Macronutrient intakes of adolescent rowers for growth, development and sports performance

A thesis presented in partial fulfilment of the requirements for the degree of

Master of Science

in

Nutrition and Dietetics

at Massey University, Albany,

New Zealand.

Samantha Watts

2023

Abstract

Introduction: Dietary intake plays a central role in athletic performance in competitive rowing (Cornford & Metcalfe, 2019). During moderate training, it is recommended that adolescent athletes aim for 5.0-7.0 $g.kg^{-1}$ of carbohydrates, 1.3-1.8 $g.kg^{-1}$ of protein, and 20-35% energy from fat (Desbrow et al., 2014). Suboptimal nutrition within the adolescent rowing population may negatively impact growth and development, rowing performance, professional athlete development and career longevity. Previous research has indicated that suboptimal carbohydrate intake is a common issue in rowing (Baranauskas et al., 2014). The quality of dietary intake in adolescent rowers has seldom been explored. This study aimed to examine the dietary intake of adolescent rowers in New Zealand and compare it with nutritional guidelines for normal growth, development, and sports performance.

Methods: A cross-sectional study design involved data collection on two hard training days and two recovery days from rowers aged 14-21 years from around New Zealand. During the four 24-hour collection periods participants recorded food intake, training duration and intensity. The food records were verified for accuracy, and dietary data was entered into Foodworks software for nutritional analysis. IBM SPSS software was used to calculate the mean intake and standard deviations for carbohydrate, protein, and dietary fat. Independent t-tests were used to compare the carbohydrate and protein intakes between males and females.

Results: Of the initial 40 participants, 35 fully (females n=23, 16.8 ± 1.9 years; males n=12, 17.3 ± 1.6 years) completed the study. Participants consumed 319 ± 116 g (4.5 ± 1.7 $g.kg^{-1}.day^{-1}$) of carbohydrates, 121 ± 56 g (1.7 ± 0.7 $g.kg^{-1}.day^{-1}$) of protein and 113 ± 46 g (1.6 ± 0.6 $g.kg^{-1}.day^{-1}$) of fat per day. Females consumed 290 ± 80 g (4.4 ± 1.3 g.kg^{-1}.day^{-1}) of carbohydrates and males consumed 400 ± 78 g (5.0 ± 1.4 g.kg^{-1}.day^{-1}) per day, with no significant difference between males and females intake per kilogram of bodyweight per day ($p=0.165$). Minimum carbohydrate levels of 5.0 g.kg^{-1} per day were only achieved by seven females (30.4%) and four (33.3%) males. Females consumed significantly less protein per day, 106 ± 38 g (1.6 ± 0.6 g.kg^{-1}.day^{-1}), in comparison to males who consumed 164 ± 46 g (2.0 ± 0.5 g.kg^{-1}.day^{-1}) per day ($p=0.04$). Fourteen females (60.9%) and ten males (83.3%) consumed more than the minimum requirement of 1.3 g.kg^{-1} of protein per day.

Conclusion: The findings suggest that two out of three adolescent rowers in New Zealand fail to reach the minimum recommendation for carbohydrate intake (Desbrow et al., 2014), and males more readily meet the recommended intakes of protein when compared to females. Nutrition education for adolescent rowers in New Zealand should emphasise adequate carbohydrate and protein intakes that meet sports nutrition guidelines in order to support normal growth, development and optimised performance for these athletes.

Keywords

adolescent athletes; sports nutrition guidelines; carbohydrate; protein

Acknowledgements

First and foremost, I wish to extend my heartfelt gratitude to Claire Badenhorst and Kathryn Beck for their continual support throughout this journey. Your guidance and encouragement have been invaluable, and I am truly fortunate to have had such dedicated supervisors. Claire, your enthusiasm for this project has been a source of inspiration and your guidance has been instrumental to my growth as a writer. Kathryn, your calming presence has been a source of reassurance, and your insights have been extremely valuable. I express my sincere appreciation to Rebecca Paul, who dedicated countless hours to the challenging task of recruitment, data collection, and initial data entry. To my colleague, Jessie Speedy, thank you for your positivity and encouragement throughout this past year. A special acknowledgment to High-Performance Sport New Zealand and Rowing New Zealand for their support and collaboration on this project.

Finally, to my friends and family, I want to express my deepest gratitude for your unwavering support. Mum, thank you for the comforting cups of tea and snacks during those long hours in isolation, and Dad, your continual encouragement has kept me on track and motivated. To my brother and sister-in-law, Jeremy and Megan, your kind words of support have meant a lot. My sister, Sarah; my brother-in-law, Hugh; and their team, Evie, Theo, Clara, and Gabe, thank you for being a constant source of support and entertainment on those days when I needed a break. The completion of this thesis stands as a testament to the collective efforts and unwavering support of each one of you. I am profoundly grateful and could not have finished this thesis without all of you

Table of Contents

List of Tables

List of Abbreviations

%E	Percent contribution to total energy
AI	Adequate intake
ASCM	American College of Sports Medicine
BIA	Bioelectrical Impedance analysis
BMI	Body mass index
BW	Bodyweight
CHD	Coronary heart disease
CHO	Carbohydrate
CVD	Cardiovascular disease
EAA	Essential amino acids
EAR	Estimated average requirement
GI	Glycaemic index
ISSN	International Society of Sports Nutrition
IOC	International Olympic Committee
LCHF	Low carbohydrate high fat
MPB	Muscle protein breakdown
MPS	Muscle protein synthesis
MUFA	Monounsaturated fatty acids
NA	Not available
NZSSSC	School Sport New Zealand
PUFA	Polyunsaturated fatty acids
RDI	Recommended dietary intake
RPE	Rating of perceived exertion
SDA	Sports Dietitians Australia
SFA	Saturated fat

Chapter 1 : Purpose

1.1 Background

Rowing is a physically demanding strength-endurance sport that requires optimal dietary intake to maximise training adaptations, enhance rowing performance, and contribute to the long-term health and success of these athletes. Adherence to recommended sports nutrition guidelines is instrumental in enabling rowers to develop the strength and power necessary for maintaining peak effort throughout the 2000-metre course. Additionally, optimal dietary intake contributes to building the endurance essential for participating in regattas, often over multiple days of racing.

Typically initiated during adolescence, competitive rowing relishes widespread popularity in New Zealand. The Maadi Cup 2021 rowing regatta attracted 2623 rowers from 122 secondary schools (Rowing NZ, 2021), making it the largest secondary school sporting event in the Southern Hemisphere. Aside from the high energy demands on adolescent rowers, achieving the ideal distribution of macronutrients (of which are carbohydrates, proteins, and fat) is vital as each macronutrient plays a specific role in supporting performance, aiding recovery and contributing to overall health (Burke et al., 2021). For instance, carbohydrates (CHO) are important for adolescent rowers as they are the primary fuel source during high-intensity training and competition (Kim & Kim, 2020). Furthermore, understanding when adolescent rowers consume their meals and snacks in relation to training sessions and competitions is crucial, as proper timing of nutrition can impact energy levels and overall performance (Kerksick et al., 2017). Equally significant is the consideration of post-exercise nutrition strategies, as effective recovery nutrition plays a key role in replenishing glycogen stores, facilitating muscle repair, and reducing the risk of injuries (Kerksick et al., 2017).

Adolescents have increased nutritional requirements due to the biological changes that accompany puberty. Significant demands are placed on energy, of which the primary source is CHO, and protein requirements to support sexual maturation, linear growth, and changes in body composition during this phase (Brown, 2019). Inadequate dietary intake may compromise cognitive function and development, accretion of lean body mass, bone remodelling, and delay the onset of puberty and the linear growth spurt (Brown, 2019). Considering the critical role of protein intake in influencing growth, individuals adhering to vegetarian diets may be at risk of marginal or low protein intakes (Brown, 2019). In addition, certain protein-rich foods contain iron, and the recommendations for iron intake increase for both male and female adolescents as they progress through adolescence (Brown, 2019). While adequate dietary fat and essential fatty acids are also needed for growth and development during adolescence, sufficient dietary fibre is recommended for normal bowel function and may play a role in preventing obesity and the development of chronic disease (Brown, 2019).

Adolescence is also a critical time for osteoporosis prevention, as nearly half of adult peak bone mass is accrued during this developmental stage (Brown, 2019). Consequently, an adequate dietary intake becomes imperative during adolescence to support overall growth and also lay the foundation for long-term bone health (Brown, 2019). This holds significant importance as adolescents face a greater susceptibility to injuries than adults, particularly for stress fractures and joint injuries (Burke et al., 2021). In contrast to adolescents who lead a sedentary lifestyle, adolescent athletes involved in endurance and power sports require higher CHO and protein intakes as a result of their higher energy needs, increased demands on glycogen reserves and increased muscular strength (Burke et al., 2021). Recognising the long-term impact of dietary habits established during adolescence holds great importance, given that the quality of nutrition during this developmental phase can profoundly influence overall health and future athletic performance (Burke et al., 2021; Desbrow, 2021).

Adolescent rowers face significant barriers and nutritional considerations when attempting to upregulate their dietary intake. Adolescence is often associated with the need for independence and peer acceptance, and during this time, some adolescents may adopt unhealthy eating behaviours, such as regular meal skipping or resorting to unhealthy weight control practices, affecting the intake of CHO, protein and fat (Brown, 2019; Desbrow, 2021). Dietary decisions are also influenced by some factors of social determinants of health, including levels of nutritional knowledge, disposable income available to purchase food, cultural background, food beliefs and taste preferences, established family eating habits, cooking skills, and available facilities (Stokes et al., 2018). Therefore, there is a risk that adolescent rowers may fail to upregulate their dietary intake adequately to optimise training adaptations, performance, recovery, and support growth, development and maturation as a result of one or more of these social determinants of health.

Athletes navigating high volume training loads face challenges, such as exercise-induced appetite suppression and food-related gastrointestinal distress. Earlier research has indicated that vigorous exercise, even in short training sessions, can induce post-exercise appetite suppression in endurance-trained men and women (Broom et al., 2009; Broom et al., 2007; Howe et al., 2016; King et al., 2010; Ueda et al., 2009; Vatansever-Ozen et al., 2011). Previous studies have reported a decrease or maintenance of dietary energy intake following vigorous exercise which is insufficient to correct the relative energy deficit generated by the energy expenditure during vigorous exercise (King et al., 2010; Ueda et al., 2009; Vatansever-Ozen et al., 2011). This phenomenon could have significant implications for rowers who regularly train and compete at high intensities, affecting their performance, nutritional needs, and dietary intake strategies.

Previous studies have demonstrated that adolescent athletes lack the fundamental sports nutrition knowledge around nutritional requirements for sport performance and recovery, nutritional content in foods, sports food and supplement use, and weight management (Bird & Rushton, 2020; Buckhart & Coad, 2010; Manore et al., 2017). With the appropriate nutrition knowledge, adolescent athletes may become better at making informed decisions around appropriate food options and upregulating dietary intake to their training loads (Desbrow et al., 2019). When aligning dietary intake with current sports nutrition recommendations that support growth, development, and sports performance of adolescent athletes, research has shown that effective nutritional education can increase sports nutrition knowledge and improve dietary intake practices (Debnath et al., 2023; Foo et al., 2021).

Since the 1960s, extensive research has established the importance of dietary CHO in enhancing the capacity for endurance exercise (Burke et al., 2021). In response to the accumulating evidence, the 1991 IOC Consensus on Nutrition for Athletes convened to review the evidence on the role of nutrition in performance and athlete health (Burke et al., 2004). Subsequently, the findings were introduced as the inaugural set of guidelines for CHO intake, outlining the percentage of energy derived from CHO and the recommended total grams to maximise muscle glycogen levels for endurance athletes (Burke et al., 2004). Since then, the sports nutrition guidelines have progressed significantly with advancements in research. Revised definitions and terminology within the guidelines have redirected focus to CHO availability, particularly in relation to training intensity and duration (Burke et al., 2011). The updated recommendations highlight dietary intake based on grams relative to bodyweight, reflecting a nuanced approach to optimise performance and fuelling strategies (Burke et al., 2011).

Current daily recommendations for adolescent athletes suggest the following nutritional guidelines for moderate training: 5.0-7.0 $g \cdot kg^{-1}$ CHO, 1.3-1.8 $g \cdot kg^{-1}$ protein and 20-35% of total energy from fat (Desbrow et al., 2014; Deutz et al., 2014; Kerksick et al., 2018; Sports Dietitians Australia, 2023a; Thomas et al., 2016). For adolescent athletes engaging in high-intensity exercise for ≥1 hour, the suggested nutrient timing includes consuming 1.0–4.0 $g \cdot kg^{-1}$ CHO 1–4 hours before exercise, 30–60 $g \cdot h^{-1}$ CHO during exercise, and post-exercise intake of 1–1.2 $g \cdot kg^{-1} \cdot h^{-1}$ CHO and 0.3-0.4 $g.kg^{-1}$ protein as soon as possible after exercise (Baker et al., 2014; Burke et al., 2021; Kerksick et al., 2017). Best practice is to use the outlined recommendations to assist in setting nutrition targets for the individual athlete, taking into account exercise intensity, duration, and type of training.

Due to the limited number of controlled studies with adolescents, it is important to point out that current sports nutrition recommendations for adolescent athletes are largely extrapolated from research with adults (Burke et al., 2021). Challenges arise from differences in exercise metabolism and substrate utilisation between adults and prepubertal children (Burke et al., 2021; Riddell et al., 2008; Taylor et al., 1997; Timmons et al., 2003). However, as children progress through puberty, these differences start to decrease (Riddell et al., 2008). Consequently, sports nutrition experts infer the applicability of adult sports nutrition guidelines to adolescent populations (Burke et al., 2021).

Previous research on the observed dietary intake of adolescent rowers is limited, and few investigations include aspects such as CHO and protein timing relative to training, fibre content, sugar intake, and types of fat. The primary data collection method in the majority of the studies was

24-hour food recalls or written food records, often considered the "gold standard" for validating dietary assessment tools in observational research with adolescents (Rumbold et al., 2011). Out of the available studies, only two focused exclusively on adolescent rowers. In one study conducted by Bond et al. (2012), male rowers were reported to consume 5.8 $g.kg^{-1}$ CHO and 2.1 $g.kg^{-1}$ protein per day, while another study by Hanley (2014) reported intake levels of 4.9 $g.kg^{-1}$ CHO and 1.36 $g.kg^{-1}$ protein. Notably, Hanley (2014) found that only 53% of rowers consumed more than 5.0 $g.kg^{-1}$ CHO and 73% consumed more than 1.2 $g.kg^{-1}$ protein. Gender-based variations in CHO and protein intake were often observed, with female lightweight rowers demonstrating the most substantial deviation from recommendation levels, recorded at 3.5 $g.kg^{-1}$ CHO and 0.6 $g.kg^{-1}$ protein (Morris & Payne, 1996). An earlier study on young female rowers by Steen et al. (1995) reported that 63% of rowers consumed less than 5.0 $g{\cdot}kg^{-1}$ CHO. The most extensive study on female rowers, conducted by Miyamoto et al. (2021) reported intake levels of 5.5 $g.kg^{-1}$ CHO and 1.7 $g.kg^{-1}$ protein. Studies of the dietary intakes of elite and collegiate rowers found the requirements for protein and dietary fat were generally met. However, the findings were contradictory with regard to CHO intakes of collegiate-level rowers. Unlike elite rowers, collegiate rowers consumed less CHO per day and were also less inclined to adhere to the current sports nutrition recommendations for CHO intake (De Wijn et al., 1979; Heinemann & Zerbes, 1989; Iguchi & Kuzuhara, 2020; Short & Short, 1983; Steen et al., 1995; Van Erp-Baart et al., 1989; Zorn, 2017).

In summary, adolescent rowers require increased dietary intake; however, suboptimal dietary habits during the adolescent phase may compromise growth, development, and maturation. To ensure adolescents reach adequate intake, specific nutrition guidelines were established with additional recommendations for adolescent athletes. The basic principles of sports nutrition guidelines were derived from decades of research and best practice is to use the nutritional guidelines to assist in setting nutrition targets for the individual athlete. Understanding athlete dietary intake is valuable in identifying areas for improvement, enabling the delivery of focussed and effective nutrition education to adolescent rowers. Despite this, previous studies of dietary intake in adolescent rowers are limited, which poses a challenge in identifying common nutritional gaps in dietary intake. In pursuit of advancing the understanding of dietary patterns among adolescent rowers, the present study seeks to contribute a comparative analysis of the dietary intake among New Zealand rowers aged 14-21 years to the existing literature. The study utilises food records collected on two hard training days and two recovery days, with a specific emphasis on CHO, protein, and fat consumption. The findings will be assessed in relation to current sports nutrition recommendations for adolescent athletes. This study aims to identify potential disparities and areas of alignment with current sports nutrition guidelines, and offer insights that can supplement existing nutritional knowledge of adolescent rowers, coaches, and the New Zealand rowing community.

1.2 Aims

The primary aim of this study is to explore the dietary intake of New Zealand rowers aged 14-21 years. A secondary aim is to determine if dietary CHO, protein and fat intake align with sports nutrition guidelines for adolescent rowers.

1.3 Objectives

1. To determine the CHO intake of rowers and compare to sports nutrition guidelines for adolescent athletes.

2. To determine the protein intake of rowers and compare to sports nutrition guidelines for adolescent athletes.
3. To determine the dietary fat intake of rowers and compare to sports nutrition guidelines for adolescent athletes.
4. To determine the difference in CHO, protein, and fat consumption between hard training days and recovery days.
5. To determine the distribution of CHO and protein intake before, during, and after training.
6. To define the daily intake of total sugar, dietary fibre, saturated fat (SFA), monounsaturated fat (MUFA) and polyunsaturated fat (PUFA) in adolescent rowers.

1.4 Hypotheses

1. Most adolescent rowers do not meet the recommended CHO intake levels to support their training intensity and duration.
2. Variances in dietary protein intake exist between male and female adolescent rowers based on their gender.
3. Most adolescent rowers fail to adhere to the recommended nutritional timing for CHO intake for pre-exercise, during exercise and post-exercise recovery.

1.5 Structure of Thesis

The structure of this thesis begins with Chapter 1, an introduction to the study, which provides a background on rowing in New Zealand and the dietary intakes in adolescent rowers to support growth, development and sports performance. Chapter 2 is a comprehensive review of the current literature describing the influence of CHO, protein and dietary fat intake on the normal growth and development of adolescents and adolescent athletes, and the evidence-based rationale behind recommended macronutrient quantities and timing for improved performance. Chapter 3 is a manuscript of the research study for publication, which includes the introduction, study methods, results summary and discussion of the research findings. Finally, Chapter 4 summarises the implications of this study, the strengths and limitations, practical applications for adolescent rowers and future research directions.

1.6 Researcher's Contributions

Table 1.1: Summary of each researcher's contributions to the study

Author	Contributions to Thesis
Samantha Watts MSc Student nutrition and dietetics	Primary author of the thesis. Data processing and statistical analysis. Interpretation and presentation of results.
Dr Claire Badenhorst Primary Supervisor Lecturer School of Sport, Exercise and Nutrition	Designed research, applied for ethics, recruited participants, collected data, assisted with interpretation of results, revised and approved the thesis.
Dr Kathryn Beck Co-supervisor Associate Professor School of Sport, Exercise and Nutrition	Assisted with research design and data collection, assisted with statistical analysis, revised and approved the thesis.
Rebecca Paul Research Assistant School of Sport, Exercise and Nutrition	Assisted with data collection and processing.
Jessie Speedy MSc Student nutrition and dietetics	Assisted with data processing.

Chapter 2 : Literature Review

2.1 Introduction to the literature

Rowing is a physically demanding strength-endurance sport in which commitment to training often starts in adolescence. Given the high energy demands, adolescent rowers need to scale dietary intake to exercise intensity and duration to optimise physiological adaptation, performance, and recovery (Desbrow et al., 2014). In addition to training and competition, adolescents require increased nutritional needs to support rapid growth, development, and maturation (Brown, 2019). Inadequate dietary intake during this critical developmental stage can have detrimental effects on normal adolescent development (Brown, 2019). Therefore, an assessment of dietary intake is necessary to identify discrepancies in dietary intake so that targeted nutritional education can be established to support adequate CHO, protein, and fat intake.

This literature review explores the existing research on dietary intake and adherence to nutritional recommendations for adolescent rowers' growth, development, and sports performance. It is limited to exploring CHO, protein, and dietary fat intakes and briefly describes diet quality. Since the existing body of research into the dietary intake of adolescent rowers is sparse, this literature review will also critically analyse studies on collegiate and elite adult rowers.

The structure of this literature review first explains the nutritional considerations that influence the food intake and dietary patterns of adolescent rowers in New Zealand. The review will then outline the current sports nutrition guidelines for adult rowers and comprehensively examines the evidence from which these recommendations are derived. Subsequently, the population nutritional recommendations and sports nutrition guidelines for growth, development, and sports performance will be discussed. Lastly, a critical analysis of previous research on the dietary intake of adolescent and elite rowers will summarise the current understandings from research in this area, while also highlighting the current gaps and future directions for research.

2.2 Competitive rowing in New Zealand

Rowing is one of New Zealand's most successful Olympic sports (New Zealand Olympic Committee, 2023). Given its popularity, participation in competitive rowing often begins during adolescence (Rowing NZ, 2021). Rowing is a physically demanding sport that involves 6-8 minutes of near-maximal high-intensity exercise over a 2000-metre course (Kim & Kim, 2020) which requires high levels of nutritional support. In addition, elite rowers often train long hours, with 1-2 daily rowing sessions and gym sessions 3-4 times a week to develop strength and endurance (Sports Dietitians Australia, 2023b). Therefore, an adequate dietary energy intake derived from CHO, protein and fat is an important consideration given the high energy demands of the sport. Competitive rowing presents major nutritional considerations that influence the upregulation of the dietary intake of adolescent rowers, such as competition weight divisions, heavy training loads, eating for and during competitions and nutritional knowledge on how much food to eat to support training and competition demands.

