese
- Protein+ yoghurt
- Tofu
- Chickpeas
- Red kidney beans
- Black beans

CARBS

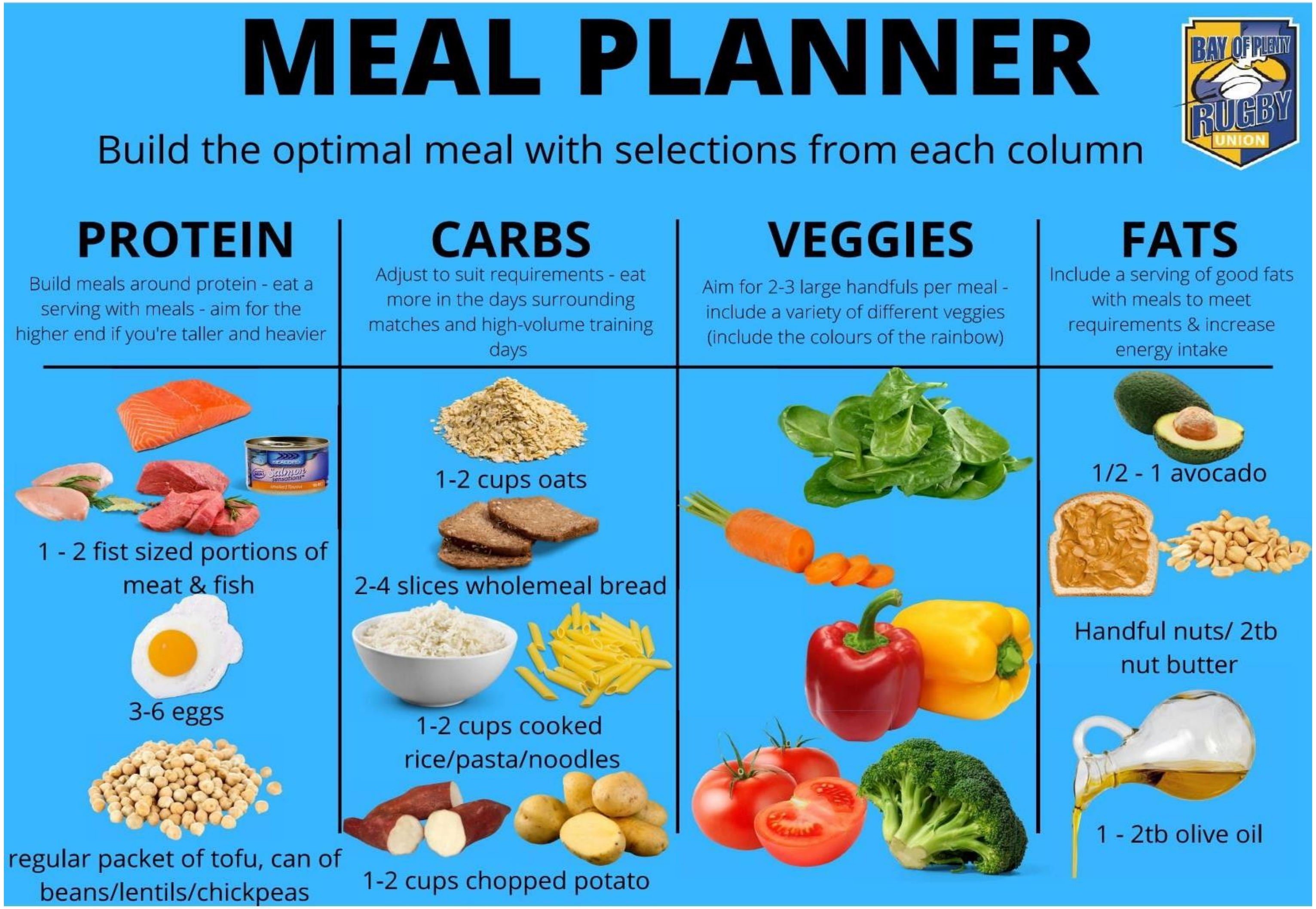
- Oats
- Rice
- Pasta
- Noodles
- Potato
- Multi-grain wraps
- Whole-meal bread