2.2.1 Competition weight divisions

Rowers generally exhibit greater height, strength, and weight compared to their counterparts in other endurance sports (Burke, 2007). This preference in rowing favours individuals with longer limbs and a larger muscle mass, enabling them to generate high power outputs over sustained periods (Burke, 2007). Rowing is categorised into lightweight and heavyweight divisions, each with specific weight criteria that may influence food choice and dietary patterns (Burke, 2007). Restricting dietary intake to meet weight division criteria may influence the daily intake of CHO, protein and fat, potentially misaligning with current sport nutrition guidelines. In particular, lightweight rowers face the challenge of balancing adequate dietary intake with weight management. Previous studies have reported inadequate dietary CHO, protein and fat intake in lightweight rowers adhering to an energy-restricted diet in preparation for the upcoming competition season (Morris & Payne, 1996). However, it has been proposed that maintaining higher dietary protein intakes (≥ 1.6 $g.kg^{-1}.d^{-1}$) could be beneficial for lightweight rowers aiming to preserve muscle protein while in a significant energy deficit (Helms et al., 2014; Longland et al., 2016; Mettler et al., 2010; Pasiakos et al., 2010).

2.2.2 High-volume training loads

A rower's dietary intake is likely to be affected by their training schedule. With daily variations in training volume, dietary intake must be upregulated to align with exercise intensity and duration to optimise physiological adaptation and performance (Noll et al., 2017). For example, early morning training sessions are a common practice in rowing (Kölling et al., 2016). However, the decreased sleep duration and quality linked to this routine may negatively impact appetite and influence dietary intake and composition (Al-Disi et al., 2010; Doherty et al., 2021; Kölling et al., 2016). Rowers may skip breakfast meals or snacks pre-training (Cornford & Metcalfe, 2019), which deviates from recommended pre-exercise dietary intake guidelines specifying the optimal amount to be consumed before training (Table 2.1). Furthermore, appetite suppression from pre-event nerves (Ans et al., 2018) or as a result of completing high-intensity exercise (Howe et al., 2016; Oshima et al., 2017; Vatansever-Ozen et al., 2011) may also lead to a deficit in dietary intake following early morning training or competition. Rowers may also lack sufficient time to manage adequate dietary intake around training, travel, and busy daily schedules of work or school (Black et al., 2018; Burke, 2007; Jagim et al., 2021), and as a result may struggle to consume the volume of food needed to support large muscular bodies and training.

2.2.3 Competition eating

Adolescent rowers will compete in large multi-day regattas and are likely to have busy race schedules, in which aggressive nutritional protocols for rapid refuelling and muscle repair are needed (Burke, 2007). Current sports nutrition guidelines offer specific recommendations to support pre-, during, and post-exercise dietary intake for performance and recovery (Table 2.1). However, pre-race and recovery nutrition may be forgotten or regarded as not important due to other commitments and priorities (e.g. coach meetings, boat loading, warm-up/down activities or stretching, traditional post-competition celebration activities), post-exercise fatigue interfering with the ability or interest to obtain food, limited access to food at isolated event location and food availability at accommodation, or travel schedules interfering with meal and snack times (Burke, 2007; Jagim et al., 2021). In support of this, a previous study has reported that female adolescent athletes failed to meet minimum recommendations for daily and post-exercise CHO intake (Baker et al., 2014). On the other hand, males more readily met nutrient timing recommendations, suggesting some adolescents may need additional support to achieve adequate CHO intake for fuelling and recovery during competition (Baker et al., 2014).

2.2.4 Other factors that influence the upregulation of dietary intake

Outside of training and competition, additional factors that may influence the dietary intake of adolescent rowers include level of nutritional knowledge, cost of food, cultural background, food beliefs and preferences, established family habits, lack of cooking skills, catered dormitory accommodation, food anxiety associated with body-image issues or potential gastrointestinal distress associated with dietary intake before high-intensity exercise in susceptible individuals (Black et al., 2018; Burke et al., 2021; Ioanna & Tonia, 2021; Jagim et al., 2021).

Adolescent dietary choices and weight control behaviours are influenced by media exposure and the prevalence of popular dietary patterns within their peer group (Spadine & Patterson, 2022). Despite the influencing nature of these trends, there is a lack of research investigating their safety and efficacy in the adolescent population. A recent review by Burke (2021) explored the existing literature on low CHO high fat diets (LCHF), highlighting the physiological changes associated with chronic keto-adaptation. The initial weeks of keto-adaptation may induce fatigue, irritability, and impair performance due to the insufficient supply of CHO to skeletal muscles and the brain (Burke, 2021). In elite endurance athletes, prolonged keto-adaptation can impair CHO oxidation, muscle glycogen utilisation and recovery during higher intensity and anaerobic exercise, without evidence of enhanced performance (Burke, 2021; Burke et al., 2020; Kaufman et al., 2023). Previous studies indicate that chronic keto-adaptation may increase the reliance on muscle fat oxidation and utilisation during moderate-intensity exercise, which may be beneficial if the intended outcome is a reduction in adipose tissue (Burke, 2021; Spriet, 2014). However, the evidence for improved performance at this intensity remains inconsistent (Burke, 2021). Another trending dietary pattern, intermittent fasting, has been shown to negatively impact athletic performance (Levy & Chu, 2019). As the nutritional priorities of adolescents focus on growth, development and maturation (Brown, 2019), adopting a LCHF diet or intermittent fasting is unlikely to align with nutritional recommendations for long-term health and chronic disease prevention in the adolescent population, or yield positive effects on rowing performance and recovery.

2.3 Current nutritional guidelines for rowers

Nutritional strategies to optimise performance and training adaptations have evolved significantly over the last 30 years. Dietary manipulation has been extensively studied, primarily in strength or endurance athletes, to establish ranges for CHO, protein and fat, that support the physiological demands during heavy training loads and acute nutritional needs during competition. Subsequently, sports nutrition guidelines (Table 2.1) have been established by various sporting and nutrition associations and committees. Derived from previous and emerging evidence, these guidelines support the available research that suggest that increasing amounts of CHO and some fats are utilised as an energy source as exercise intensity increases; however, only a small amount of protein is oxidised (Stellingwerff, 2013). Best practice is to use the nutritional guidelines to assist in setting nutrition targets for the individual athlete, taking into account exercise intensity, duration and type of training. As a result, dietitians and nutritionists can ensure that the nutritional requirements are unique for each individual and sport. However, of the available nutrition resources, there are limited rowing-specific guidelines (Kim & Kim, 2020). With an emphasis on endurance, power, and fast recovery, nutrition targets should be considered to optimise rowers' athletic abilities and performance (Kim & Kim, 2020; Maughan et al., 2012; Stellingwerff et al., 2011).

2.4 Carbohydrate

2.4.1 Carbohydrate quantity

Dietary CHO is stored in liver and muscle cells as glycogen (Achten et al., 2004) or used as a substrate for energy production through glycolysis of exogenous CHO and muscle glycogen oxidation (glycogenolysis) during exercise intensities above 75% maximal oxygen consumption ($\dot{V}O_2max$) (Martin & Tomescu, 2017; Stellingwerff et al., 2011). Rowers need highly developed aerobic and anaerobic energy systems supported by dietary intake with adequate CHO for their exercise intensity and duration (Kim & Kim, 2020). One study reported during the initial stages of rowing, 33% of the energy supply was derived from exogenous CHO through the anaerobic energy system (Martin & Tomescu, 2017). The remaining energy (77%) was supplied by muscle glycogen through the aerobic energy system (Martin & Tomescu, 2017).

During rowing competitions, the commencement of races with depleted muscle glycogen stores may lead to an early onset of fatigue and reduced rowing performance (Kim & Kim, 2020). During the competition season, rowers may have high-intensity training requirements ranging from 1-3 hours a day, 5-6 times a week (Kim & Kim, 2020). Therefore, a high CHO intake before training is recommended to increase glycogen availability and reduce the risk of early fatigue and poor performance (Cornford & Metcalfe, 2019; Kim & Kim, 2020; Simonsen et al., 1991). In a 4-week cross-sectional study, rowers with a high (10.0 $g·kg^{-1}$) CHO intake had 65% more glycogen stored in their muscles by day 26 than on day 1 (p= 0.03) and showed a 7.8% increase in performance than rowers consuming moderate amounts (5.0 $g·kg^{-1}$) of CHO intake (Simonsen et al., 1991). Therefore, although consumption of 5.0 $g·kg^{-1}$ CHO was not associated with glycogen depletion or impairment during rowing performance, 10.0 $g·kg^{-1}$ CHO promoted greater muscle glycogen storage and increased power output during training (Simonsen et al., 1991). Furthermore, isolated muscle biopsies from endurance athletes reported low-moderate CHO intakes (1.49-5.41 $g·kg^{-1}$) were inefficient at restoring muscle glycogen to baseline levels 24-hours post-training (Achten et al., 2004; Sherman et al., 1981). Thus, low-moderate intakes of CHO (15-40% total energy) equated to less muscle glycogen storage and a lower glycogen utilisation rate (Achten et al., 2004; Sherman et al., 1981), resulting in reduced rowing performance. Conversely, high CHO intakes (7.75-8.45 $g·kg^{-1}$) were more effective at restoring muscle glycogen stores and results demonstrated a higher utilisation of glycogen stores which was proposed to support improved rowing performance (Achten et al., 2004; Sherman et al., 1981). However, it was noted that the rate of muscle glycogen oxidation was higher but not significantly different between high (8.5 g·kg^{-1}) and moderate (5.4 g·kg^{-1}) CHO intakes at both 58% VO_2max ($p = 0.093$) and 77% VO_2max ($p = 0.053$) (Achten et al., 2004). It is likely the differences observed in muscle glycogen oxidation rates may result from differences in pre-exercise muscle glycogen levels (Achten et al., 2004), as it has been demonstrated that the rate of glycogenolysis is related to the amount of stored muscle glycogen (Hargreaves et al., 1995). Previous research has reported that rowers may typically ingest 3.5-4.9 g·kg^{-1} CHO a day (Baranauskas et al., 2014; Hanley, 2014; Morris & Payne, 1996; Steen et al., 1995; Zorn, 2017), which would be less than the high CHO intakes required to maximise muscle glycogen storage and utilisation (Achten et al., 2004).

2.4.2 Carbohydrate timing

Previous research has suggested that some rowers skip breakfast, yet still participate in morning or afternoon training sessions (Kim & Kim, 2020). This practice may negatively impact training performance (Cornford & Metcalfe, 2019). A recent study would suggest skipping breakfast may reduce performance in rowers, with results demonstrating decreased power output over time ($p < 0.001$), increased rating of perceived exertion (RPE) and decreased 2000-metre time trial performance by 3.5 seconds ($p = 0.05$) (Cornford & Metcalfe, 2019).

The current recommendations for pre-exercise CHO intake for athletes are described in Table 2.1. In cases where rowers are unable to meet adequate CHO intake in previous meals, individuals can consume easily digestible high glycaemic index (GI) CHO 30-60 minutes before training (Kim & Kim, 2020) to increase CHO oxidation during training (Jeukendrup & Killer, 2010). Ingestion of high GI CHO before exercise may result in rebound hypoglycaemia in susceptible individuals; however, this is unlikely to negatively impact rowing performance (Jeukendrup & Killer, 2010).

Carbohydrate intake has been identified as an ergogenic aid during exercise (Cermak & Van Loon, 2013; Kerksick et al., 2018). For ergogenic benefits, athletes are advised to ingest CHO at a rate of 60 $g \cdot h^{-1}$ (1.0-1.1 $g \cdot min^{-1}$) during prolonged exercise (2-3 hours) (Cermak & Van Loon, 2013). However, evidence also suggests that performance during short (45-60 min) high-intensity (>75% VO_2max) exercise sessions may also benefit from a small amount (0.8 $g \cdot kg \cdot h^{-1}$) of high GI CHO intake (Cermak & Van Loon, 2013). Although the practicalities of CHO intake while on the water may be challenging, rowing-specific guidelines suggest consuming easily digestible forms such as sports drinks or gels, or low-fat, low protein, low fibre solid energy bars (Kim & Kim, 2020). An alternative strategy that has been suggested in previous research for delivering CHO during exercise is CHO mouth rinsing (Jensen et al., 2015). Here a sports or maltodextrin drink is taken orally, swirled in the mouth and spat out after 5-10 seconds, and can be performed at 10–15-minute intervals (Jeukendrup, 2014). Jensen et al. (2015) reported that CHO mouth rinsing with an 8% maltodextrin solution reduced fatigue and increased performance in rowers while performing maximal isometric knee extensions. While the physiological mechanisms were not identified, Jensen et al. (2015) hypothesised that taste receptor cells transmit electrical activity to gustatory neurons, which, upon tasting the CHO, were activated leading to enhanced performance (Chambers et al., 2009). Therefore, to enable increased performance through CHO intake in rowers with lower gastrointestinal tolerance, individuals may find CHO mouth-rinsing an effective strategy to overcome this inconvenience (Kim & Kim, 2020).

For rowers who train more than once per day or compete in races close together, immediate CHO intake post-exercise is recommended due to higher rates of muscle glycogen synthesis 0-4 hours post-exercise (Burke et al., 2017). In doing so, rowers may be able to sustain performance and prevent fatigue more effectively (Maughan et al., 2012). Previous research has shown that the immediate consumption of high-dose CHO (1.2 $g \cdot kg^{-1} \cdot h^{-1}$) during the acute recovery phase supports rapid maximal muscle glycogen repletion after exhaustive exercise, which may be beneficial for athletes who need to train twice within 24-hours (Cermak & Van Loon, 2013). Post-exercise CHO recommendations are derived from previous research by Ivy (1998), who demonstrated that ingestion of ≥1.0 $g·kg^{-1}$ CHO delivered within 30 minutes after prolonged moderate-high intensity exercise resulted in 50% faster and greater muscle glycogen repletion over the four hour post-exercise recovery period (153 $mmol.kg^{-1}$ glycogen at a synthesis rate of 33.0 $mmol·kg^{-1}·h^{-1}$ from 0-2 hours) compared with a two-hour delay of ingestion post-exercise (132 $mmol.kg^{-1}$ glycogen at a synthesis rate of 17.5 $mmol·kg^{-1}·h^{-1}$ from 2-4 hours). A review by Jentjens and Jeukendrup (2003) reported rapid muscle glycogen repletion rates of 20-50 $mmol·kg^{-1}·h^{-1}$ when 0.6-1.6 $g·kg^{-1}$ CHO was consumed immediately after exercise and at regular intervals (15-30 minutes) throughout a 4-6 hour recovery period. Similarly, a study by Jentjens et al. (2001) reported muscle glycogen synthesis rates of 40 $mmol·kg^{-1}·h^{-1}$ when ingesting 1.2 $g·kg^{-1}·h^{-1}$ every 30 minutes over a three-hour period after exercise, resulting in 106 $mmol.kg^{-1}$ of muscle glycogen. Conversely, Van Loon et al. (2000) reported muscle glycogen synthesis rates of 16.6 $mmol·kg^{-1}·h^{-1}$ when ingesting 0.8 $g·kg^{-1}·h^{-1}$ every 30 minutes over a five-hour period after exercise, resulting in 190 $mmol.kg^{-1}$ of muscle glycogen. Current nutritional guidelines of the American College of Sports Medicine (ACSM), International Society of Sports Nutrition (ISSN) and International Olympic Committee (IOC) align with this previous research, and in rowers, best practice may be consuming 1.0-1.2 $g·kg^{-1}$ CHO at frequent intervals (15-30 minutes), immediately after rowing training or competition. However, if large amounts of CHO post-exercise cause gastrointestinal discomfort in rowers, previous research has suggested that co-ingesting 0.8 $g·kg^{-1}·h^{-1}$ CHO with 0.2-0.4 $g·kg^{-1}·h^{-1}$ protein may achieve similar muscle glycogen repletion (Cermak & Van Loon, 2013). Furthermore, in cases where rapid recovery is not required by rowers, a high CHO intake (7.0-10.0 $g·kg^{-1}$) evenly distributed over the entire recovery period will normalise muscle glycogen within 24-hours in the absence of muscle damage (Burke et al., 2017).

2.5 Protein

2.5.1 Protein quantity

Rowers may need to consider protein intake and aim to meet the sport nutrition guidelines for adequate protein within their daily energy intake (Table 2.1). In doing so, their protein intake is likely to support a positive muscle protein balance and have increased amino acid availability for muscle protein synthesis (MPS) which will enable increased lean body mass, development of strength and maximise training adaptations (Areta et al., 2014; Pasiakos et al., 2010; Witard et al., 2019). Based on previous research, most sports nutrition guidelines concur that majority of athletes can meet their protein requirements with a daily protein intake of 1.2-2.0 $g{\cdot}kg^{-1}{\cdot}d^{-1}$ (Table 2.1) (Kerksick et al., 2018; Thomas et al., 2016). However, it is noted that there have been few studies to establish protein guidelines for power sport athletes (e.g. rowers), with most research investigations based on resistance trained individuals (Areta et al., 2014; Burd et al., 2011; Moore et al., 2009). Regardless, Stellingwerff et al. (2011) suggest that elite power sport athletes with intense training loads (e.g. elite rowers) should aim to meet their protein requirements with an intake of 1.5-1.7 $g{\cdot}kg^{-1}{\cdot}d^{-1}$.

2.5.2 Protein timing

A review of post-exercise protein intake suggests that while sports nutrition guidelines provide protein targets daily, previous research has reported a dose-response relationship between dietary protein and MPS stimulation after resistance exercise (Moore et al., 2009). Therefore, it suggests that the timing, protein type, and meal pattern have a significantly greater effect on post-exercise recovery than the total protein intake per day (Moore, 2019). A study by Moore et al. (2009) demonstrated that ingesting 5g, 10g, 20g of protein resulted in a 37%, 56% and 93% increase in mixed MPS, respectively, compared with the fasted state. Differences between 20g and 40g doses were not significant. Higher protein intakes (~40g) led to increased amino acid oxidation without parallel increases in the anabolic response in muscle, suggesting a plateau in MPS stimulation when protein intake is in excess of protein needs (Moore et al., 2009; Tipton et al., 1999). Moreover, large portions of protein in a single meal may also lead to the displacement of CHO and energy due to its satiating effects (MacKenzie-Shalders et al., 2015; Monteyne et al., 2018), and may have undesirable effects on the rate of recovery and subsequent training or rowing competition performance. Interestingly, recent research has suggested there is a protein dose response to MPS rates which is relative to bodyweight (0.24-0.4 $g \cdot kg^{-1}$) (Moore et al., 2015). This has been incorporated into the current consensus which states that protein dose should be taken relative to bodyweight and distributed evenly across the day (Burke et al., 2021; Kerksick et al., 2017; Kerksick et al., 2018; Kim & Kim, 2020; Maughan et al., 2012; Thomas et al., 2016).

2.5.3 Post-exercise protein intake

Previous research has suggested a narrow anabolic "window of opportunity" ($\leq$ 2 hours) for protein ingestion (Atherton et al., 2010). Conversely, other studies have suggested that the post-exercise anabolic response is longer at 4-6 hours post-exercise (Aragon & Schoenfeld, 2013), or even up to 24-48 hours post-exercise (Burd et al., 2011; Damas et al., 2016). A study by Atherton et al. (2010), reported that after consumption of an isolated whey protein (48g) drink equivalent to ~20g essential amino acids (EAA), the rate of MPS in the initial ~45 minutes ($0.034 \pm 0.003\%.h^{-1}$) was tripled between 45-90 min ($0.104 \pm 0.015\% \cdot h^{-1}$, $p < 0.05$), before returning to basal rates by 180 minutes post oral protein bolus. However, Aragon and Schoenfeld (2013) highlight that this previous study design was based on the consumption of protein after an overnight fasted state. During fasted exercise, the rate of muscle protein breakdown (MPB) exceeds the rate of training-induced MPS stimulation, leading to a persistent negative amino acid net balance into the post-exercise period (Kumar et al., 2009). Therefore, immediate protein intake is needed to provide sufficient amino acids (positive amino acid net balance) to increase MPS stimulation (Aragon & Schoenfeld, 2013). However, since training is only sometimes performed in a fasted state, Aragon and Schoenfeld (2013) argue the urgency for post-exercise protein intake is high if pre-exercise protein has not been consumed to ensure sufficient intramuscular amino acid availability post-exercise. More recently, a study testing the anabolic "window of opportunity" theory reported no significant difference in pre- and post-exercise protein intake ($p > 0.05$) on muscle adaptation if adequate protein intake and timing were achieved throughout the day (Schoenfeld et al., 2017). In addition, a meta-analysis in this field of research indicates the existing literature does not support an immediate "window of opportunity" (<2 hours) for an anabolic response (Schoenfeld et al., 2013). This conclusion arose due to the constraints imposed by small sample sizes and inconsistencies in dosage timing observed across studies (Schoenfeld et al., 2013). Furthermore, the meta-analysis suggests that any favourable outcomes noted in timing studies are more likely to be attributed to increased protein intake rather than the timing of consumption (Schoenfeld et al., 2013). Nonetheless, a recent review underscores possible methodological concerns associated with the meta-analysis and argues that benefits of immediate ingestion of protein may reach beyond hypertrophy and strength gains (Arent et al., 2020). For instance, several studies have suggested protein consumption promptly after exercise may enhance the recovery of fluids, indicating a broader spectrum of benefits to athletes (Ghigiarelli et al., 2009; James et al., 2011).

Until further evidence on the anabolic response to protein intake is discovered, current nutritional guidelines suggest the regular spread of protein (0.3-0.4 $g \cdot kg^{-1}$) over 4-5 meals across the day (Witard et al., 2019). However, position statements released by the ACSM and ISSN recommend consuming protein <2 hours post-exercise to promote any additional positive effects of protein timing on recovery and strength (Kerksick et al., 2017; Thomas et al., 2016). In addition, there is emerging evidence that a casein-rich protein snack (0.5-0.6 $g \cdot kg^{-1}$) before bed may assist in sustaining optimal MPS stimulation overnight (Kim, 2020; Trommelen & Van Loon, 2016) and may be a consideration for adolescent athletes.

2.6 Dietary fat

Although research may suggest that rowers rely on CHO as the primary energy substrate during high-intensity exercise (Stellingwerff et al., 2011), dietary fat may serve as an important fuel source during moderate-intensity exercise (up to ~85% VO_2max) in the form of intramuscular triacylglyceride stored in skeletal muscle (Stellingwerff et al., 2007; Stellingwerff et al., 2011). A cross-sectional study of well-trained rowers and cyclists reported rowers demonstrated greater fat utilisation (0.71 ± 0.05 $g \cdot min^{-1}$) during exercise to fuel low to moderate-high exercise intensities (~43-84% VO_2max) when compared with cyclists (0.49 ± 0.04 $g \cdot min^{-1}$, $P < 0.05$) (Egan et al., 2016). Intramuscular triacylglyceride can be replenished after prolonged endurance training (>2 hours) by ingesting an estimated 2.0 $g \cdot kg^{-1} \cdot d^{-1}$ of dietary fat (Decombaz, 2003). However, greater than recommended dietary fat intakes may displace the consumption of dietary protein and CHO. This may compromise muscle tissue repair, muscle glycogen resynthesis (Decombaz, 2003), and the rate of glycogenolysis during exercise. All of which may have considerable implications on muscle hypertrophy and performance for rowers as discussed in the preceding sections.

The anti-inflammatory properties and effects on oxidative stress of MUFA and PUFA is well documented (Calder, 2015; Crupi & Cuzzocrea, 2022; Fitó et al., 2005). Within the human body, MUFAs and PUFAs demonstrate a significant capacity to reduce oxidative stress, a factor linked to inflammatory-related conditions including diabetes (Lee et al., 2014; Wallin et al., 2012), metabolic syndrome (Lee et al., 2014), and cardiovascular disease (CVD) (De Lorgeril & Renaud, 1994). A study revealed that the consumption of one avocado (~136 g) daily with a medium-fat diet can reduce circulating oxidised LDL particles in the bloodstream (Wang et al., 2020). The effect was also observed in reducing small, dense LDL particles, implicated in cardiovascular risk (Wang et al., 2020). Furthermore, a cohort study reported higher intakes of PUFA from sources like oily fish, walnuts, and flaxseeds is associated with a reduced risk of coronary heart disease (CHD) (Li et al., 2015). Replacing 5% of energy from SFA with an equivalent amount of energy from either PUFA or MUFA, found in sources like olive oil, nuts, and avocados, was associated with a 25% and 15% lower risk of CHD, respectively (Li et al., 2015).

Minimum dietary fat requirements (≥20%) in relation to total energy intake (%E) must be met to aid the absorption of fat-soluble vitamins, hormone synthesis and cell membrane integrity which are crucial for general health and rowing performance (Stellingwerff et al., 2011). Therefore, current sports and nutrition guidelines encourage dietary intakes that are within the general public health guidelines of 20-35%E (Kerksick et al., 2018; Thomas et al., 2016). However, additional information is needed for recommendations around MUFA and PUFA consumption.

2.7 Emerging nutritional considerations for sports nutrition guidelines

2.7.1 The vegetarian athlete

Vegetarian diets are at a higher risk of predisposing athletes to some micronutrient deficiencies, suboptimal protein intake, and lower serum creatine and testosterone levels (Maier et al., 2023). Despite rowers' higher protein and amino acid needs compared with sedentary individuals, the additional protein requirements for vegetarian or vegan rowers need to be reflected in current sports nutrition guidelines (Burke et al., 2021). As such, it has been estimated that vegetarian athletes need an additional 10-22 $g \cdot d^{-1}$ of protein to account for the reduced bioavailability of plant proteins (Ciuris et al., 2019). Certain recommendations encourage vegetarian athletes to aim for a protein intake towards the upper limit of the protein range outlined in the ISSN guidelines (Rogerson, 2017). However, a cross-sectional study of endurance athletes reported a 20% lower protein availability in vegetarian athletes (1.1 $g \cdot kg^{-1}$) than in omnivore athletes (1.4 $g \cdot kg^{-1}$, p= 0.022) (Ciuris et al., 2019). Despite this, a recent review reported no significant differences in performance between athletes consuming plant-based and omnivore diets (Maier et al., 2023). It is notable that outcomes may be influenced by the intervention of a nutritionist or dietitian who can help optimise a vegetarian diet for improved performance (Ciuris et al., 2019). The current research into vegetarian diets in adolescent athletes is limited, and further investigations are needed to set specific nutritional guidelines for protein intake.

2.7.2 Gender-specific recommendations

Currently, there is a growing body of female-specific research on the effects of menstrual cycle. This research is acknowledging sex differences both physiological and endocrinological between male and female athletes that influence their nutritional requirements for the optimisation of performance and training adaptations (Holtzman & Ackerman, 2021; Sims et al., 2023). Existing evidence was primarily based on male athletes or a combination of male and female athletes (Areta et al., 2014; Clayton et al., 2015; Egan et al., 2016; Iguchi & Kuzuhara, 2020; Martin & Tomescu, 2017; Stellingwerff et al., 2007; Tinline-Goodfellow et al., 2020). Historically, study findings from male-focused research were often applied to female athletes when establishing sports and nutrition guidelines (Sims et al., 2023). However, research has demonstrated that female athletes oxidise less CHO (exogenous and endogenous CHO) proportionally and have a greater reliance on fat oxidation than male athletes (Sims et al., 2023). Clinical research on sex-based differences in protein metabolism is limited, although studies have suggest protein catabolism is increased during the luteal phase while at rest or after aerobic endurance exercise (Burd et al., 2009; Phillips et al., 1993;

Tarnopolsky et al., 1990). Recently, Sims et al. (2023) in an ISSN position statement, established evidence-based guidelines for the female athlete, including athletes using hormonal contraceptives, and reported that female athletes may experience reduced glycogen storage during the follicular phase of the menstrual cycle, reduced gastrointestinal tolerance to CHO during exercise related to menstrual cycle effects, sleep disturbances and decreased sleep quality which may lead to poor recovery (Sims et al., 2023). Subsequent revisions of current sports nutrition guidelines from other professional sport nutrition bodies may consider including new evidence for optimal dietary intake for female rowers to support their performance, training adaptations and health.

Table 2.1: Adult sports nutrition guidelines

Nutrient	American College of Sports Medicine (ACSM) (2016)	International Society of Sports Nutrition (ISSN) (2017; 2018)	International Olympic Committee (IOC) (2012)	Burke, Deakin, & Minehan (2021)	Kim and Kim (2020)
Energy	*Overall* • Estimate energy requirements based on individual needs with consideration to training volume and intensity, periodised training load and competition.	*Overall* • General fitness program (30-40 min/d, 3x week) 1,800-2,400 $kcal \cdot d^{-1}$ (or 25-35 $kcal \cdot kg^{-1} \cdot d^{-1}$) for a 50-80 kg individual. • Moderate (2-3 h/d, 5-6 d/week) to high volume (3-6 h/d, 5-6 d/w) intensity training program - 2,000-7,000 $kcal \cdot d^{-1}$ (or 40-70 $kcal \cdot kg^{-1} \cdot d^{-1}$) for a 50-100 kg individual. • Energy needs may be significantly higher for large athletes (100-150 kg) and elite athletes during heavy training or competition.	*Overall* • Scale energy intake to account for changes in training load and competition, while considering additional needs for growth.	*Overall* • The best predictor of individual estimated energy requirements for athletes is the Cunningham equation, and in situations where minimal information is available, the Harris-Benedict equation can be used.	*Overall* • The average energy intake of rowers is 2,600-4,900 $kcal \cdot d^{-1}$, up to 7,000 $kcal \cdot d^{-1}$ depending on training.
CHO	*Overall* • Low intensity 3.0-5.0 $g \cdot kg^{-1}$.	*Overall* • Moderate intense exercise (2-3 h/d, 5-6 d/w) 5.0-8.0 $g \cdot kg^{-1}$.	*Overall* • Light 3.0-5.0 $g \cdot kg^{-1}$. • Moderate (1 h/d) 5.0-7.0 $g \cdot kg^{-1}$.	*Overall* • Low intensity 3.0-5.0 $g \cdot kg^{-1}$.	*Overall* • Low intensity or skills based 3.0-5.0 $g \cdot kg^{-1}$.

Nutrient	American College of Sports Medicine (ACSM) (2016)	International Society of Sports Nutrition (ISSN) (2017; 2018)	International Olympic Committee (IOC) (2012)	Burke, Deakin, & Minehan (2021)	Kim and Kim (2020)
	• Moderate training program (1 h/d) 5.0-7.0 $g{\cdot}kg^{-1}$. • Endurance program (1-3 h/d) 6.0-10.0 $g{\cdot}kg^{-1}$. • Extreme training program (4-5 h/d) 8.0-12.0 $g{\cdot}kg^{-1}$. *CHO loading* • CHO load 36-48h of 10-12 $g{\cdot}kg^{-1}{\cdot}d^{-1}$ for sustained or intermittent exercise lasting >90 mins. *Pre-exercise* • 7.0-12.0 $g{\cdot}kg^{-1}{\cdot}d^{-1}$ for events lasting <90mins. • Ingest 1.0-4.0 $g{\cdot}kg^{-1}$ 1-4h prior to exercise >60 mins.	• High volume intense training (3-6 h/d, 5-6 d/w) 8.0-10.0 $g{\cdot}kg^{-1}$. *Pre-exercise* • CHO-rich meal consumed 4-6 h prior to exercise. • Co-ingest (e.g. 50 g CHO and 5.0-10.0 g protein) 30-60 min prior to exercise. *During exercise* • 0.7 $g{\cdot}kg^{-1}{\cdot}h^{-1}$ in a 6-8% solution >60mins. *Post-exercise (immediately-post to 2 h post-exercise)* • Co-ingest CHO (e.g. 1.0 $g{\cdot}kg^{-1}{\cdot}d^{-1}$) and protein (e.g. 0.5 $g{\cdot}kg^{-1}{\cdot}d^{-1}$) within 30 mins of exercise. • High-CHO meal within 2 h post-exercise if rapid recovery is needed and habitual CHO intake is adequate (<6.0 $g{\cdot}kg^{-1}{\cdot}d^{-1}$).	• High (1-3 h/d moderate-high intensity) 6.0-10.0 $g{\cdot}kg^{-1}$. • Very high (4-5 h/d moderate-high intensity) 8.0-12.0 $g{\cdot}kg^{-1}$. *CHO loading* • CHO load 24-48h of 9.0-12.0 $g{\cdot}kg^{-1}{\cdot}d^{-1}$ for events lasting longer than 90 mins. *Pre-exercise* • Pre-event meal >1.0 $g{\cdot}kg^{-1}$ 1-6 h before exercise lasting ~60 mins. • Pre-event meal 1.0-4.0 $g{\cdot}kg^{-1}$ 1-6 h before exercise lasting >60 mins.	• Moderate training program (1 h/d) 5.0-7.0 $g{\cdot}kg^{-1}$. • Endurance program (1-3 h/d) 6.0-10.0 $g{\cdot}kg^{-1}$. • Extreme training program (4-5 h/d) 8.0-12.0 $g{\cdot}kg^{-1}$. *Pre-exercise* • 200-300 g 2-4 h prior to exercise. • 75 g 30-60 min prior to exercise. *During exercise* • 30-60$g.h^{-1}$ or 0.7 $g{\cdot}kg^{-1}{\cdot}h^{-1}$ (<2h). • 30-90 $g{\cdot}h^{-1}$ according to intensity (>2.5h).	• 1-3 h/d of moderate-high intensity 6.0-10.0 $g{\cdot}kg^{-1}$. • 4-5 h moderate-high intensity 8.0-12.0 $g{\cdot}kg^{-1}$. *Pre-exercise* • If CHO at meals in insufficient, consume easily digestible CHO 30-60mins before training or competition. *During exercise* • In general, sports drinks or gels, or low fat, low protein, low fibre energy bars. • CHO (sports drink or maltodextrin) mouth rinsing can be performed every 10-15 mins in high intensity training lasting <60mins.

Nutrient	American College of Sports Medicine (ACSM) (2016)	International Society of Sports Nutrition (ISSN) (2017; 2018)	International Olympic Committee (IOC) (2012)	Burke, Deakin, & Minehan (2021)	Kim and Kim (2020)
	During exercise • No CHO needed (<45 mins). • Small amounts of liquid CHO or mouth rinse (45-75 mins). • 30-60 $g \cdot h^{-1}$ spread across exercise period (1-2.5h). • <90 $g \cdot h^{-1}$ spread across exercise period (>2.5-3 h). *Rapid recovery (<8h between exercise sessions)* • ~1.0-1.2 $g \cdot kg^{-1} \cdot h^{-1}$ at frequent intervals, immediately post-exercise where glycogen storage is highest in the first 2 h.	• At least 1.2 $g \cdot kg^{-1} \cdot h^{-1}$ in the first 4 h or absolute delivery of >8.0 $g \cdot kg^{-1} \cdot d^{-1}$.	*During exercise* • No CHO needed (<45 mins). • Small amounts of liquid CHO or mouth rinse (45-75 mins). • 30-60 $g \cdot h^{-1}$ spread across exercise period (1-2.5h). • <90 $g \cdot h^{-1}$ spread across exercise period (>2.5-3h). *Rapid recovery (<8h between exercise sessions)* • ~1.0-1.2 $g \cdot kg^{-1} \cdot h^{-1}$ at frequent intervals, immediately post-exercise where glycogen storage is highest in the first 2h.	*Rapid recovery (<8h between exercise sessions)* • ~1.0-1.2 $g \cdot kg^{-1} \cdot h^{-1}$ at frequent intervals, immediately post-exercise where glycogen storage is highest in the first 2h. • Co-ingestion of ~0.3 $g \cdot kg^{-1}$ of protein facilitates maximum rates of muscle glycogen restoration. *Post-exercise recovery (when rapid recovery is not needed)* • 7.0-10.0 $g \cdot kg^{-1} \cdot d^{-1}$ will normalise glycogen stores within 24h.	*Post-exercise recovery* • 1.2 $g \cdot kg^{-1}$ in liquid or solid form and high glycaemic index CHO Immediately after training or competition as a meal or snack.

Nutrient	American College of Sports Medicine (ACSM) (2016)	International Society of Sports Nutrition (ISSN) (2017; 2018)	International Olympic Committee (IOC) (2012)	Burke, Deakin, & Minehan (2021)	Kim and Kim (2020)
Protein	*Overall* • 1.2-2.0 g·kg^{-1} • At least 2.0 g·kg^{-1} during calorie restriction. • Include protein in post-exercise meal. *Periodisation* • 0.25-0.3 g·kg^{-1} (15-25 g) every 3-5 h. • Higher doses (>40 g) for large athletes. • Optimal benefits observed with ingestion immediately-post to 2 h post-exercise.	*Overall* • Moderate exercise 60-300 g·d^{-1} (or 1.2-2.0 g·kg^{-1}) for a 50-150 kg individual. • High volume intense training 85-330 g·d^{-1} (or 1.7-2.2 g·kg^{-1}) for a 50-150 kg individual. • 1.4-2.0 g·kg^{-1} is sufficient for most exercising individuals. *Periodisation* • 0.25-0.55 g·kg^{-1} (or absolute dose of 20-40 g) at each eating session delivered every 3-4h.	*Overall* • 1.2-1.6 g·kg^{-1}·d^{-1} *Periodisation* • 20-25 g protein at each eating session.	*Overall* • 1.2- 2.0 g·kg^{-1}·d-1 *Periodisation* • 20-30 g (~0.3-0.4 g·kg-1) every 3 hours over 24-hr period. • ~0.5-0.6 g·kg^{-1} pre-bedtime protein.	*Periodisation* • 0.3-0.4 g·kg^{-1} (20-25 g to 40 g) every 3-5 h. • Choose whey protein. • 40 g casein protein 30 min before sleep to promote recovery.
Total fat	*Overall* • 20-35%E	*Overall* • Moderate amounts of dietary fat ~30%E.	*No recommendations provided.*	*No recommendations provided.* • Explores the emerging evidence for the application of LCHF diets in athletes.	*No recommendations provided.*

Guidelines sourced from the American College of Sports Medicine (ACSM), International Society of Sports Nutrition (ISSN), International Olympic Committee (IOC) and Burke, Deakin, & Minehan (2021) Clinical Sports Nutrition (6th ed.) and rowing-specific guidelines based on meta-analysis of evidence (Kim & Kim, 2020).
$kcal \cdot d^{-1}$ kilocalories per day
$g \cdot kg^{-1}$ grams per kilogram bodyweight
$g.kg^{-1}.h^{-1}$ grams per kilogram bodyweight per hour
$g \cdot kg^{-1} \cdot d^{-1}$ grams per kilogram bodyweight per day
$g \cdot d^{-1}$ grams per day
$g \cdot h^{-1}$ grams per hour
CHO Carbohydrate
LCHF low CHO high fat
%E macronutrient contribution to total energy intake

2.8 Adolescent nutritional guidelines for growth, development and sports performance

Sports Dietitians Australia (SDA) defines an adolescent athlete as "an individual aged 12-18 years who demonstrates gifts/talents in the physical, physiological and movement domains which may indicate future potential in high-performance sport" (Desbrow et al., 2014). Dietary intakes of adolescent athletes must meet their unique nutritional demands for daily training, competition, growth and development (Desbrow et al., 2014). Furthermore, nutritional education and recommendations should reinforce eating for long-term health and ideally should be met using a "food first" approach rather than dietary supplements to enhance performance (Burke et al., 2021).

2.8.1 Overview of dietary intakes of adolescents living in New Zealand

In 2008-2009, the Ministry of Health collected information on the habitual dietary intake of adolescents aged 15-18 years as part of the New Zealand Adult Nutrition Survey. Although likely outdated, the survey findings may provide insight into adolescent dietary intake and quality for comparison with New Zealand population nutrition standards for growth and development (Table 2.2), assuming dietary habits have not changed in this population in the last 15 years. Key findings showed the median intake of young males was 307 g (95% CI: 283,332) CHO 107 g (95% CI: 97,117) protein, and 99 g (95% CI: 89,109) total fat, which made up 48%, 16% and 34.9% of total energy intake, respectively (Ministry of Health & University of Otago, 2011). In comparison, the median intake of young females was 231 g (95% CI: 220,242) CHO 67 g (95% CI: 63,71) protein, and 68 g (95% CI: 64,72) total fat, which made up 50.8%, 15.2% and 33.6% of total energy intake, respectively (Ministry of Health & University of Otago, 2011). Based on this previous data, adolescent males and females in New Zealand narrowly met the recommended dietary CHO and protein intake, while consumption of dietary fat was at the higher end of recommendations. Additionally, adolescent males (median 21.1 $g.d^{-1}$) and females (median 15.6 $g.d^{-1}$) were noted to not be meeting the adequate intake (AI) requirements for dietary fibre (males 28 $g.d^{-1}$, females 22 $g.d^{-1}$) while the median SFA intakes for male and female adolescents (14%E) exceeded the recommended 10%E (Ministry of Health & University of Otago, 2011).

2.8.2 Adolescent guidelines for growth and development

The onset of puberty occurs during early adolescence and is defined by biological changes including sexual maturation, increases in height and weight, accumulation of skeletal mass, and changes in body composition (Brown, 2019). The onset and duration of puberty varies among adolescents, and the stage of development directly affects each individual's nutritional requirements (Brown, 2019). The physical growth and development during early adolescence often matches or exceeds the rate of growth experienced during infancy, which significantly increases their energy (of which the primary source is CHO) and protein requirements (Brown, 2019). In addition, adequate dietary fat and essential fatty acids are needed for growth and development, while sufficient dietary fibre is recommended for normal bowel function, and may play a role in preventing obesity and the development of chronic disease (Brown, 2019). However, for some adolescents, the search for personal autonomy and peer acceptance can lead to the development of health-compromising eating behaviours, such as meal skipping or unhealthy weight control behaviours, which may impact dietary intake of CHO, protein and fat (Brown, 2019). During this critical developmental stage, inadequate dietary intake may compromise cognitive function and development, bone remodelling, and delay the onset of puberty and the linear growth spurt (Brown, 2019).

Adolescent protein requirements are influenced by the amount needed to maintain and allow for lean body mass to accrue during the adolescent growth spurt (Brown, 2019). Given that growth is affected by protein intake, those who consume vegetarian diets may be at risk for marginal or low protein intakes (Brown, 2019). In addition, adolescence is a critical time for osteoporosis prevention since almost half of adult peak bone mass is accrued during this time (Brown, 2019). Therefore, adequate energy, protein, vitamins, and minerals are critical to support optimal bone growth and development (Brown, 2019). Furthermore, certain protein foods are rich in iron. Recommendations for iron increase in both male and female adolescent groups during adolescence (Brown, 2019). Developing females have additional iron needs as a result of blood loss with the commencement of menstrual bleeding (Alaunyte et al., 2015).

The New Zealand nutritional guidelines for adolescent growth and development are described in Table 2.2, and address the balance of CHO, protein, and dietary fat in terms of their relative contribution to dietary energy. Established population nutritional standards help evaluate the adequacy of dietary intakes of sedentary adolescents for growth, development, and prevention of chronic disease. However, it is well documented that adolescent athletes involved in endurance and power sports require higher CHO and protein intakes than sedentary populations as a result of their higher energy needs, increased demands on glycogen reserves and increased muscular strength (Burke et al., 2021).