FAT & OTHER

- Nuts of choice
- Peanut butter
- Olive Oil
- Cooking sauces of choice
- Spices

FRUIT & VEG

- Spinach
- Lettuce
- Onion
- Capsicum
- Broccoli
- Carrot
- Frozen veggie mix
- Kiwi fruit
- Banana
- Apples
- Mixed berries
- Avocado



MEAL PLANNER
Build the optimal meal with selections from each column
BAY OF PLENTY RUGBY UNION
PROTEIN
Build meals around protein - eat a serving with meals - aim for the higher end if you're taller and heavier
1 - 2 fist sized portions of meat & fish
3-6 eggs
regular packet of tofu, can of beans/lentils/chickpeas
CARBS
Adjust to suit requirements - eat more in the days surrounding matches and high-volume training days
1-2 cups oats
2-4 slices wholemeal bread
1-2 cups cooked rice/pasta/noodles
1-2 cups chopped potato
VEGGIES
Aim for 2-3 large handfuls per meal - include a variety of different veggies (include the colours of the rainbow)
FATS
Include a serving of good fats with meals to meet requirements & increase energy intake
1/2 - 1 avocado
Handful nuts/ 2tb nut butter
1 - 2tb olive oil

Nutrition Knowledge in provincial academy rugby athletes in New Zealand

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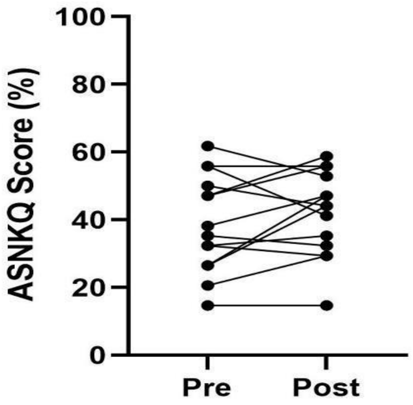
Introduction

Nutrition education and knowledge are known factors that can influence dietary intake in athletes. Sport nutrition practitioners can emphasize the importance of certain nutrition practices but the uptake by athletes is variable, depending on the environment in which the information is given. In New Zealand, there are unique developmental rugby academies, the goal of which is to provide young players with coaching support, professional level programming and access to facilities to prepare individuals for professional level play. Despite the inclusivity of the programmes, nutrition support is minimal. Due to the unusual demands of the developmental athlete's environment, as the athletes are managing training and playing at the local club level, and also working, studying, or have other high demand obligations, nutrition guidance for recovery is paramount. As such, academy rugby athletes will require specific guidance due to the high training volumes, specificity around body composition, and on-pitch demands. Furthermore, food availability, financial, and social constraints are likely to influence nutritional timing and food choices.

Materials and Methods

Fourteen provincial academy rugby athletes (age: 20.3 ± 1.5 y; body mass: 104.2 ± 17.2 kg; height:186.3 ± 9.0 cm) from a single academy engaged in a 4-week nutrition support programme led by a certified nutritionist to provide the nutritional support that was otherwise lacking. The programme was part of a larger project aimed at improving basic dietary practices in the Target population and consisted of a single 60-minute education group seminar, individual 15-minute consultations, regular cellular and in-person contact and provision of educational pamphlets detailing how to structure and cook appropriate meals. Nutrition knowledge was measured pre- and post-intervention using the validated Abridged-Sports Nutrition Knowledge Questionnaire (ASNKQ)(Trakman et al, 2018).



Results

Individual and mean nutrition knowledge scores are displayed in Table 1. No difference was observed between pre-intervention (38.9 ± 14.4%) and post-intervention (42.0 ± 12.6%) ASNKQ scores ($p=0.26$). Pre- and post-intervention scores were classified as "poor". Five individual scores decreased post-intervention whilst 2 remained the same.

Trakman, G.L., Forsyth, A., Hoye, R. and Belski, R., 2018. Development and validation of a brief general and sports nutrition knowledge questionnaire and assessment of athletes' nutrition knowledge. Journal of the International Society of Sports Nutrition, 15(1), pp.1-8.

Conclusions

Nutrition knowledge did not improve in response to the nutrition support programme. Additionally, nutrition knowledge scores of the cohort were classified as "poor" however large intra- individual variation was apparent in the athletes. Particularly at developmental levels, nutrition knowledge may be inadequate and many factors can negatively influence dietary choices for health and performance. This highlights the importance of providing consistent and individual nutrition support and education sessions to athletes.