2.8.3 Physiological characteristics of the adolescent athlete

Up to late adolescence, young athletes' physiological, metabolic and hormonal systems are still yet to mature and reach total functional capacity (Burke et al., 2021). Compared with adults, adolescent athletes have altered thermoregulatory response mechanisms and fluid regulation for sweat loss, lower sweat rates with exercise, lower capacity to train at high intensities for prolonged durations, lower tolerance for anaerobic metabolism, less bone mineral deposition, and smaller muscle mass (Burke et al., 2021). In addition, adolescents have a higher risk of injury than adults, particularly for stress fractures and joint injuries (Burke et al., 2021). Despite this, the effects of resistance exercise and high-level sports training on growth, timing of puberty and nutrient requirements still need to be studied (Burke et al., 2021).

2.8.4 Adolescent athlete guidelines for training adaptation and sports performance

The physical demands of high-level sports during adolescence require optimal dietary intake to promote growth, development and performance (Desbrow et al., 2014). Despite this, the body of research for deriving evidence-based nutritional guidelines for highly active children and adolescents is limited. Earlier studies found that the stage of maturation has a significant impact on peak fat oxidation rates during exercise, especially in prepubertal children (Riddell et al., 2008). However, as children progress through puberty, some of the disparities in fat oxidation rates start to decrease (Riddell et al., 2008). Therefore, despite the differences in exercise response between adults and adolescents, the basic principles of the current adult sports nutrition guidelines are also applied to adolescent athletes (Burke et al., 2021).

As previously highlighted in preceding sections, consuming pre-, during and recovery CHO from high-intensity and endurance training positively affects sports performance. However, previous research indicates potential differences between adolescents and adults in CHO storage and substrate utilisation (Taylor et al., 1997; Timmons et al., 2003). Earlier studies had reported reduced enzyme levels in anaerobic activity in adolescents compared with adults, suggesting the capacity for training adaption was still developing (Eriksson et al., 1973; Eriksson & Saltin, 1974). However, these findings have not been reproduced in subsequent studies (Haralambie, 1982). Studies have demonstrated that during exercise, the oxidation of exogenous CHO is higher in children than in adults (Timmons et al., 2003), with children tending to rely more on aerobic metabolism during high-intensity exercise (Taylor et al., 1997). Researchers have widely debated these study findings, due to the enzyme activity not being adjusted for free fat mass, which is variable during adolescence (Brandou et al., 2006). Therefore, until further evidence can conclude that glycolytic metabolism is age-dependent (Petersen et al., 1999), experts in the field recommend that deviation from adult CHO fuelling guidelines is not warranted (Burke et al., 2021). Since CHO utilisation patterns and refuelling requirements depend on training duration and intensity, CHO intake should be considered in regards to the individuals training and competition load (Desbrow et al., 2014). However, the total load may differ from adults with variations noted in competition formats, training commitments, and the potential for adolescent athletes to participate in several different sports (Burke et al., 2021). The type of dietary CHO is also important. Recent studies on adolescent diet quality have identified habitual overconsumption of sugar-sweetened beverages and energy drinks in adolescent athletes, which may have significant repercussions for performance and long-term health (Baleeiro et al., 2021; Burke et al., 2021; Nowak & Jasionowski, 2016).

Adolescents athletes have additional protein requirements to support growth, development and performance (Aerenhouts et al., 2011), which may be even higher in adolescent athletes with suboptimal energy intakes (Burke et al., 2021). Since the existing research into the optimal pattern for dietary protein intake for MPS stimulation was conducted in adults but not adolescents (Moore et al., 2015; Moore et al., 2009), it is still being determined whether adolescents have a similar anabolic response to protein intake and exercise. Any similarity is inferred based on comparable physiological functions (Burke et al., 2021). Some adolescent athletes may have slightly higher protein requirements than the population reference standards, particularly if they have higher LBM, are above reference weight for age, or are involved in high-intensity training (Aerenhouts et al., 2011; Aerenhouts et al., 2013; Boisseau et al., 2007; Mazzulla et al., 2018). Studies have reported values of 1.35-1.6 $g.kg^{-1}.d^{-1}$ which is significantly higher than the recommended dietary intake (RDI) for adolescent males (0.99 $g.kg^{-1}.d^{-1}$) and adolescent females (0.77 $g.kg^{-1}.d^{-1}$) (Burke et al., 2021). Many adolescent male athletes believe protein supplements are necessary to maximise strength training adaptations (Bloodworth et al., 2012). Previous studies report 74-85% of elite rowers use CHO dietary supplements and 65-74% use supplementary amino acids to maximise their physiological adaptations and rowing performance (Baranauskas et al., 2014; Domínguez et al., 2020). However, most adolescent athletes who meet their energy requirements are likely to meet their protein requirements and should not need protein supplements to reach adequate protein intake (Aerenhouts et al., 2011; Gibson et al., 2004; Heaney et al., 2010; Petrie et al., 2004).

Adolescent athletes need adequate fat intake to meet requirements for fat-soluble vitamins and hormone production and to help provide energy to support growth and development (Petrie et al., 2004). Although there is emerging evidence for nutritional strategies to promote intramuscular triacylglycerols to improve performance in adult athletes, the impact of these strategies is yet to be studied in adolescent athletes (Burke et al., 2021). Chronically high fat intakes are associated with a positive energy balance and a higher risk of overweight and obesity (National Health and Medical Research Council et al., 2006). Hence, the dietary fat recommendations for the general population of 20-35%E for total fat, and 10%E for saturated and trans-fats, are also applicable to adolescent athletes to reduce their risk chronic disease (Australian National Health and Medical Research Council & NZ Ministry of Health, 2014).

While there is emerging evidence suggesting that MUFAs and PUFAs may contribute to the recovery from sports-related concussions (Lust et al., 2020) and post-exercise inflammation (Lewis et al., 2020), studies on fatty acid supplementation report inconclusive evidence regarding any significant benefit to physical performance during exercise (D'Angelo & Madonna, 2020; Da Boit et al., 2017; Lewis et al., 2020). Presently, there are no definitive recommendations for minimum requirements of MUFAs and PUFAs for adolescent athletes. Despite this, adolescent athletes should aim to replace foods containing high levels of saturated and trans-fats with foods that are rich in MUFAs and PUFAs to maintain functional health and prevent chronic disease (Li et al., 2015).

Table 2.2: Adolescent population health and sports nutrition guidelines

Nutrient	Nutrient Reference Values for Australia and New Zealand (2006)	Sports Dietitians Australia (SDA) (2014; 2023a)	Desbrow (2021; 2019)	Burke, Deakin, & Minehan (2021)
Energy	*Overall* • As energy requirements vary with age, gender, body size and activity, recommendations are needed for each age and gender group. • NZ recommendations for energy are based on predictive estimates of resting energy expenditure (Schofield equation) multiplied by a physical activity factor.	*Overall* • Estimates for energy are based on predictive estimates of resting energy expenditure (Schofield equation) multiplied by an activity factor. • However, the equation is based on the weight and height within the 10–17-year age category and does not allow for further differentiation by pubertal maturation.	*Overall* • Previous estimates of energy expenditure in adolescent athletes. • Males 3,640 ± 830 $kcal \cdot d^{-1}$. • Females 3,100 ± 720 $kcal \cdot d^{-1}$.	*Overall* • The use of standard adult predictive equations often underestimate resting metabolic rate in adolescents. • Suggested energy requirements for adolescent populations with different levels of habitual physical activity have been published by Torun (2005).
CHO	*Overall* • 45-65%E	*Overall* • Low intensity 3.0-5.0 $g \cdot kg^{-1}$. • Moderate training program (1 hr/d) 5.0-7.0 $g \cdot kg^{-1}$. • Endurance program (1-3 hr/d) 6.0-10.0 $g \cdot kg^{-1}$.	*Overall* • CHO intake should be considered in light of training loads and competition characteristics. *During exercise* • Small amounts of CHO or mouth rinse (<1 h).	*Overall* • Although children use more CHO as an energy substrate than adults, there are no definitive CHO recommendations available for adolescents involved in high-level sport training.

Nutrient	Nutrient Reference Values for Australia and New Zealand (2006)	Sports Dietitians Australia (SDA) (2014; 2023a)	Desbrow (2021; 2019)	Burke, Deakin, & Minehan (2021)
		• Extreme training program (4-5 hr/d) 8.0-12.0 $g{\cdot}kg^{-1}$. *During exercise* • Small amounts or not required (0-75 mins). • 30-60 $g.h^{-1}$ (75mins-2.5 h).	• ~0.6 $g.kg^{-1}.h^{-1}$ (~30 g) for prolonged exercise (>90 mins).	• CHO intake should be considered in light of training loads and competition characteristics and suggests following ACSM guidelines for CHO intake.
Protein	*Overall* • 15-25%E *Boys 14-18y* • EAR 49 $g.d^{-1}$ (0.76 $g{\cdot}kg^{-1}$) • RDI 65 $g.d^{-1}$ (0.99 $g{\cdot}kg^{-1}$) *Girls 14-18y* • EAR 35 $g.d^{-1}$ (0.62 $g{\cdot}kg^{-1}$) • RDI 45 $g.d^{-1}$ (0.77 $g{\cdot}kg^{-1}$)	*Overall* • 1.3-1.8 $g{\cdot}kg^{-1}$ *Periodisation* • Evidence to support distribution of protein intake throughout the day in smaller amounts (~20 g).	*Overall* • 0.11 $g{\cdot}kg^{-1}{\cdot}h^{-1}$ during post-exercise recovery or equivalent of ~1.5 $g{\cdot}kg^{-1}{\cdot}d^{-1}$. *Periodisation* • ~0.3 $g{\cdot}kg^{-1}$ x 5 mealtimes.	*Overall* • 1.2-1.6 $g{\cdot}kg^{-1}$
Total fat	*Overall* • 20-35%E	*Overall* • 20-35%E	*Overall* • 20-35%E	*Overall* • >30%E
Dietary fibre	*Boys 14-18y* • AI 28 $g{\cdot}d^{-1}$ *Girls 14-18y* • AI 22 $g{\cdot}d^{-1}$	*No recommendations provided.*	*No recommendations provided.*	*No recommendations provided.*
Refined sugars	*Overall* • <10%E (World Health Organisation, 2015).	*No recommendations provided.*	*No recommendations provided.*	*No recommendations provided.*

Nutrient	Nutrient Reference Values for Australia and New Zealand (2006)	Sports Dietitians Australia (SDA) (2014; 2023a)	Desbrow (2021; 2019)	Burke, Deakin, & Minehan (2021)
Saturated and trans-fat	Overall • <8-10%E	Overall • <10%E	*No recommendations provided.*	Overall • <10%E

Guidelines sourced from Nutrient Reference Values for Australia and New Zealand (2006), Sports Dietitians Australia (SDA) (2014; 2023a), Desbrow (2021; 2019), and Burke, Deakin, & Minehan (2021) Clinical Sports Nutrition (6th ed.).

$kcal \cdot d^{-1}$ kilocalories per day

$g \cdot kg^{-1}$ grams per kilogram bodyweight

$g.kg^{-1}.h^{-1}$ grams per kilogram bodyweight per hour

$g \cdot kg^{-1} \cdot d^{-1}$ grams per kilogram bodyweight per day

$g \cdot d^{-1}$ grams per day

CHO Carbohydrate

%E macronutrient contribution to total energy intake

ACSM American College of Sports Medicine

2.9 The current understanding of the dietary intake of adolescent rowers

Research studies into the usual dietary intake of adolescent rowers are limited (Table 2.3). The majority of the available studies investigate collegiate or elite-level rowers and tend to focus on energy intake with regard to energy availability and performance (Hill & Davies, 2002). Therefore, the composition of the diet, specifically, CHO, protein and fat intake is not often investigated. More evidence is needed to understand and adjust adolescent dietary intake to meet the nutritional requirements to support the development of these individuals into healthy elite athletes (Sabato et al., 2016).

A total of 15 studies have investigated the dietary intake of rowers, two of which focus solely on adolescent rowers (Bond et al., 2012; Hanley, 2014). The research by Hanley (2014) on adolescent rowers (14-18 years) demonstrated that dietary fat intake was adequate. However, no rowers met 100% of their energy needs based on their rowing energy expenditure, and only 53% consumed more than the minimum 5.0 $g \cdot kg^{-1}$ CHO intake. In addition, 73% of rowers met 100% of their protein requirements (1.2 $g \cdot kg^{-1}$) by consuming an average of 116 g of protein per day (1.36 $g \cdot kg^{-1}$) without the assistance of protein supplements. These findings align with evidence that a "food first" approach to nutrition can be used to achieve adequate protein intakes of rowers (Baranauskas et al., 2014). A limitation of the study is that the measured physical activity levels were solely focused on the duration and intensity of rowing training. It is not uncommon for adolescents to be involved in multiple sporting activities (Desbrow et al., 2014), which would increase their daily energy and CHO requirements. Therefore, it is plausible that prior research may have underestimated energy needs, resulting in an underestimation of the CHO intake needed to support performance and training.

A study investigating nitrate supplementation in male adolescent rowers (16.7 ± 0.5 years) in New Zealand (Bond et al., 2012) described dietary intake for population characteristics with no additional analysis. From this descriptive data, rowers were reportedly consuming adequate CHO (5.8 g·kg^{-1}) and protein (2.1 g·kg^{-1}). Their intakes did appear to be greater than adolescent sports nutrition guidelines of 5.0 g·kg^{-1} and 1.2 g·kg^{-1} for CHO and protein respectively (Desbrow et al., 2014). However, during testing, the rowers were asked to avoid foods high in nitrates, which is likely to have influenced their usual dietary intake. In addition, supplements were included in the dietary analysis; therefore, it is unknown if the rowers would have been able to reach dietary requirements without supplementation. Observational studies by Baranauskas et al. (2014); Bond et al. (2012) and Hanley (2014) used 24-hour food recall for their food intake analysis. A methodological limitation is that a single 24-hour food recall only provides a "snapshot" of dietary intake and does not consider the daily variation in their usual dietary intake. Administering multiple 24-hour food recalls over multiple days is likely more representative of habitual dietary intake (Basiotis et al., 1987) and would have provided more comprehensive dietary intake data for analysis. Additionally, the studies used small sample sizes (n=14-21) and recruited few females (n=0-3). Therefore, the findings may only be representative of male rowers and hence, generalising the findings to the adolescent rowing population is challenging.

A study by Baranauskas et al. (2014) on elite rowers (18.2 ± 2.3 years) examined the adequacy of the “food first” approach. Similar to previously discussed research (Hanley, 2014), Baranauskas et al. (2014) reported that, regardless of gender, the dietary intake of the Lithuanian Olympic rowers did not meet their nutritional requirements for energy and CHO intake (4.6 g·kg^{-1}). However, elite rowers did consume adequate amounts of protein (1.4-1.6 g·kg^{-1}). Timing of protein intake was not examined; therefore, it is difficult to determine if protein intake was optimal for MPS stimulation (Moore et al., 2015). Dietary fibre was found to be below current dietary recommendations, while fat intake exceeded recommended norms (20-35%E). Within this cohort of elite athletes, 73.9% consumed supplements regularly. Therefore, the authors suggested that with reported dietary intakes being below the current recommendations for elite rowers, there may be a role for supplementation in meeting high energy and nutrient needs to support performance and training adaptations in elite sports.

Braakhuis et al. (2013) conducted the first study investigating relationships between dietary intake (primarily micronutrients and antioxidants), exercise-induced oxidative stress and performance on 62 (males n=28, 20 ± 3 years; females n=34, 22 ± 1 year(s)) New Zealand elite rowers. Regardless of gender, rowers struggled to meet sufficient energy and CHO intakes (5.3-6.1 $g \cdot kg^{-1}$) even when including supplements. Unlike previous studies, a seven day weighed food diary and the Goldberg equation were used to increase the ability to accurately capture usual dietary intake during the dietary assessment and exclude potentially under-reported dietary intakes (n=3), respectively. In addition, the large sample size and inclusion of male and female rowers support the applicability of the study results to the population of elite rowers. However, the results still demonstrate that rowers fail to meet sports nutrition recommendations which is consistent with previous evidence of the dietary intake of endurance athletes (Jenner et al., 2019; Masson & Lamarche, 2016).

The most extensive female-only rowers (n=104, 16-23 years) study by Miyamoto et al. (2021) assessed dietary intake using emerging image-based technology validated in the adolescent athlete population (Costello et al., 2017), which shows similar measurement errors in estimating energy intake and macronutrients to traditional methods such as 24-hour food recalls and weighed food records (Ho et al., 2020). Compared to current sports nutrition guidelines, the study reported that 61 rowers consumed CHO above 5.0 $g \cdot kg^{-1}$ and 35 rowers above 6.0 $g \cdot kg^{-1}$. In addition, 103 rowers consumed protein above 1.0 $g \cdot kg^{-1}$, 73 consumed above 1.5 $g \cdot kg^{-1}$, and 24 consumed above 2.0 $g \cdot kg^{-1}$. However, it is noted that more research is required to validate image-based dietary assessment tools in athlete populations (Capling et al., 2017). An additional limitation of the study is that the dietary intakes of adolescent and young adult rowers were analysed together. Since adolescents oxidise more exogenous CHO for energy (Timmons et al., 2003) and may have higher CHO needs than adult rowers, adolescent and adult rowers should be examined independently.

A longitudinal study on lightweight rowers (males n=12, 23.5 ± 3.5 years; females n=6, 23.1 ± 4.5 years) demonstrated significant gender differences in dietary intake while in an energy deficit to achieve race weight (Morris & Payne, 1996). Acute weight loss techniques (Steen & Brownell, 1990) have been shown to have detrimental effects on rowing performance (Burge et al., 1993). However, Morris and Payne (1996) reported that rowers did not admit to using aggressive weight reduction strategies during the study. Female lightweight rowers were less readily able to meet current sports nutrition guidelines for CHO and protein than male rowers, suggesting that the seasonal body weight reduction in female lightweight rowers may compromise adequate dietary intake to support optimal sports performance (Morris & Payne, 1996). In addition, male and female lightweight rowers failed to meet the minimum requirement for dietary fat intake (Morris & Payne, 1996). However, the impact on rower performance is unknown and was not reported. A strength of the study was the collection of a four day food record, which would increase the likelihood that the study findings reflect the usual intake of the rowers and effectively show the seasonal change in dietary intake related to weight loss throughout the study period.

An early study on female rowers (n=16, 21 ± 1.1 years) assessed dietary intake with a five day food record which was reviewed by a nutritionist (Steen et al., 1995). The study demonstrated that most (63%) rowers consumed less than 5.0 $g \cdot kg^{-1}$ CHO, and 63% consumed more than the recommended 35%E of dietary fat (Steen et al., 1995). The advantages of using a food record are an accurate estimation of usual intake and a reduction of inaccuracies in reporting. A minimum of three days of food records is sufficient to estimate usual intake in small groups (n=13) (Basiotis et al., 1987). However, it only partially negates the possibility of systematic under-reporting of dietary intake (Basiotis et al., 1987). A strength of the study was that it recorded some timing of pre-exercise dietary intake. These results suggest that a pre-event meal (335 kcal) was consumed by 63% of rowers two hours before racing, derived of 66% CHO (0.8 $g.kg^{-1}$), 12% protein, and 22% fat (Steen et al., 1995). The reported reasons for not consuming a pre-race meal were due to lack of time, and prioritisation of extra sleep or concerns about potential gastrointestinal distress (Steen et al., 1995).

Most previous research on dietary intakes in rowers typically took the form of cross-sectional or longitudinal study designs and used conventional food records or emerging image-based technology, that required expert review and oversight by a nutritionist or dietitian (Table 2.3). Existing evidence has established that, regardless of age, gender or rowing level, rowers often fail to meet minimum recommendations for CHO intake. Male rowers are more readily able to meet nutritional guidelines than female rowers, especially for protein intake. Lightweight rowers may consume dietary intakes far below recommendations (Morris & Payne, 1996). However, the School Sport New Zealand (NZSSSC) has since banned weight-restricted rowing in secondary school competitions in New Zealand (School Sport New Zealand, 2016), which better protects adolescents from participating in unsafe weight-loss and restrictive dietary practices that may jeopardise adolescent growth and maturation.

While significant research has been conducted on the daily intake of CHO, protein and fat in adolescent rowers, different fibre and fat types, have been disproportionality overlooked. Additionally, there is a lack of meaningful exploration into nutritional timing in relation to training and exercise. Bridging this research gap will yield a comprehensive understanding of the dietary requirements of adolescent rowers, encompassing the nuanced contributions of fibre and fat types to performance, recovery, and functional health. This insight is crucial for establishing healthy eating patterns within this demographic that align with population health guidelines for growth and development.

Table 2.3: Summary of the current literature of dietary intake in rowers

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
Baranauskas et al. (2014)	Lithuanian Olympic team, n=21 male n=3 female, age 18.2 ± 2.3 years total rowing experience 7.1 ± 4.1 years training per day 175.3 ± 45.9min	Descriptive cross-sectional study during pre-season competition.	Single day 24-hr food recall by trained interviewer using standardised measures.	***Males*** **Energy** ^Ø^ 16,536.0 ± 3,956.8 kJ·d^{-1} **CHO†** 405.3 g·d^{-1} **CHO.BW** 4.6 ± 1.3 g·kg^{-1} **CHO %E** 40.9 ± 10.6% **Protein†** 141.0 g·d^{-1} **Protein.BW** 1.6 ± 0.4 g·kg^{-1} **Protein %E†** 14.3% **Fat.BW** 2.3 ± 0.8g·kg^{-1} **Fat %E** 45.1 ± 10.2% ***Females*** **Energy** ^Ø^ 12,550.3 ± 2,533.8 kJ·d^{-1} **CHO†** 328.4 g·d^{-1} **CHO.BW** 4.6 ± 0.8 g·kg^{-1} **CHO %E** 44.1 ± 5.7% **Protein†** 100 g·d^{-1} **Protein.BW** 1.4 ± 0.2 g·kg^{-1} **Protein %E†** 13.3% **Fat %E** 42.3 ± 7.3%	The frequency of dietary supplement use was recorded but not included in the chemical composition analysis.
Bond et al. (2012)	New Zealand junior team, n=14 male age 16.7 ± 0.5 years training per day ~4h	Double-blind cross-over study to assess effect of nitrate supplementation on performance.	A completed food diary recorded over a single 24-hr period. Participants were asked to avoid foods high in nitrates during testing period which	***Males*** **Energy** 15,400 ± 5,400 kJ·d^{-1} **CHO** 485.5 ± 200 g·d^{-1} **CHO.BW†** 5.8 g·kg^{-1} **CHO %E†** 53% **Protein** 177.6 ± 70 g·d^{-1} **Protein.BW†** 2.1 g·kg^{-1} **Protein %E†** 19%	Dietary supplementation intake was included in chemical composition analysis and reported results.

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
			may have impacted habitual intake.	**Fat** not stated	
Braakhuis et al. (2013)	New Zealand elite rowers n=62 n=28 male age 20 ± 3 years total rowing experience 4.4 ± 2.3 years training hours per week 17 ± 5h n=34 female age 22 ± 1 years total rowing experience 5.4 ± 2.5 years training hours per week 16 ± 3h	Descriptive cross-sectional study.	7-day weighed food diary using food scales with instructions on how to complete food diary and antioxidant FFQ. Food diaries were reviewed for completeness and subjects excluded if food diaries for all seven days were not completed.	***Males*** **Energy** 15,600 ± 5,400 $kJ \cdot d^{-1}$ **CHO** 510 ± 190 $g \cdot d^{-1}$ **CHO.BW†** 6.1 $g \cdot kg^{-1}$ **CHO %E†** 55% **Protein** 170 ± 70 $g \cdot d^{-1}$ **Protein.BW†** 2.0 $g \cdot kg^{-1}$ **Protein %E†** 18% **Fat** 110 ± 45 $g \cdot d^{-1}$ **Fat.BW†** 1.3 $g \cdot kg^{-1}$ **Fat %E†** 27% ***Females*** **Energy** 10,800 ± 3,800 $kJ \cdot d^{-1}$ **CHO** 370 ± 160 $g \cdot d^{-1}$ **CHO.BW†** 5.3 $g \cdot kg^{-1}$ **CHO %E†** 57% **Protein** 104 ± 44 $g \cdot d^{-1}$ **Protein.BW†** 1.5 $g \cdot kg^{-1}$ **Protein %E†** 16% **Fat** 91 ± 44 $g \cdot d^{-1}$ **Fat.BW†** 1.3 $g \cdot kg^{-1}$ **Fat %E†** 32%	Dietary supplementation intake was included in chemical composition analysis and reported results.
De Wijn et al. (1979)	Dutch Olympic rowing team n=8 male	Descriptive cross-sectional study.	7-day food diary using household measures.	***Males*** **CHO** 467 $g \cdot d^{-1}$ **CHO.BW** 5.4 $g \cdot kg^{-1}$ **CHO %E** 43% **Protein** 139 $g \cdot d^{-1}$	Unknown if dietary supplements were included in the chemical composition

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
				Protein.BW 1.6 g·kg^{-1} **Protein %E** 13% **Fat** 192 g·d^{-1} **Fat %E** 43%	analysis and reported results.
Durkalec-Michalski and Jeszka (2015)	Polish elite rowers n=16 male age 19.5 ± 1.4 years total rowing experience 8.2 ± 2.8 years training hours per week 16.8 ± 5.9 hours	Randomised placebo controlled double-blind cross-over study for evaluation of β-hydroxy-β-methyl butyrate supplementation.	Not stated.	***Males*** **Energy** ^{ø} 234.7 ± 59.4 kJ·kg^{-1}·d^{-1} **CHO†** 550 g·d^{-1} **CHO.BW** 6.3 ± 1.4 g·kg^{-1}·d^{-1} **CHO %E†** 45% **Protein†** 139 g·d^{-1} **Protein.BW** 1.6 ± 0.6 g·kg^{-1}·d^{-1} **Protein %E†** 11% **Fat†** 148 g·d^{-1} **Fat.BW** 1.7 ± 0.4 g·kg^{-1}·d^{-1} **Fat %E†** 27%	Dietary supplementation intake was included in chemical composition analysis and reported results.
Hanley (2014)	U.S. adolescent rowers, n= 15 male age range 14-18 years who had completed at least one rowing season.	Descriptive cross-sectional study during in-season competition.	Single 24-hr food recall conducted via phone interview by researcher. Recorded dietary intake uploaded to National Cancer Institute online 24-hr food recall program.	***Males*** **Energy** ^{ø} 12,167.1 kJ·d^{-1} **CHO** 354 g·d^{-1} **CHO.BW** 4.9g·kg^{-1} **CHO %E†** 49% **Protein** 116 g·d^{-1} **Protein.BW** 1.36 g·kg^{-1} **Protein %E†** 16% **Fat** 105 g·d^{-1} **Fat %E** 32%	Unknown if dietary supplements were included in the chemical composition analysis and reported results.
Hassapidou (2001)	Greek national team, n=16 male	Descriptive cross-sectional study during the	Consecutive 7-day weighed food diary analysed by dietitians using	***Males*** **Energy** ^{ø} 17,618.8 ± 949.8 kJ·d^{-1} **CHO** 587 ± 15 g·d^{-1} **CHO.BW** 6.7 ± 0.2 g·kg^{-1}	Unknown if dietary supplements were included in the chemical

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
	age 23 ± 3 years	competitive season.	McCance and Widdowson's food composition tables (U.K.).	**CHO %E** 55 ± 5% **Protein** 188 ± 19 g·d^{-1} **Protein.BW** 2.2 ± 0.2 g·kg^{-1} **Protein %E** 19 ± 3% **Fat** 124 ± 22 g·d^{-1} **Fat.BW** 1.4 ± 0.2 g·kg^{-1} **Fat %E** 26 ± 4%	composition analysis and reported results.
Heinemann and Zerbes (1989)	German national-level rowers n=3 male age range 18-23 years	Cross-sectional study of elite athletes during pre-season training and the general population.	3-day food diary using household measures to weekdays and 1 weekend day, and an interviewer-administered FFQ.	***Males*** **CHO** 770 g·d^{-1} **CHO.BW** 8.8 g·kg^{-1} **CHO %E** 52% **Protein** 205 g·d^{-1} **Protein.BW** 2.3 g·kg^{-1} **Protein %E** 13% **Fat** 238 g·d^{-1} **Fat %E** 35%	Unknown if dietary supplements were included in the chemical composition analysis and reported results.
Iguchi and Kuzuhara (2020)	Japanese collegiate rowers n=15 male age 20.1 ± 1.0 years total rowing experience 3.0 ± 1.4 years	Prospective longitudinal study of pre-season, competitive season and off-season dietary intakes.	7-day food diary. Meals were cooked according to a menu prepared by a registered dietitian. Dietary records were also analysed by a registered dietitian.	***Males*** **Energy** ^{Ø} 14,412.2 ± 1,541.8 kJ·d^{-1} **CHO†** 562.4 g·d^{-1} **CHO.BW** 7.8 ± 1.7 g·kg^{-1} **CHO %E†** 65% **Protein†** 122.6 g·d^{-1} **Protein.BW** 1.7 ± 0.3 g·kg^{-1} **Protein %E*** 14% **Fat†** 64.9 g·d^{-1} **Fat.BW** 0.9 ± 0.2 g·kg^{-1} **Fat %E†** 17%	Unknown if dietary supplements were included in the chemical composition analysis and reported results.
Miyamoto et al. (2021)	Japanese elite national rowing team	Descriptive cross-sectional study.	Photos of meal and snacks for 3 days (1 non-training day and	***Females*** **Energy** ^{Ø} 11,152.0 ± 199.2 kJ·d^{-1} **CHO** 349 ± 7.4 g·d^{-1}	Unknown if dietary supplements were included in the

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
	n=104 female age 16-23 years		2 training days) during 1 week and sent to the team dietitian.	**CHO.BW** 5.5 g·kg^{-1} **CHO %E†** 52% **Protein** 109.2 ± 2.3 g·d^{-1} **Protein.BW** 1.7 g·kg^{-1} **Protein %E†** 16% **Fat** not stated **Fibre** 16.5 ± 0.5 g·d^{-1}	chemical composition analysis and reported results.
Morris and Payne (1996)	Australian lightweight rowers n=18 n=12 male age 23.5 ± 3.5 years n=6 female age 23.1 ± 4.5 years	Descriptive cross-sectional study.	4-day food record (3 mid-week days + 1 weekend day) and analysed using the NUTTAB program.	***Males*** **Energy** 9795 kJ·d^{-1} **CHO** 415 g·d^{-1} **CHO.BW** 5.5 g·kg^{-1} **CHO %E** 67% **Protein** 100 g·d^{-1} **Protein.BW** 1.3 g·kg^{-1} **Protein %E** 18% **Fat** 33 g·d^{-1} **Fat.BW** 0.44 g·kg^{-1} **Fat %E** 14% ***Females*** **Energy** 4972 kJ·d^{-1} **CHO** 214 g·d^{-1} **CHO.BW** 3.5 g·kg^{-1} **CHO %E** 68% **Protein** 37 g·d^{-1} **Protein.BW** 0.6 g·kg^{-1} **Protein %E** 15% **Fat** 32 g·d^{-1} **Fat.BW** 0.53 g·kg^{-1} **Fat %E** 15%	Unknown if dietary supplements were included in the chemical composition analysis and reported results.

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
Short and Short (1983)	U.S. collegiate rowers, n=27 male n=24 female	Descriptive cross-sectional study.	3-day food diary using household measures	***Males*** **CHO** 456 g·d^{-1} **CHO.BW** 5.4 g·kg^{-1} **CHO %E** 44% **Protein** 183 g·d^{-1} **Protein.BW** 2.2 g·kg^{-1} **Protein %E** 17% **Fat** 168 g·d^{-1} **Fat %E** 37% ***Females*** **CHO** 272 g·d^{-1} **CHO.BW** 4.0 g·kg^{-1} **CHO %E** 46% **Protein** 96 g·d^{-1} **Protein.BW** 1.8 g·kg^{-1} **Protein %E** 16% **Fat** 96 g·d^{-1} **Fat %E** 36%	Unknown if dietary supplements were included in the chemical composition analysis and reported results.
Steen et al. (1995)	U.S. collegiate heavyweight rowers, n=16 female age 21.0 ± 1.1 years total rowing experience 3.2 ± 1.2 years training hours per week: 12h	Descriptive cross-sectional study.	5-day food record using household measures (3 week days + 2 weekend days) using standard measures and reviewed by a nutritionist.	***Females*** **Energy** ^{Ø} 11,016.5 ± 1,878.6 kJ·d^{-1} **CHO** 337 ± 68 g·d^{-1} **CHO.BW** 4.9 g·kg^{-1} **CHO %E** 51% **Protein** 88 ± 15 g·d^{-1} **Protein.BW** 1.3 g·kg^{-1} **Protein %E** 13% **Fat** 104 ± 25 g·d^{-1} **Fat %E** 36%	Unknown if dietary supplements were included in the chemical composition analysis and reported results.

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
	on-water + 2h weight training				
Van Erp-Baart et al. (1989)	Dutch international-level rowers n=18 male age 22 ± 2 years n=8 female age 23 ± 2 years	Descriptive cross-sectional study.	2 x 4- to 7-day food diary using household measures in which 2 weekdays and 1 weekend day is included. Food diaries were reviewed by a dietitian.	***Males*** **Energy** ^{ø} 189 kJ·kg^{-1} **CHO** 472 g·d^{-1} **CHO.BW** 6.1 g·kg^{-1} **CHO %E** 52% **Protein** 118 g·d^{-1} **Protein.BW** 1.5 g·kg^{-1} **Protein %E** 13% **Fat** 138 g·d^{-1} **Fat %E** 35% ***Females*** **Energy** ^{ø} 186 kJ·kg^{-1} **CHO** 374 g·d^{-1} **CHO.BW** 5.4 g·kg^{-1} **CHO %E** 46% **Protein** 114 g·d^{-1} **Protein.BW** 1.6 g·kg^{-1} **Protein %E** 14% **Fat** 140 g·d^{-1} **Fat %E** 40%	Dietary supplementation intake was included in chemical composition analysis and reported results.
Zorn (2017)	U.S. collegiate rowers n=17 male age 19.8 ± 1.2 years n=6 varsity level	Descriptive cross-sectional study.	VioScreen Graphical Food Frequency System (an algorithm driven computer delivered FFQ) using Nutrition Coordinating Centre	***Males*** *VioScreen Tool* **Energy** ^{ø} 11,987.2 ± 6,179.8 kJ·d^{-1} **CHO** 345 ± 153 g·d^{-1} **CHO.BW** 4.3 ± 1.9 g·kg^{-1} **CHO %E†** 48% **Protein** 132 ± 76 g·d^{-1}	Unknown if dietary supplements were included in the chemical composition analysis and reported results.

References	Rower demographics	Study design	Dietary assessment method	Dietary intake	Comments
	n=11 novice level		Food and Nutrient Database) and 3 x automated self-administered 24-hour (ASA24) dietary assessment tool developed by the National Cancer Institute, Bethesda, MD.	**Protein.BW** 1.6 ± 1.0 $g·kg^{-1}$ **Protein %E†** 18% **Fat** 109 ± 67 $g·d^{-1}$ **Fat.BW** 1.3 ± 0.8 $g·kg^{-1}$ **Fat %E†** 34% *ASA24 Tool* **Energy** Ø 12,091 ± 3,401.6 $kJ·d^{-1}$ **CHO** 332 ± 88 $g·d^{-1}$ **CHO.BW** 4.1 ± 1.1 $g·kg^{-1}$ **CHO %E†** 46% **Protein** 132 ± 58 $g·d^{-1}$ **Protein.BW** 1.6 ± 0.7 $g·kg^{-1}$ **Protein %E†** 18% **Fat** 113 ± 37 $g·d^{-1}$ **Fat.BW** 1.4 ± 0.5 $g·kg^{-1}$ **Fat %E†** 35%	

$kJ·d^{-1}$ kilojoules per day
$g·d^{-1}$ grams per day
$g·kg^{-1}$ grams per kilogram bodyweight
† Calculated $g.day^{-1}$ & $g.BW\ kg^{-1}$
Ø Multiplied by a factor of 4.184 to convert kilocalories to kilojoules (kJ)
ASA24 Automated Self-Administered 24-hour Dietary Assessment
BW bodyweight
NUTTAB Nutrient Tables for Use in Australia (renamed to the Australian Food Composition Database)
FFQ Food Frequency Questionnaire
%E macronutrient contribution to total energy intake

2.10 Summary

Competitive rowing is a physically demanding strength-endurance sport where commitment to high-volume training often begins in adolescence. The increased energy demands placed on adolescent rowers requires an adjustment to their dietary intake to adequately fuel the type of training, intensity, and duration. However, various factors such as specific weight criteria, high training loads, eating during competition, and individual preferences, can influence food intake and dietary patterns.

Decades of research have led to the establishment of sports nutrition guidelines aimed at supporting glycolysis, maximising glycogen storage, stimulating MPS and overall health (Burke et al., 2021). Best practice is to use the nutritional guidelines to determine optimal dietary intake based on the individual athlete and training schedule. Despite physiological differences between adults and adolescents during exercise, limited studies have led to the application of the basic principles from adult sports nutrition guidelines to adolescent athletes. For moderate training, adolescent sports nutrition guidelines recommend daily intake of 5.0-7.0 $g \cdot kg^{-1}$ CHO, 1.3-1.8 $g \cdot kg^{-1}$ protein and 20-35% of total energy derived from fat per day (Sports Dietitians Australia, 2023a). High-intensity exercise greater than 60 minutes necessitates specific nutrient timing, including 1.0–4.0 $g \cdot kg^{-1}$ CHO 1–4 hour before, 30–60 $g \cdot h^{-1}$ CHO during exercise, and 1.0–1.2 $g \cdot kg^{-1} \cdot h^{-1}$ CHO and 0.3-0.4 $g.kg^{-1}$ protein as soon as possible after exercise (Burke et al., 2021).

Nutrition population surveys conducted in New Zealand reveal that adolescents narrowly meet CHO and protein recommendations for growth and development (Ministry of Health & University of Otago, 2011). Should suboptimal nutrition persist among the adolescent rowing population, it could have detrimental effects on their rowing performance and training adaptations, as well as impede growth, development, and maturation. Despite these concerns, there is a notable gap in the evidence regarding the dietary intake of adolescent rowers. Existing research on dietary intake in rowers typically focuses on collegiate or elite-level rowers, with a particular emphasis on aspects such as energy intake, energy availability and their impact on rowing performance. Previous findings indicate a commonality across rowers, irrespective of age, gender or skill level, in which they often fail to meet minimum recommendations for CHO intake. Further insights into gender-specific patterns indicate male rowers are more readily able to meet nutritional guidelines than female rowers, especially for protein intake. This highlights the need for further research into the adolescent rowing population and customised nutritional education to ensure optimal rowing performance, growth and development.

Existing research on adolescent rowers primarily focuses on daily CHO, protein and fat intake, often overlooking specific fat types (SFA, trans-fat, MUFA, PUFA), refined sugar, dietary fibre, and nutritional timing in relation to training and exercise. Highlighting the need for comprehensive insights into these nutritional categories. Addressing this research is pivotal for a thorough understanding of the dietary needs of adolescent rowers, considering the nuanced contributions these nutritional categories may have on performance, recovery, and functional health. Future research should also consider larger-scale studies involving both male and female adolescent rowers utilising robust dietary assessment methodologies to obtain more comprehensive data on their usual food intake and dietary patterns (e.g., vegetarian diets). Given that previous research suggests adolescent male athletes may perceive protein supplements as necessary for strength training adaptations (Bloodworth et al., 2012), tracking protein supplement use in adolescent rowers could provide valuable insights into their ability to meet recommendations using a “food first” approach, as encouraged by adolescent sports nutrition guidelines. Analysing nutritional timing may help guide dietary intake around training and competition, as pre-exercise nutrition has the potential to enhance performance and promote recovery in athletes who have yet to achieve their daily CHO and protein requirements (Arent et al., 2020).

Chapter 3 : Research study manuscript

3.1 Abstract

Introduction: Dietary intake plays a key role in rowing performance (Cornford & Metcalfe, 2019). During moderate training, adolescent athletes should aim for 5.0-7.0 $g.kg^{-1}$ of carbohydrates (CHO), 1.3-1.8 $g.kg^{-1}$ of protein, and 20-35% energy from fat (Desbrow et al., 2014). This study aimed to examine the dietary intake of adolescent rowers in New Zealand and compare it with nutritional guidelines for normal growth, development, and sports performance.

Method: A cross-sectional study design involved data collection of dietary intake on two 'hard' training days and two 'recovery' days from rowers aged 14-21 years in New Zealand. Dietary analysis was performed using Foodworks, and IBM SPSS software was used for statistical analysis.

Results: Of the initial 40 participants, 35 fully (females n=23, 16.8 ± 1.9 years; males n=12, 17.3 ± 1.6 years) completed the study. Participants consumed 319 ± 116 g (4.5 ± 1.7 $g.kg^{-1}.day^{-1}$) of CHO, 121 ± 56 g (1.7 ± 0.7$g.kg^{-1}.day^{-1}$) of protein and 113 ± 46 g of fat per day (1.6 ± 0.6 $g.kg^{-1}.day^{-1}$), equivalent to 35 ± 7.2%E. Minimum CHO levels of 5.0 $g.kg^{-1}$ per day were only achieved by seven females (30.4%) and four (33.3%) males. Females consumed significantly less protein per day, 106 ± 38 g (1.6 ± 0.6 $g.kg^{-1}.day^{-1}$), in comparison to males who consumed 164 ± 46 g (2.0 ± 0.5 $g.kg^{-1}.day^{-1}$) per day ($p= 0.04$). The analysis of nutritional timing, demonstrated that pre-exercise 0.9 ± 0.7 $g.kg^{-1}$ CHO and 0.27 ± 0.3 $g.kg^{-1}$ protein were ingested, a CHO intake rate of 2.4 ± 7.9 $g.h^{-1}$ occurred during exercise, and intake post-exercise consisted of 0.58 ± 0.7 $g.kg^{-1}$ CHO and 0.06 ± 0.1 $g.kg^{-1}$ protein.

Conclusion: The findings suggest that two out of three adolescent rowers in New Zealand fail to reach the minimum recommendations for CHO intake, and male rowers more readily meet the recommended protein intake than female rowers. Adolescent rowers failed to achieve appropriate timing of CHO and protein pre-, during, and post-training. Nutrition education should consider emphasising adequate CHO and protein intakes that meet sports nutrition guidelines and the appropriate timing of CHO and protein for maximum muscle glycogen repletion and stimulation of muscle protein synthesis (MPS).

3.2 Introduction

Rowing is among New Zealand's most successful Olympic sports (New Zealand Olympic Committee, 2023). Given its popularity, commitment to high-intensity training and competition often begins during adolescence (Rowing NZ, 2021). Increased dietary intake is therefore required to support the increased physical demands of heavy training loads and fuel the 6-8 minutes of near-maximal effort over the 2000-metre race course (Kim & Kim, 2020). However, rowing presents several nutritional considerations and barriers to dietary intake, such as early morning training, exercise-induced appetite suppression, busy schedules, and adoption of popular dietary patterns (Burke, 2007; Howe et al., 2016), that may lead to missed feeding opportunities and suboptimal dietary intake that could adversely impact rowing performance (Cornford & Metcalfe, 2019).

Previous research suggests that adolescents living in New Zealand need to improve their dietary intake to meet their nutritional requirements (Ministry of Health & University of Otago, 2011). Adolescent athletes, including rowers, require increased energy, CHO, and protein intake compared to their sedentary counterparts. These nutritional needs are essential for not only meeting the demands of training and competition, as highlighted by Desbrow et al. (2014), but also for supporting the concurrent processes of growth, development, and maturation (Brown, 2019). Therefore, the evaluation of adolescent dietary intake is crucial in identifying areas of suboptimal dietary intake during this critical growth and development stage.

Despite potential differences in exercise metabolism in adults (Timmons et al., 2003), there have been few controlled studies on dietary manipulation and exercise in adolescent athletes. Current adult sports nutrition guidelines have been inferred to establish adolescent guidelines due to the suggested comparable physiology (Burke et al., 2021). In addition, there are limited rowing-specific guidelines, therefore best practice is to use the sports nutritional recommendations to guide athlete dietary intake based on individual training intensity, duration, and athlete goals. Current adolescent sports guidelines for moderate training recommend daily intakes of 5.0-7.0 $g.kg^{-1}$ CHO, 1.3-1.8 $g.kg^{-1}$ protein and 20-35% contribution of dietary fat to total energy (Desbrow et al., 2014). Recent evidence has also suggested that the timing of dietary intake around training is important for maximum training adaptations and performance (Kerksick et al., 2017). Current timing recommendations suggest consuming 1.0-4.0 $g.kg^{-1}$ CHO pre-exercise, 30-60 $g.h^{-1}$ CHO during exercise >60 min, and 1.0-1.2 $g.kg^{-1}$ CHO and 0.3-0.4 $g.kg^{-1}$ protein as soon as possible post-exercise (Burke et al., 2021).

An examination of the literature found only one previous observational study exclusively investigating the dietary intake of adolescent rowers using a single-day, 24-hour dietary recall (Hanley, 2014). The study reported that rowers consumed 4.9 $g.kg^{-1}$ CHO and 1.36 $g.kg^{-1}$ protein per day, and dietary fat contributed 32% of total energy (%E) (Hanley, 2014). Surprisingly, only 53% of adolescent rowers consumed the recommended ≥5.0 $g.kg^{-1}$ CHO (Hanley, 2014). Moreover, while the rowers more readily met the minimum protein and dietary fat recommendations, several rowers failed to meet the minimum daily intake for all macronutrients (Hanley, 2014).

Suboptimal nutrition within the adolescent rowing population may negatively affect growth, development, maturation, performance, professional athlete development, and career longevity. However, the identified shortfalls in dietary intake can be bridged by high-quality targeted nutritional education. Therefore, the primary aim of this study is to explore the macronutrient intake of New Zealand rowers aged 14-21 years. A secondary aim is to determine if dietary CHO, protein and fat intakes align with current nutritional recommendations for adolescent athletes.

3.3 Methodology

3.3.1 Study design

This cross-sectional study had four separate points of data collection, including dietary intakes and training information reported on two hard training days and two recovery training days.

A-priori power analysis was conducted using G*power version 3.1.9.7 (Faul et al., 2007) to determine the minimum sample size required to test the study hypothesis. With a significance criterion of 0.05 and power of 0.95, the minimum sample size needed with an effect size of 0.25 was n=36 for dependent t-tests.

3.3.2 Participants

In 2022, the study recruited 40 rowers aged 14-21 years throughout New Zealand who had completed at least one rowing season. Participants were recruited through the lead researcher's contacts and approached online and by email through rowing clubs and schools nationwide. After the dissemination of the study information (see Appendices), rowers interested in participating could contact the research officer and research lead via email to express their interest. Once they confirmed that they had reviewed the information sheet, had all of their inquiries addressed, and were still willing to participate, a consent form was sent out for signing. An initial session was then scheduled upon the return of the signed consent form.

3.3.3 Ethics

The Massey University Human Ethics Committee (application ID: SOA 21/70) approved the study. Participants were assigned an identification number under which the reported data was stored to ensure individuals were not identifiable in the reported data or presentations. All participants provided written informed consent and parental consent was gained for rowers under the age of 16 years.

3.3.4 Data collection

Baseline data collection Participants completed an in-person (Auckland-based participants) or online video call (participants outside of Auckland) with the project's research officer. During this session, each participant completed an online survey regarding participant demographics, years of rowing, competitive level achieved, primary training boat, and medical and injury history in the last 12 months. For participants located within Auckland, body composition data was then obtained using Bioelectrical Impedance analysis (BIA) conducted at Massey University's Albany campus. Participants residing outside of Auckland, where a BIA was unavailable, provided details on their weight and height. The calendar dates for the four dietary intake and training records were determined for each participant by the research officer based on their scheduled training cycle.

Dietary assessment Following completion of baseline data collection, instructions on collecting a food record were provided. During the 24-hour data collection, participants completed a visual food record on their assigned data collection day. Participants sent photos of their food and drink intake throughout the 24-hours. Each of the 24-hour food diaries were verified upon completion via a phone call by the research officer within 48 hours of completion. The verified food records were analysed using Foodworks software (Xyris Pty Ltd, 2019). Dietary intake was analysed for overall diet composition, including energy and macronutrients (CHO, protein, and fat).

Training records Participants provided nutrition and training data on the days when the 24-hour dietary intake was provided. For each 24-hour collection period, written details of training start time, duration, intensity (hard or recovery), and rating of perceived exertion were collected from the participants.

3.3.5 Statistical analysis

Foodworks data was exported and cleaned in a Microsoft Excel (Version 16.66.1). Five participants were excluded due to incomplete body composition data required for statistical analysis. A single-day outlier was also removed due to the individual completing a 12-hour run. The cleaned data was imported into IBM SPSS Statistics (Version 29) and tested for normality. The mean statistics and standard deviations were used to compute the average participant demographic information. Additionally, each participant's body mass index (BMI) was determined by utilising participant weight and height, and the resulting BMI values were averaged to determine the overall mean for the group. Averaging the four-day dietary data, the mean and standard deviation of the macronutrient grams (g), grams per kg of bodyweight ($g.kg^{-1}$), and % contribution to energy (%E) were calculated for each macronutrient. Dietary supplements were included in the Foodworks data entry. Single t-tests were used to compare the dietary CHO, protein and fat intake (grams per bodyweight) with the upper and lower limits of the nutritional recommendations guidelines for adolescent athletes. Macronutrient timing was evaluated based on 0-4 hours pre-exercise, during exercise ≥60 minutes, and post-exercise 0-1 hour and tested against current timing recommendations using single t-tests. Independent t-tests were performed to assess gender differences in macronutrient intakes. Paired t-tests were performed to determine differences in dietary intake of hard and recovery days. Dietary intakes were transformed and coded to determine the frequency (%) of rowers that met the sports nutrition guidelines.

3.4 Results

Following the removal of outliers and incomplete data, the demographic characteristics of the remaining 35 participants are outlined in Table 3.1.

Table 3.1 Participant demographic information

Variable	Female n=23	Male n=12
Age (years)†	16.9 ± 2.0	17.3 ± 1.7
Bodyweight (kg)†	67.7 ± 7.9	81.2 ± 8.7
Height (cm)†	173.8 ± 5.4	186.4 ± 4.9
BMI (kg/m^2)†	22.4 ± 2.1	23.3 ± 1.9
Training (hr/day)†	1.8 ± 1.3	1.9 ± 1.4

†Mean±SD

Table 3.2 presents the daily CHO, protein, and fat intake of the adolescent rowers' in this study and comparison with current nutritional recommendations. Mean CHO intake was significantly lower than the recommended 5.0-7.0 g·kg^{-1} for moderate training. Only 31.4% of rowers consumed adequate daily intakes of more than 5.0 g·kg^{-1} CHO.

The mean dietary intake of CHO per kilogram of bodyweight per day of male rowers was not different than the lower limit for CHO recommendations (Table 3.2). In contrast, the mean CHO intake of female rowers was significantly lower than the minimum CHO recommendations. There was no significant difference between males and females CHO intake per kilogram of bodyweight per day ($p=0.165$). Minimum CHO levels of 5.0 g·kg^{-1} per day were only achieved by seven (30.4%) females and four (33.3%) males.

Rowers achieved adequate dietary intakes of protein per day, with no significant difference reported between protein intakes and current protein recommendations. Fourteen females (60.9%) and ten males (83.3%) consumed more than the minimum requirement of 1.3 $g \cdot kg^{-1}$ of protein per day. However, female rowers consumed significantly less protein per day, in comparison to males ($p= 0.04$).

Mean dietary fat intake was not significantly different from the upper limit of fat nutrition intake recommendations. Thirteen (57.1%) female rowers and seven (58.3%) male rowers dietary fat intake fell within the recommended 20-35%E per day. In contrast, 15 rowers (n=10 females, n=5 males) consumed more dietary fat than the upper limit recommended for fat intake. No rowers consumed dietary fat below minimum recommendations.

Table 3.2 Total participant dietary intake compared with adolescent sports nutrition guidelines					
Nutrient	g	g·kg^{-1}	%E	Recommended range	% athletes that met minimum recommendation
Total n=35 Energy 11865 ± 4296 kJ					
CHO†	316 ± 123	4.4 ± 1.8*^	44 ± 8.1	5.0-7.0 g.kg^{-1}	31.4
Protein†	119 ± 58	1.6 ± 0.7*	17 ± 4.7	1.3-1.8 g.kg^{-1}	68.6
Fat†	113 ± 47	1.6 ± 0.7	35 ± 7.2*	20-35% E	57.1$^{\delta}$
Females n=23 Energy 10589 ± 2590 kJ					
CHO†	290 ± 80	4.3 ± 1.3*^	46 ± 7.7	5.0-7.0 g.kg^{-1}	30.4
Protein†	106 ± 38	1.6 ± 0.6*^$^{\phi}$	16 ± 4.5	1.3-1.8 g.kg^{-1}	60.9
Fat†	99 ± 32	1.5 ± 0.5	34 ± 7.5*	20-35% E	57.1$^{\delta}$
Males n=12 Energy 15193 ± 2463 kJ					
CHO†	400 ± 77	5.0 ± 1.4^	44 ± 6.9	5.0-7.0 g.kg^{-1}	33.3
Protein†	164 ± 46	2.0 ± 0.5*$^{\phi}$	18 ± 4.2	1.3-1.8 g.kg^{-1}	83.3
Fat†	144 ± 41	1.8 ± 0.6	35 ± 6.7*	20-35% E	58.3$^{\delta}$
†Mean±SD $^{\phi}$ Male vs female P=0.04 $^{\delta}$ % within population health range * Recorded intake was significantly different to lower end of the recommended range <0.001 ^ Recorded intake was significantly different upper end of the recommended range <0.001					

The mean CHO intake on hard training days was 338 ± 116 g per day compared with 301 ± 114 g per day on recovery days. There was no significant difference between the dietary intake of CHO, protein, or fat between hard and recovery training days in the whole group analysis (Table 3.3).

Table 3.3 Dietary intake according to self-perceived training load on hard and recovery days						
	Hard			Recovery		
Nutrient	g	g·kg^{-1}	%E	g	g·kg^{-1}	%E
CHO†	338 ± 116	4.7 ± 1.6	45 ± 7.0	301 ± 114	4.3 ± 1.7	44 ± 8.7
Protein†	127 ± 61	1.7 ± 0.8	17 ± 4.1	115 ± 49	1.6 ± 0.6	17 ± 5.1
Fat†	116 ± 44	1.6 ± 0.63	34 ± 7.0	110 ± 48	1.5 ± 0.6	35 ± 7.3
†Mean±SD						

An analysis of the whole group identified pre-exercise (0-4 hours) dietary intake to include 0.9 ± 0.7 g·kg^{-1} CHO and 0.27 ± 0.3 g·kg^{-1} protein. In contrast, post-exercise dietary intake included 0.58 ± 0.7 g·kg^{-1} CHO and 0.06 ± 0.1 g·kg^{-1} protein. During prolonged exercise greater than 60 minutes, a rate of 2.4 ± 7.9 g.h^{-1} CHO was achieved (Table 3.4). The amount of CHO intake within the recommended timeframe pre-exercise, during, and post-exercise was lower than current recommendations. In contrast, pre-exercise protein intake was not significantly different from current recommendations with regards to amount and timing. However, post-exercise protein intake within one hour of exercise was significantly lower than the recommended level.

Table 3.4 Distribution of CHO and protein intake pre- (0-4 h), during (≥60min), and post- (0-1 h) training compared to recommended nutrient timing guidelines			
	Recommended range	Mean±SD	% feeding occasions achieved lower limit of recommendation
Pre-exercise CHO (g.kg^{-1})	1.0-4.0	0.9 ± 0.7*	34.6
During exercise CHO (g.h^{-1})	30-60	2.4 ± 7.9*	3.7
Post-exercise CHO (g.kg^{-1})	1.0-1.2	0.58 ± 0.6*	19.9
Pre-exercise protein (g.kg^{-1})	0.3-0.4	0.27 ± 0.3	29.4
Post-exercise protein (g.kg^{-1})	0.3-0.4	0.06 ± 0.1*	0.7
*Recorded intake was significantly different to lower end of the recommended range <0.05			

For the whole group, SFA was higher than current nutritional recommendations, and dietary fibre intake was higher than the recommended AI levels for male and female rowers (Table 3.5).

Table 3.5 Descriptive statistics of other dietary categories of adolescent rowers' dietary intake

	$g.d^{-1}$	%E	Recommendation
Sugar†	127 ± 63	18 ± 8.9	Refined sugar <10%E
Dietary fibre†	Female 33 ± 9* Male 38 ± 11*	NA	Female 14-18y AI=22g.d^{-1} Male 14-18y AI=28g.d^{-1}
Saturated and trans-fat†	45 ± 21	14 ± 4.0*	<10%E
MUFA†	39 ± 19	NA	NA
PUFA†	15 ± 8	NA	NA

†Mean±SD
*Recorded intake was significantly different to the recommended target <0.001
NA Not available
Sugar intake recommendation from World Health Organisation (2015)
Saturated and trans-fat intake recommendation from National Health and Medical Research Council et al. (2006)

3.5 Discussion

3.5.1 Summary of key findings

The present study provides the first comprehensive assessment of the dietary intake of adolescent rowers across four separate data collection points, including hard and recovery days and macronutrient timing pre-, during, and post-exercise. The main finding of this study indicates that two out of three adolescent rowers do not meet the minimum recommendation for CHO intake daily. In addition, while 68.6% of adolescent rowers met the daily minimum recommendations for protein intake (1.3-1.8 $g.kg^{-1}$), analysis of protein timing pre- and post-training suggests adolescent rowers may not be consuming protein in smaller doses at regular intervals throughout the day to achieve optimal MPS stimulation to maximise training adaptations. This study has also demonstrated that adolescent rowers consume dietary fat in the higher range of recommendations, with only 57.1% of adolescent rowers consuming dietary fat within the recommended range (20-35%E) and no rowers consuming dietary fat below the minimum recommendation.

3.5.2 Carbohydrate intake

Adolescent rowers are recommended to consume 5.0-7.0 $g.kg^{-1}$ CHO daily for moderate training (Desbrow et al., 2014). However, the findings from this study (4.4 ± 1.8 $g.kg^{-1}$ CHO) support evidence from previous observational studies that adolescent and collegiate rowers tend to have inadequate CHO intakes of 3.5-4.9 $g.kg^{-1}$, thus below the minimum recommendation of 5.0 $g.kg^{-1}$ CHO per day (Baranauskas et al., 2014; Hanley, 2014; Morris & Payne, 1996; Short & Short, 1983; Steen et al., 1995; Zorn, 2017). The results of the present study demonstrate that the dietary CHO intake of 24 (68.6%) of the participating adolescent rowers do not align with the minimum CHO intake recommendations required to support growth, development and rowing performance. Previous research has demonstrated similar results with 41-63% of female rowers and ~47% of male rowers failing to meet the recommended daily CHO intake (Hanley, 2014; Miyamoto et al., 2021; Steen et al., 1995). Of note, there are some studies that report CHO intakes of 5.3-8.8 $g.kg^{-1}$, which align with current recommendations (Braakhuis et al., 2013; De Wijn et al., 1979; Durkalec-Michalski & Jeszka, 2015; Hassapidou, 2001; Heinemann & Zerbes, 1989; Miyamoto et al., 2021; Morris & Payne, 1996; Short & Short, 1983; Van Erp-Baart et al., 1989). However, these studies primarily focus on elite rowers at the national or international level of competition. The disparity between the CHO intake of elite, collegiate and adolescent rowers may be explained by potential under-reporting during dietary assessment. Despite our participants being trained in how to complete food record keeping and a research assistant verifying food records, under reporting may still have occurred (Capling et al., 2017; Ferraris et al., 2019). Accurate dietary assessment in athletes can be challenging due to the increased burden of recording large food intakes and frequent eating occasions, irregular meal patterns and use of sports foods and dietary supplements (Capling et al., 2017). Although our study utilised food records, the “gold standard” method, dietary intake was self-reported by the rowers and as such may result in under-reporting in athletes due to inaccurate athlete recording, possible changes in usual food intake during the assessment period and the incorrect coding of data (Capling et al., 2017). Conversely, another possible explanation is that our results indicate significant discrepancies in education and support on dietary intake for adolescent and collegiate rowers. Elite rowers are more likely to have access to high-quality nutritional education and support (e.g., sport dietitians) which may significantly improve nutrition knowledge and therefore encourage informed decision-making around dietary intake and food choices that supports athlete health and sports performance (Garner et al., 2012). Interestingly, a study reported that collegiate rowers who lived in a dormitory and consumed meals cooked according to a menu prepared by a registered dietitian were able to achieve a high CHO intake of 7.8 $g.kg^{-1}$ (65%E) (Iguchi & Kuzuhara, 2020). Therefore, based on previous research, inadequate nutritional education may factor into suboptimal CHO intake and other dietary intake inadequacies noted in young athlete cohorts (Hanley, 2014). Research has suggested that dietitian-led interventions are more likely to support dietary CHO intakes that align with current sports nutrition recommendations, and may be a consideration for this age group of athletes (Iguchi & Kuzuhara, 2020). An alternative option was presented by another study which reported that constructive feedback on dietary intake may result in improved dietary intake of young athletes (Anderson, 2010). However, it is worth noting that the most effective approach to nutritional data collection, athlete reporting and education is yet to be determined (Boidin et al., 2021).

3.5.3 Carbohydrate intake in relation to training intensity and duration

Our study found no significant differences between the intake of CHO on recovery and hard training days. This result indicates that the adolescent rowers in our study did not appear to upregulate their dietary intake according to their training intensity and duration needs, as current sports nutrition guidelines recommend. Similar results of athletes failing to upregulate CHO intake with increasing training loads have been observed in studies on adolescent athletes involved in swimming, football and figure skating (Briggs et al., 2015; Kabasakalis et al., 2007; Ziegler et al., 2002). Given the limited research in this area, the upregulation of CHO intake has yet to be demonstrated in day-to-day fluctuations of training load in rowers during in-season competition. However, it has been demonstrated that the upregulation of CHO intake (off-season 6.8 ± 1.7 $g.kg^{-1}$; pre-season 7.0 ± 1.1 $g.kg^{-1}$; in-season

7.8 ± 1.7 $g.kg^{-1}$) during the lead up to the competition season with increases in high-intensity training results in the peak rowing performance that aligns with the start of the competition season (time trial: off-season 7.04 minutes; pre-season 7.01 minutes; in-season 6.55 minutes) (Iguchi & Kuzuhara, 2020). This outcome is likely due to higher muscle glycogen storage with increased CHO intake and subsequent increase in mean power output (Simonsen et al., 1991). It is suggested that CHO is the primary source of energy substrate for rowers, therefore the possible implication of not upregulating CHO intake is that rowers are less likely to meet the increasing energy demands as training loads increase, resulting in suboptimal training adaptation and not reaching their peak rowing performance potential in time for competition. As such, adolescent rowers may benefit from nutritional education on upregulating CHO intake as training intensity and duration increase on hard training days.

3.5.4 Sugar intake

The mean sugar intake was determined to be 127 ± 63 $g.d^{-1}$ (18%E). However, the Foodworks software could not differentiate between sugar from natural food sources, such as fruit, and processed sources. Currently, there is no guideline for total sugar consumption within sport nutrition or for rowers. Instead, according to population health guidelines, it is recommended that refined sugar contributes to no more than <10%E (National Health and Medical Research Council et al., 2006). Therefore, the contribution of refined sugar intake to adolescent dietary intake within the context of competitive rowing still needs to be assessed.

3.5.5 Dietary fibre intake

Vegetables, fruits, legumes, and wholegrains are recognised as good sources of dietary fibre and previous research has shown dietary fibre intake to be a marker for the consumption of these foods and, as such, an indicator of diet quality (Fayet-Moore et al., 2018). Previous studies on rowers have reported mean fibre intakes (16.5 ± 0.5 g·d^{-1}) below population health recommendations (Miyamoto et al., 2021). Conversely, the present study suggests adolescent male rowers (38 $\pm$ 11 g.d^{-1}) and female rowers (33 $\pm$ 9 g.d^{-1}) are likely to consume adequate levels of dietary fibre for normal bowel function and chronic disease prevention (Brown, 2019). However, since the types of dietary fibre consumed was not analysed, the diversity and contribution of different fibre sources from the different food groups is unknown.

3.5.6 Protein intake

The majority of adolescent rowers met the minimum recommendations for protein intake (68.6%). This result aligns with previous research in in adolescent rowers where 73% achieved the minimum protein recommendations (Hanley, 2014). It was noted that male rowers (83.3%) in this study more readily met the recommended daily protein intake than female rowers (60.9%). Previous studies have also reported similar gender differences in protein intake, where male rowers are often reported to consume higher protein levels than female rowers (Braakhuis et al., 2013; Morris & Payne, 1996; Short & Short, 1983).

3.5.7 Protein intake in male adolescent rowers

In the present study, male rowers tended to consume above the recommendations with a mean intake of 2.0 ± 0.5 g.kg^{-1} protein ingested per day. While large amounts of dietary protein are not harmful to healthy individuals (Antonio et al., 2016), a recent study has reported that chronic overconsumption of protein can lead to adaptive processes that increase amino acid oxidation (Tinline-Goodfellow et al., 2020). Tinline-Goodfellow et al. (2020) suggest that consuming excessive amounts of protein could attenuate the protein synthesis response to smaller doses (<20 g) of protein over time. This reduced responsiveness could result in a lower stimulation response in MPS (Tinline-Goodfellow et al., 2020). The authors propose that athletes who chronically overconsume protein may inadvertently establish a higher protein “requirement” for MPS stimulation (Tinline-Goodfellow et al., 2020). Notably, the higher protein intake observed among the participants did not translate into any additional deposition into muscle protein (Tinline-Goodfellow et al., 2020). Given this perspective, it would be interesting to investigate if protein supplement use by adolescent rowers contributes to excessively high daily protein intake, and potentially displaces dietary intake of energy and CHO.

3.5.8 Protein intake in female adolescent rowers

In the present study, female rowers tended to consume within the recommendations, with a mean intake of 1.6 ± 0.6 $g.kg^{-1}$ protein ingested per day. Despite this, only 60.9% of female rowers achieved the minimum recommendation level of 1.3 $g.kg^{-1}$ protein. This is consistent with previous research that indicated female rowers are capable of achieving minimum protein requirements and can readily consume 1.4-1.8 $g.kg^{-1}$ protein per day (Baranauskas et al., 2014; Braakhuis et al., 2013; Miyamoto et al., 2021; Short & Short, 1983; Van Erp-Baart et al., 1989). However, one study with female lightweight rowers reported a significantly lower protein intake of 0.6 $g.kg^{-1}$ per day (Morris & Payne, 1996). These rowers were following an energy-restricted diet as they were preparing for the upcoming competition season (Morris & Payne, 1996). This suggests that rowers, particularly females, who are following an energy-restricted diet may be at risk of severely under-consuming protein far below the recommended sports nutrition guidelines and may be a factor to consider in both future research and nutrition education.

3.5.9 Total fat intake

Adolescent sports nutrition guidelines recommend dietary fat intake that is in line with population health ranges of 20-35% total energy intake to prevent chronic disease (Desbrow et al., 2014). Our findings show that adolescent rowers, regardless of gender, consume dietary fat in the upper end or above the recommended range and approximately 57.1% of adolescent rowers consumed fat within the population health range. Previous research demonstrates mixed findings in terms of fat intake, regardless of rowing level (14-45.1%E) (Baranauskas et al., 2014; Hassapidou, 2001; Morris & Payne, 1996). However, the majority of studies suggest rowers consume dietary fat at the higher end or above (32-45.1%E) the recommended range for dietary fat (Baranauskas et al., 2014; Braakhuis et al., 2013; De Wijn et al., 1979; Heinemann & Zerbes, 1989; Short & Short, 1983; Steen & Brownell, 1990; Van Erp-Baart et al., 1989; Zorn, 2017). In particular, a previous study on adolescent rowers also reported elevated dietary fat intake of 32%E (Hanley, 2014), a result that is consistent with our population group. Hanley (2014) found 80% of rowers consumed fat above the minimum recommendation of 20%E, however, this does not represent the percentage of rowers that consume fat within the population health range. Conversely, lightweight rowers are often reported to consume dietary fat well below recommendations (14-15%E) (Morris & Payne, 1996). However, the result in lightweight rowers is likely due to the intentional restriction of overall energy intake to reduce weight for competition season. Research on elite rowers from New Zealand, Greece and Poland reported lower dietary fat intakes of 26-27%E (Braakhuis et al., 2013; Durkalec-Michalski & Jeszka, 2015; Hassapidou, 2001). However, these studies do not provide reasoning for the lower fat intake. It could be hypothesised that these elite teams have greater access to high-performance nutritional education and support which resulted in the lower dietary fat intakes. This hypothesis is supported by a study that reported low dietary fat intake (17%E) when dietary intake was designed and overseen by a registered dietitian (Iguchi & Kuzuhara, 2020). Alternatively, the culinary traditions in specific regions like Greece could influence lifestyle preferences towards healthier food options and cooking techniques, and the social practice of sharing home-cooked meals with friends and family. For instance, Greek rowers may be more conscious of incorporating fibre-rich and lean protein foods, which form the foundation of the primarily plant-based Mediterranean diet (Hassapidou, 2001). Since rowing performance depends on exogenous CHO availability and saturation of muscle glycogen stores (Kim & Kim, 2020), monitoring dietary fat intake is important to ensure that a high fat intake does not displace CHO intake. The displacement of CHO intake by elevated fat intake may adversely affect rowing performance (Achten et al., 2004; Sherman et al., 1981) and may also have long-term health implications (National Health and Medical Research Council et al., 2006). Our findings are consistent with previous studies of the dietary fat intake of rowers. However, previous studies suggest nutritionist or dietitian input may help reduce fat intake to within recommended levels so that daily CHO intake is not displaced.

3.5.10 Saturated fat intake

The findings also suggest adolescent rowers consume significantly higher SFA (13.7 ± 4.0%E) levels than current population health recommendations (SFA and trans-fats <10%E) (National Health and Medical Research Council et al., 2006). This is consistent with research by Baranauskas et al. (2014) who reported a SFA intake of 12.9-15.5%E in young (18.2 ± 2.3 years) rowers. Given that high SFA levels are associated with obesity and chronic disease (National Health and Medical Research Council et al., 2006), it may be imperative to provide education tailored to effectively managing total fat and SFA intake, ensuring the long-term health of adolescent rowers.

3.5.11 Macronutrient timing

Currently, there is little research focused on the timing of macronutrient intake in rowers. Our findings suggest that adolescent rowers did not achieve the appropriate timing of CHO and protein across all feeding occasions (pre-, during, post-exercise), except for protein intake pre-exercise. The most significant deficiencies in nutrient timing were CHO intake during training and protein intake within one-hour post-training. Such results are similar to those of (Steen et al., 1995) who reported that only 63% of rowers consumed a pre-exercise meal of 0.8 $g.kg^{-1}$ CHO before training. A study on macronutrient timing in adolescent athletes found CHO intake during exercise to be the most problematic feeding occasion, with only 18% of adolescent athletes achieving recommended levels (Baker et al., 2014). Based on ours and previous results, adolescent rowers do not appear to be adequately fuelling for training and may not be adequately timing their protein intake to regular intervals to maximise MPS stimulation and training adaptation. This shortfall in nutrient timing may have detrimental effects on rowing performance and recovery (Cermak & Van Loon, 2013; Kerksick et al., 2017).

3.6 Strengths and limitations

This study is the first of its kind in adolescent rowers, focusing on dietary intake during hard and recovery training days and evaluation of nutritional timing compared with current sports nutrition recommendations. The robust methodology includes detailed participant training information, the utilisation of four 24-hour food records, considered the "gold standard" of athlete dietary assessment. Moreover, additional steps were taken to minimise misreporting, such as collecting multiple days of food records, conducting a follow-up after each report within 36 hours of receiving the food record, the creation of a food code book to ensure consistency throughout the Foodworks analysis, and three researchers performing the food analysis and cross-checking entries to minimise random errors. The study involves a reasonably large cohort of 35 adolescent rowers, predominantly female, contributing valuable data to the literature, which has often been biased towards male rowers. The findings offer insights for rowers, parents, coaches, sports nutritionists, and dietitians, providing valuable information for tailoring nutritional education to support both adolescent health and rowing performance.

While recognising potential uncertainties linked to measurement errors in dietary assessment, proactive measures were implemented to minimise misreporting. Notably, the participants likely interest in nutrition increases the potential for selection bias for certain dietary behaviours that are more health driven, limiting the generalisability of the findings to the wider adolescent population. Additionally, the categorisation of recovery and hard training days is subject to individual perception, although the involvement of coaching staff helps alleviate the risk of misclassification. The inherent risk of self-reported height and weight data may impact anthropometric calculations and reported macronutrient levels relative to bodyweight. However this was considered the best available option as the study was conducted during the COVID-19 pandemic in New Zealand. The study also highlights the challenge of differentiating sugars from natural and processed sources in dietary analysis. Other limitations include not considering the impact of specific eating behaviours, such as the use of protein supplements or vegetarian diets, on protein intake in adolescent rowers. Future research is suggested to explore the prevalence and impact of protein supplement use and vegetarian diets among adolescent rowers and to investigate into the contribution and impact of refined sugar intake on rowing performance.

3.7 Conclusions

The present study set out to determine the nutritional gaps in the dietary intake (CHO, protein, and fat) of adolescent rowers living in New Zealand. The findings suggest adolescent rowers fail to consume the necessary levels of CHO to achieve the minimum quantities and timing of CHO intake according to sport nutrition recommendations. Although adolescent rowers consumed adequate protein intake, the timing of protein intake post-exercise was not in line with protein recommendations for optimal training recovery. Another significant finding was that adolescent rowers tend to meet fibre recommendations but consume diets high in total fat and SFA. The outcomes of this study support the need for nutritional education aimed at adolescent rowers. Emphasis should be placed on increasing CHO intake in alignment with training volume, optimising the timing of dietary intake around training sessions, and reducing dietary fat consumption. These measures are crucial to support overall adolescent health, development, and enhance rowing performance and training adaptations.

Chapter 4 : Conclusions

4.1 Achievement of aims and hypotheses

This study examined the dietary intake of adolescent rowers in New Zealand by exploring the CHO, protein, and fat intake of male and female rowers across four training days with two different training intensities. Macronutrient timing at pre-, during, and post-exercise and other nutritional categories (total sugar, types of fat, and dietary fibre) were also examined. The findings were compared with relevant adolescent sports nutrition guidelines and population health recommendations for growth, development, and sports performance.

A key finding was that two out of three rowers (68.6%) consumed suboptimal levels of CHO compared to nutritional recommendations. This supports the hypothesis that adolescent rowers do not consume the recommended CHO quantities to support their intensive training. Given that sedentary adolescents living in New Zealand narrowly meet population health CHO recommendations (Ministry of Health & University of Otago, 2011), it is unsurprising that adolescent rowers struggle to consume adequate CHO despite requiring a higher CHO intake to meet their additional nutritional needs for training. Similar to our findings, other studies have reported suboptimal CHO intakes in adolescent or collegiate-level rowers (Hanley, 2014; Short & Short, 1983; Steen et al., 1995; Zorn, 2017). This is a significant concern since saturated muscle glycogen stores are important for enhanced rowing performance (Sherman et al., 1981). Given that muscle glycogen is the primary energy substrate in rowing (Stellingwerff et al., 2011), a low CHO intake leads to low muscle glycogen stores and reduced utilisation rate (Achten et al., 2004; Sherman et al., 1981) which impacts rowing performance. Adverse health outcomes due to suboptimal CHO intake during adolescence include compromised cognitive function and development, bone remodelling, and delayed maturation and linear growth (Brown, 2019). Participants also failed to upregulate their

CHO dietary intake on hard training days despite increased energy demands and therefore the need for increased dietary intake. Furthermore, the timing of CHO intake did not align with recommendations to maximise rapid muscle glycogen repletion and the ergogenic effects of exogenous CHO for optimal rowing performance and recovery. However, the risk to health and performance may be mitigated by implementing robust and comprehensive nutritional education and eating strategies to ensure adequate daily CHO intake and the upregulation of CHO intake to match the intensity and duration of training.

Most adolescent rowers achieved sufficient protein intake, aligning with sports nutrition guidelines for enhanced training adaptations and accretion of lean body mass for growth (Brown, 2019). As hypothesised, males could more readily meet protein recommendations than females. However, although not considered unsafe, male rowers demonstrated high protein intakes above daily recommendations. Previous research has suggested that this could potentially lead to the displacement of CHO or reduce the adaptive processes in the MPS stimulation response (Tinline-Goodfellow et al., 2020). The use of protein supplementation may lead to a higher protein intake, deviating from adolescent sports nutrition guidelines, which recommend achieving optimal protein intake through a “food first” approach (Burke et al., 2021). Of note, previous research has reported similar findings to the current study, with most adolescents and collegiate rowers meeting protein requirements (Bond et al., 2012; Hanley, 2014; Iguchi & Kuzuhara, 2020; Short & Short, 1983; Steen et al., 1995; Zorn, 2017). The literature review indicated that regular small protein doses trigger greater MPS stimulation rather than achieving the recommended daily protein intake alone (Moore et al., 2015). Therefore, nutritional education for this age group should consider emphasising the distribution of protein intake into smaller doses at regular intervals throughout the day and attainment of protein needs through a “food first” approach.

Dietary fat was consumed at the higher end of recommendations, and SFA was higher than expected, while also exceeding population health recommendations. The implications of a high-fat diet during adolescence may be the potential displacement of CHO intake. Insufficient CHO intake may likely impact growth and development (Brown, 2019), and rowing performance since exogenous CHO and muscle glycogen are utilised more efficiently than fat as an energy substrate in adolescent rowers (Burke et al., 2021; Timmons et al., 2003). In addition, chronically high SFA intake may have implications associated with adverse health outcomes following a career in competitive rowing. Although rowers consumed significant levels of dietary fibre and fats, nutritional education should continue to encourage a variety of fibre sources for normal bowel function and consumption of MUFA and PUFA in substitution of SFA to support cardiovascular health (Li et al., 2015).

Our findings support the hypothesis that adolescent rowers do not achieve the recommended timing of CHO to optimise performance and recovery. Our findings suggest that their daily CHO intake of 4.4 ± 1.8 $g.kg^{-1}$ and pre-exercise intake of 0.9 ± 0.7 $g.kg^{-1}$ may leave them with suboptimal muscle glycogen stores. Since dietary CHO intake is related to the accretion of muscle glycogen stores (Sherman et al., 1981), poor CHO fuelling may negatively affect rowing performance. This is supported by previous research indicating that insufficient muscle glycogen stores may decrease the utilisation rate of muscle glycogen (Achten et al., 2004; Sherman et al., 1981). Another factor that may contribute to reduced rowing performance is the lack of CHO intake during exercise, which is known to delay fatigue and provide ergogenic effects (Cermak & Van Loon, 2013). The adolescent rowers also failed to achieve the recommended CHO and protein intake post-exercise required to support muscle repair and rapid recovery. This is particularly needed when rowers want to prevent fatigue if training more than once per day or if participating in multiple races per day in competition regattas (Burke, Van Loon, et al., 2017; Maughan et al., 2012). Comprehensive nutritional education on CHO and protein intake pre-, during, and post-training may assist adolescent rowers in enhancing rowing performance and recovery, and delaying fatigue by optimising nutritional timing.

4.2 Strengths

To the best of our knowledge, this is the first study in adolescent rowers to examine dietary intake during hard and recovery training days within a competition season and assess the macronutrient timing for pre-, during, and post-exercise nutrient against current sports nutrition recommendations. The collection of participant training intensity and duration was an important feature in the study methodology which helped improve the ability to accurately measure the adequacy of nutritional timing and compare against current recommendations.

Our study investigated the dietary intake of 35 adolescent rowers, constituting a reasonably large participant cohort that facilitated the extraction of meaningful results. Furthermore, the study predominantly comprised of females, contributing valuable data to the existing literature, which has often been significantly weighted toward the dietary intake of male rowers. The inclusion of both male and female rowers in our study enabled the novel exploration of gender differences in dietary intake in this cohort.

Additionally, one significant strength of the study was the collection of four 24-hour food records, the "gold standard" dietary assessment, on non-consecutive days across two levels of training intensity, distinguishing it from many other studies that relied a single day of food recording. This approach reduced the risk of misreporting and provides a more representative "snapshot" of participants usual dietary intake. Another notable strength of the study lies in the robust data analysis process, involving written food records complemented by photos of meals eaten. The process also involved thorough follow-up verification and data analysis where three researchers employed a food code book and cross-checked data entries. This approach not only ensured consistency across researchers but also effectively minimised systematic errors in the data entry process, enhancing the overall reliability and accuracy of the study findings.

The findings hold significance for rowers, parents, coaches, nutritionists and dietitians. The understanding gained from this study could improve the customisation of nutritional education to increase nutritional knowledge in the adolescent rowing community and adjust their dietary intake to support normal growth, development, and maturation in addition to rowing performance.

4.3 Limitations

The present study has a several limitations that are important to consider. Firstly, the self-reported dietary assessment method carries the potential for under-reporting of dietary intake. However, significant measures were implemented in the methodology to minimise the risk of misreporting, such as collecting multiple days of food records and conducting timely follow-ups. In addition, the use of self-reported height and weight data for rowers located outside of Auckland is also a potential limitation, as self-reported information may be subject to inaccuracies and biases, which could impact anthropometric calculations and reported macronutrient levels relative to bodyweight. Furthermore, there is a possibility that the study participants have a greater interest in nutrition, introducing a potential selection bias. This bias may lead to more health-driven dietary behaviours in the study population which limits the ability to generalise the findings to the broader population of adolescent rowers.

Another constraint, despite significant efforts to control training intensity, the individual's perception of energy expenditure may have influenced the categorisation of hard and recovery training days. This effect was minimised by involving the participants rowing coaches in the identification of hard and recovery training days which reduced the risk of misclassification. Despite this, for some participants, certain recovery days involved extended periods of low-intensity exercise, resulting in relatively high energy expenditure on recovery days, at times often comparable to that of hard training days.

Additionally, the inclusion of rowers (n=2) following a vegetarian diet raises concerns as to their ability to adequately meet protein requirements outlined in this study, which do not specifically consider athletes following an exclusively plant-based diet. Therefore, our study does not account for the differences in protein requirements for vegetarian rowers and it remains to be clarified if vegetarian rowers are sufficiently addressing their specific dietary needs. The study also does not explore whether adolescent rowers can meet the minimum protein requirements without the assistance of protein supplements, contrary to nutritional guidelines advocating for a "food first" approach. As a result, it remains unclear whether certain adolescent rowers can maintain adequate protein levels while following a vegetarian diet or if individuals using protein supplements abruptly discontinue their use.

Additionally, the Foodworks software could not differentiate between sugars from natural food sources, such as fruit, and processed food sources. Consequently, the study does not determine the contribution of processed sugar to dietary intake, limiting an important discussion on its impact on the long-term health of adolescent rowers. Comparisons to population health recommendations would require further information on the food sources. Exploring sugar intake and overall diet quality may be an area of interest in the future, as the effects of sugar consumption on athletes is dependent on the context in which it is consumed such as energy expenditure, energy balance and timing of exercise in relation to sugar intake.

4.4 Practical Recommendations

The present study highlighted various deficiencies in the dietary intake of participants, suggesting that adolescent rowers may gain valuable insights from the evaluation of their dietary intake. When considering dietary intake for competitive scenarios, it is crucial for nutritional education to highlight the significance of achieving recommended nutritional timing for pre- and post-race to optimise rowing performance and facilitate effective recovery, as outlined below.

Rowers should be provided with support and guidance on:

- Consuming at least 5.0 $g.kg^{-1}$ CHO daily to meet current nutritional guidelines.
- Consuming protein in small doses (0.3-0.4 $g.kg^{-1}$) every 2-4 hours. For a 70 kg rower, this would be 21-28 g protein per eating occasion.
- Increasing protein intake to at least 1.3 $g.kg^{-1}$ protein by female rowers.
- Not to overconsume protein by focusing on protein-rich foods rather than adding protein supplements to their diet, a particular focus of male rowers.
- Avoiding fasted training by consuming a pre-exercise snack.
- Adhering to current nutritional intake timing recommendations including 1.0-4.0 $g.kg^{-1}$ CHO 1-4 hours before training, 30-60 $g.h^{-1}$ of easily digestible forms of CHO during exercise lasting longer than 60 minutes, 1.0-1.2 $g.kg^{-1}$ CHO and 0.3-0.4 $g.kg^{-1}$ protein as soon as possible after training for rapid recovery.
- Reducing total fat intake to within 20-35%E, and SFA and trans-fat to <10%E.

Suggested practical examples:

- Aim for a well-fuelled plate which looks like ⅓ CHO foods (e.g. bread, pasta), ⅓ protein foods (e.g., meat, fish, eggs), ⅓ fruits and/or vegetables.
- Aim for a colourful plate by incorporating colourful foods like fruits, vegetables, legumes, nuts and seeds, to enhance the diversity of fibre sources and support normal bowel function.

- Plan your weekly meals and snacks, engaging in home meal preparation for quick and nutritious options, especially on busy training days.
- Increase CHO intake on demanding training days by including additional pre-exercise snacks and post-exercise recovery foods. For instance, consider options like eggs on wholegrain toast, cheese and crackers, cereal bars, and fruit with yoghurt.
- Opt for wholegrain foods for your daily high-quality CHO intake, reserving non-wholegrain alternatives like white bread for competition days or multiple training sessions in a day.
- Distribute protein intake throughout the day by including protein with breakfast's like eggs on toast, egg omelette with ham and cheese, high protein yoghurt with cereal. Choose high-protein snacks such as, nuts, nut butters, hummus with vegetable sticks or high-protein yoghurt.
- Reduce total fat and SFA intake by cooking at home, limiting consumption of takeaway foods, substituting butter with margarine, opting for reduced-fat or low-fat milk, and selecting lean cut meats. Alternatively, visible fat can be trimmed off cuts of meat before cooking.
- Include healthy fats from sources like salmon, tuna, nuts, seeds and avocado to support cardiovascular health.
- For optimal energy levels, consider following based on pre-exercise time intervals:
- 2-3 hours before: choose a complex CHO-rich meal with moderate protein, fat and fibre. Examples include wholegrain foods such as bread, pasta, oats, lentils, rice. However, if early morning training, do not sacrifice sleep for this.
- 1-2 hours before: choose a CHO-rich meal with reduced protein, fat and fibre. Examples include cereals and/or fresh fruit.
- 0-60 minutes: prioritise easily digestible simple CHO, low in fat and fibre for readily available energy. Examples include fruit juices, dried fruit, white toast with jam or honey.

- During exercise, choose easily digestible CHO sources or consider mouth rinsing with a sports drink, being mindful to not overuse this strategy to preserve dental health.
- For post-exercise recovery, consume a small meal or snack within one hour of exercise containing CHO and protein, such as chocolate milk, a recovery smoothie, or a chicken sandwich.
- Gradually make adjustments over time to condition the stomach, reducing the risk of gastrointestinal distress.

4.5 Future directions for research

As our study discovered, suboptimal dietary intake among adolescent rowers is a significant concern. Future research should be directed towards a more comprehensive understanding of their nutritional gaps, enabling the implementation of evidence-based strategies to address barriers to dietary intake within this athlete population.

- One avenue of further research could be to explore the distribution of dietary protein across the day to determine whether the timing and dosage of protein intake is consistent with current nutritional recommendations. By doing so, researchers can ensure that adolescent rowers achieve optimal MPS stimulation and effective muscle repair, crucial for their athletic performance.
- Another area worth exploring is the prevalence of vegetarian rowers and protein supplement use within the adolescent rowing community. It would be valuable to evaluate whether nutritional education should emphasise the advantages of the “food first” approach and that meeting nutritional requirements is attainable without relying on expensive and largely unnecessary protein supplements for the majority of adolescent rowers, while also focusing on optimising protein intake, particularly for those adhering to a vegetarian diet.

- Additionally, future research could explore the implications of sufficient nutritional timing around rowing training sessions and assess its impact on rowing performance. This investigation has the potential to offer valuable insights into the advantages of aligning with nutritional timing guidelines for optimal performance outcomes.
- To further explore the adequacy of dietary intake among adolescent rowers, observational studies could investigate the adequacy of micronutrient intake. These studies may focus micronutrients crucial for athletic performance, such as iron, and the subsequent findings could then be compared against adolescent population health guidelines.
- Since recognising the significant barriers to dietary intake for adolescent rowers, it may be beneficial to investigate effective educational strategies that promote behaviour change in adolescent athletes. Such research may be helpful in ensuring the successful implementation of the study findings into daily practices of adolescent rowers leading to sustained positive dietary habits.
- Furthermore, exploring the quality of CHO, protein and fats could offer a comprehensive perspective for future research. The investigation would not only assess dietary adequacy, food variety and eating patterns of adolescent rowers, but also contribute to the nutritional education given to adolescent athletes for performance and subsequent healthy eating practices that can be sustained into adulthood.

References

Achten, J., Halson, S. L., Moseley, L., Rayson, M. P., Casey, A., & Jeukendrup, A. E. (2004). Higher dietary carbohydrate content during intensified running training results in better maintenance of performance and mood state. *Journal of Applied Physiology*, *96*(4), 1331-1340. https://doi.org/10.1152/japplphysiol.00973.2003

Aerenhouts, D., Deriemaeker, P., Hebbelinck, M., & Clarys, P. (2011). Energy and macronutrient intake in adolescent sprint athletes: a follow-up study. *Journal of Sports Sciences*, *29*(1), 73-82. https://doi.org/doi:10.1080/02640414.2010.521946

Aerenhouts, D., Van Cauwenberg, J., Poortmans, J. R., Hauspie, R., & Clarys, P. (2013). Influence of growth rate on nitrogen balance in adolescent sprint athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *23*(4), 409-417. https://doi.org/10.1123/ijsnem.23.4.409

Al-Disi, D., Al-Othman, A., Al-Saif, M., Al-Daghri, N., Sabico, S., Chrousos, G., & Khanam, L. (2010). Subjective sleep duration and quality influence diet composition and circulating adipocytokines and ghrelin levels in teen-age girls. *Endocrine Journal*, *57*(10), 915-923-923. https://doi.org/10.1507/endocrj.K10E-145

Alaunyte, I., Stojceska, V., & Plunkett, A. (2015). Iron and the female athlete: A review of dietary treatment methods for improving iron status and exercise performance. *Journal of the International Society of Sports Nutrition*, *12*(1), 1-7. https://doi.org/doi:10.1186/s12970-015-0099-2

Anderson, D. E. (2010). The impact of feedback on dietary intake and body composition of college women volleyball players over a competitive season. *Journal of Strength and Conditioning Research*, *24*(8), 2220-2226-2226. https://doi.org/10.1519/JSC.0b013e3181def6b9

Ans, A. H., Anjum, I., Satija, V., Inayat, A., Asghar, Z., Akram, I., & Shrestha, B. (2018). Neurohormonal regulation of appetite and its relationship with stress: a mini literature review. *Cureus*, *10*(7), e3032. https://doi.org/10.7759/cureus.3032

Antonio, J., Ellerbroek, A., Silver, T., Vargas, L., & Peacock, C. (2016). The effects of a high protein diet on indices of health and body composition – a crossover trial in resistance-trained men. *Journal of the International Society of Sports Nutrition*, *13*(1), 1-7. https://doi.org/10.1186/s12970-016-0114-2

Aragon, A. A., & Schoenfeld, B. J. (2013). Nutrient timing revisited: is there a post-exercise anabolic window? *Journal of the International Society of Sports Nutrition*, *10*(1), 5. https://doi.org/10.1186/1550-2783-10-5

Arent, S. M., Cintineo, H. P., McFadden, B. A., Chandler, A. J., & Arent, M. A. (2020). Nutrient timing: a garage door of opportunity? *Nutrients*, *12*(1948), 1948-1948. https://doi.org/10.3390/nu12071948

Areta, J. L., Burke, L. M., Camera, D. M., Hawley, J. A., Coffey, V. G., Crawshay, S., West, D. W. D., Phillips, S. M., Stellingwerff, T., & Moore, D. R. (2014). Reduced resting skeletal muscle protein synthesis is rescued by resistance exercise and protein ingestion following short-term energy deficit. *American Journal of Physiology - Endocrinology and Metabolism*, *306*(8), E989-E997. https://doi.org/10.1152/ajpendo.00590.2013

Atherton, P. J., Etheridge, T., Watt, P. W., Wilkinson, D., Selby, A., Rankin, D., Smith, K., & Rennie, M. J. (2010). Muscle full effect after oral protein: time-dependent concordance and discordance between human muscle protein synthesis and mTORC1 signaling. *The American Journal of Clinical Nutrition*, *92*(5), 1080-1088. https://doi.org/10.3945/ajcn.2010.29819

Australian National Health and Medical Research Council, & NZ Ministry of Health. (2014). *Nutrient reference values: Protein.* Australian National Health and Medical Research Council. https://www.nrv.gov.au/nutrients/protein

Baker, L. B., Heaton, L. E., Nuccio, R. P., & Stein, K. W. (2014). Dietitian-observed macronutrient intakes of young skill and team-sport athletes: adequacy of pre, during, and postexercise nutrition. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(2), 166-176. https://doi.org/10.1123/ijsnem.2013-0132

Baleeiro, R. D. S., Guimarães, A. P., Andrade, R. D., Coelho, D. B., Oliveira, E. C., Becker, L. K., Souza, P. M. D., & Barbosa De Queiroz, K. (2021). Sucrose-sweetened drinks reduce the physical performance and increase the cardiovascular risk in physically active males. *Journal of Nutrition and Metabolism*, *eCollection 2021*. https://doi.org/10.1155/2021/6683657

Baranauskas, M., Tubelis, L., Stukas, R., Švedas, E., Samsonienė, L., & Karanauskienė, D. (2014). Nutrition status of high performance rowers, canoeists and kayakers. *Baltic Journal of Sport and Health Sciences*, *92*(1), 16-25. https://doi.org/10.33607/bjshs.v1i92.106

Basiotis, P. P., Welsh, S. O., Cronin, F. J., Kelsay, J. L., & Mertz, W. (1987). Number of days of food intake records required to estimate individual and group nutrient intakes with defined confidence. *Journal of Nutrition*, *117*(9), 1638-1641. https://doi.org/10.1093/jn/117.9.1638

Bird, S. P., & Rushton, B. D. (2020). Nutritional knowledge of youth academy athletes. *BMC Nutrition*, *6*(1), 35. https://doi.org/10.1186/s40795-020-00360-9

Black, K. E., Black, A. D., & Baker, D. F. (2018). Macronutrient intakes of male rugby union players: A review. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(6), 664-673. https://doi.org/10.1123/ijsnem.2017-0400

Bloodworth, A. J., Petróczi, A., Bailey, R., Pearce, G., & McNamee, M. J. (2012). Doping and supplementation: The attitudes of talented young athletes. *Scandinavian Journal of Medicine & Science in Sports*, *22*(2), 293-301. https://doi.org/10.1111/j.1600-0838.2010.01239.x

Boidin, A., Cox, G. R., Tam, R., O'Connor, H., & Mitchell, L. (2021). The effectiveness of nutrition education programmes on improving dietary intake in athletes: a systematic review. *British Journal of Nutrition*, *125*(12), 1359-1373. https://doi.org/10.1017/S0007114520003694

Boisseau, N., Vermorel, M., Rance, M., Duché, P., Patureau-Mirand, P., & Duché, P. (2007). Protein requirements in male adolescent soccer players. *European Journal of Applied Physiology*, *100*(1), 27-33. https://doi.org/10.1007/s00421-007-0400-4

Bond, H., Morton, L., & Braakhuis, A. J. (2012). Dietary nitrate supplementation improves rowing performance in well-trained rowers. *International Journal of Sport Nutrition and Exercise Metabolism*, *22*(4), 251-256. https://doi.org/10.1123/ijsnem.22.4.251

Braakhuis, A. J., Hopkins, W. G., & Lowe, T. E. (2013). Effect of dietary antioxidants, training, and performance correlates on antioxidant status in competitive rowers. *International Journal of Sports Physiology and Performance*, *8*(5), 565-572. https://doi.org/10.1123/ijspp.8.5.565

Brandou, F., Brun, J. F., Mercier, J., Savy-Pacaux, A. M., & Marie, J. (2006). Comparison of the type of substrate oxidation during exercise between pre and post pubertal markedly obese boys. *International Journal of Sports Medicine*, *27*(5), 407-414. https://doi.org/10.1055/s-2005-865751

Briggs, M., Cockburn, E., Rumbold, P., Rae, G., Stevenson, E., & Russell, M. (2015). Assessment of energy intake and energy expenditure of male adolescent academy-level soccer players during a competitive week. *Nutrients*, *7*(10), 8392-8401. https://doi.org/10.3390/nu7105400

Broom, D. R., Batterham, R. L., King, J. A., & Stensel, D. J. (2009). Influence of resistance and aerobic exercise on hunger, circulating levels of acylated ghrelin, and peptide YY in healthy males.

American Journal of Physiology-Regulatry Integrative and Comparative Physiology, *296*(1), R29-35. https://doi.org/10.1152/ajpregu.90706.2008

Broom, D. R., Stensel, D. J., Bishop, N. C., Burns, S. F., & Miyashita, M. (2007). Exercise-induced suppression of acylated ghrelin in humans. *Journal of Applied Physiology (1985)*, *102*(6), 2165-2171. https://doi.org/10.1152/japplphysiol.00759.2006

Brown, J. (2019). *Nutrition through the life cycle* (7th ed.). Cengage Learning, Inc.

Buckhart, S. J., & Coad, J. (2010). Assessment of nutrition knowledge and food skills in talented adolescent athletes. Forty-fifth Proceedings of the Nutrition Society of New Zealand, Wellington, NZ.

Burd, N. A., Tang, J. E., Moore, D. R., & Phillips, S. M. (2009). Exercise training and protein metabolism: Influences of contraction, protein intake, and sex-based differences. *Journal of Applied Physiology*, *106*(5), 1692-1701. https://doi.org/10.1152/japplphysiol.91351.2008

Burd, N. A., West, D. W. D., Moore, D. R., Staples, A. W., Prior, T., Tang, J. E., Phillips, S. M., Baker, S. K., Atherton, P. J., & Rennie, M. J. (2011). Enhanced amino acid sensitivity of myofibrillar protein synthesis persists for up to 24 h after resistance exercise in young men. *Journal of Nutrition*, *141*(4), 568-573-573. https://doi.org/10.3945/jn.110.135038

Burge, C. M., Carey, M. F., & Payne, W. R. (1993). Rowing performance, fluid balance, and metabolic function following dehydration and rehydration. *Medicine & Science in Sports & Exercise*, *25*(12), 1358-1364. https://pubmed.ncbi.nlm.nih.gov/8107542/

Burke, L. M. (2007). *Practical sports nutrition*. Human Kinetics.

Burke, L. M. (2021). Ketogenic low-CHO, high-fat diet: the future of elite endurance sport? *Journal of Physiology*, *599*(3), 819-843. https://doi.org/10.1113/JP278928

Burke, L. M., Deakin, V., & Minehan, M. (2021). *Clinical sports nutrition* (6th ed.). McGraw Hill.

Burke, L. M., Hawley, J. A., Wong, S. H., & Jeukendrup, A. E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences*, *29* (Suppl 1), S17-27. https://doi.org/10.1080/02640414.2011.585473

Burke, L. M., Kiens, B., & Ivy, J. L. (2004). Carbohydrates and fat for training and recovery. *Journal of Sports Sciences*, *22*(1), 15-30. https://doi.org/10.1080/0264041031000140527

Burke, L. M., Ross, M. L., Garvican-Lewis, L. A., Welvaert, M., Heikura, I. A., Forbes, S. G., Mirtschin, J. G., Cato, L. E., Strobel, N., Sharma, A. P., & Hawley, J. A. (2017). Low carbohydrate, high fat diet impairs exercise economy and negates the performance benefit from intensified training in elite race walkers. *Journal of Physiology*, *595*(9), 2785-2807. https://doi.org/10.1113/jp273230

Burke, L. M., Sharma, A. P., Heikura, I. A., Forbes, S. F., Holloway, M., McKay, A. K. A., Bone, J. L., Leckey, J. J., Welvaert, M., & Ross, M. L. (2020). Crisis of confidence averted: impairment of exercise economy and performance in elite race walkers by ketogenic low carbohydrate, high fat (LCHF) diet is reproducible. *PloS One*, *15*(6), 1-31. https://doi.org/10.1371/journal.pone.0234027

Burke, L. M., Van Loon, L. J. C., & Hawley, J. A. (2017). Postexercise muscle glycogen resynthesis in humans. *Journal of Applied Physiology*, *122*(5), 1055-1067. https://doi.org/10.1152/japplphysiol.00860.2016

Calder, P. C. (2015). Marine omega-3 fatty acids and inflammatory processes: effects, mechanisms and clinical relevance. *Molecular & Cell Biology of Lipids*, *1851*(4), 469-484. https://doi.org/10.1016/j.bbalip.2014.08.010

Capling, L., Beck, K. L., Gifford, J. A., Slater, G., Flood, V. M., & O'Connor, H. (2017). Validity of dietary assessment in athletes: a systematic review. *Nutrients*, *9*(12), 1313. https://doi.org/10.3390/nu9121313

Cermak, N., & Van Loon, L. J. (2013). The use of carbohydrates during exercise as an ergogenic aid. *Sports Medicine*, *43*(11), 1139-1155. https://doi.org/10.1007/s40279-013-0079-0

Chambers, E. S., Bridge, M. W., & Jones, D. A. (2009). Carbohydrate sensing in the human mouth: Effects on exercise performance and brain activity. *Journal of Physiology*, *587*(Pt 8), 1779-1794. https://doi.org/10.1113/jphysiol.2008.164285

Ciuris, C., Johnston, C. S., Lynch, H. M., & Wharton, C. (2019). A comparison of dietary protein digestibility, based on diaas scoring, in vegetarian and non-vegetarian athletes. *Nutrients*, *11*(12). https://doi.org/10.3390/nu11123016

Clayton, D. J., Barutcu, A., Machin, C., Stensel, D. J., & James, L. J. (2015). Effect of breakfast omission on energy intake and evening exercise performance. *Medicine & Science in Sports & Exercise*, *47*(12), 2645-2652. https://doi.org/10.1249/mss.0000000000000702

Cornford, E., & Metcalfe, R. (2019). Omission of carbohydrate-rich breakfast impairs evening 2000-m rowing time trial performance. *European Journal of Sport Science*, *19*(1), 133-140. https://doi.org/10.1080/17461391.2018.1545052

Costello, N., Deighton, K., Dyson, J., McKenna, J., & Jones, B. (2017). Snap-N-Send: A valid and reliable method for assessing the energy intake of elite adolescent athletes. *European Journal of Sport Science*, *17*(8), 1044-1055. https://doi.org/DOI:10.1080/17461391.2017.1337815

Crupi, R., & Cuzzocrea, S. (2022). Role of EPA in inflammation: mechanisms, effects, and clinical relevance. *Biomolecules*, *12*(2), 242-242. https://doi.org/10.3390/biom12020242

D'Angelo, S., & Madonna, G. (2020). Effects of fish oil supplementation in the sport performance. *Journal of Physical Education & Sport*, *20*(Suppl 4), 2322-2329.

Da Boit, M., Hunter, A. M., & Gray, S. R. (2017). Fit with good fat? The role of n-3 polyunsaturated fatty acids on exercise performance. *Metabolism*, *66*, 45-54. https://doi.org/10.1016/j.metabol.2016.10.007

Damas, F., Vechin, F. C., Lixandrão, M. E., Jannig, P. R., Costa, L. A. R., Bacurau, A. V., Tricoli, V., Roschel, H., Ugrinowitsch, C., Phillips, S. M., Snijders, T., Parise, G., & Libardi, C. A. (2016). Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. *Journal of Physiology*, *594*(18), 5209-5222-5222. https://doi.org/10.1113/JP272472

De Lorgeril, M., & Renaud, S. (1994). Mediterranean alpha-linolenic acid-rich diet in secondary prevention of coronary heart disease. *Lancet*, *343*(8911), 1454. https://doi.org/10.1016/S0140-6736(94)92580-1

De Wijn, J. F., Leusink, J., & Post, G. B. (1979). Diet, body composition and physical condition of champion rowers during periods of training and out of training. *Bibliotheca Nutritio et Dieta*(27), 143-148. https://doi.org/10.1159/000402380

Debnath, M., Dey, S. K., Datta, G., & Bandyopadhyay, A. (2023). Impact of nutrition education programme and controlled dietary modification on nutritional status in young male athletes. *Human Nutrition & Metabolism*, *34*, 200230. https://doi.org/https://doi.org/10.1016/j.hnm.2023.200230

Decombaz, J. (2003). Nutrition and recovery of muscle energy stores after exercise. *Schweizerische Zeitschrift fuer Sportmedizin & Sporttraumatologie*, *51*(1), 31-38. https://ssms.ch/fileadmin/user_upload/Zeitschrift/51-2003-1/07-2003-1.pdf

Desbrow, B. (2021). Youth athlete development and nutrition. *Sports Medicine*, *51*(1), 3-12. https://doi.org/10.1007/s40279-021-01534-6

Desbrow, B., Burd, N. A., Tarnopolsky, M., Moore, D. R., & Elliott-Sale, K. J. (2019). Nutrition for special populations: young, female, and masters athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(2), 220-227. https://doi.org/DOI:10.1123/ijsnem.2018-0269

Desbrow, B., McCormack, J., Hislop, M., Sawyer, S. M., Burke, L. M., & Cox, G. R., et al. (2014). Sports Dietitians Australia position statement: sports nutrition for the adolescent athlete. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(5), 570-584. https://doi.org/10.1123/ijsnem.2014-0031

Deutz, N. E. P., Bauer, J. M., Barazzoni, R., Biolo, G., Boirie, Y., Bosy-Westphal, A., Cederholm, T., Cruz-Jentoft, A., Krznariç, Z., Nair, K. S., Singer, P., Teta, D., Tipton, K. D., & Calder, P. C. (2014). Protein intake and exercise for optimal muscle function with aging: Recommendations from the ESPEN Expert Group. *Clinical Nutrition*, *33*(6), 929-936. https://doi.org/10.1016/j.clnu.2014.04.007

Doherty, R., Madigan, S. M., Ellis, J. G., Nevill, A., & Warrington, G. (2021). The sleep and recovery practices of athletes. *Nutrients*, *13*(4). https://doi.org/10.3390/nu13041330

Domínguez, R., López-Domínguez, R., Gené, P., González-Jurado, J. A., López-Samanes, Á., & Sánchez-Oliver, A. J. (2020). Analysis of sport supplement consumption and body composition in spanish elite rowers. *Nutrients*, *12*(12), 1-12. https://doi.org/10.3390/nu12123871

Durkalec-Michalski, K., & Jeszka, J. (2015). The efficacy of a β-hydroxy-β-methylbutyrate supplementation on physical capacity, body composition and biochemical markers in elite rowers: a randomised, double-blind, placebo-controlled crossover study. *Journal of the International Society of Sports Nutrition*, *12*(1), 1-11. https://doi.org/doi:10.1186/s12970-015-0092-9

Egan, B., Ashley, D. T., Kennedy, E., O'Connor, P. L., & O'Gorman, D. J. (2016). Higher rate of fat oxidation during rowing compared with cycling ergometer exercise across a range of exercise intensities. *Scandinavian Journal of Medicine & Science in Sports*, *26*(6), 630-637. https://doi.org/10.1111/sms.12498

Eriksson, B. O., Gollnick, P. D., & Saltin, B. (1973). Muscle metabolism and enzyme activities after training in boys 11–13 years old. *Acta Physiologica Scandinavica*, *87*(4), 485-497. https://doi.org/https://doi.org/10.1111/j.1748-1716.1973.tb05415.x

Eriksson, O., & Saltin, B. (1974). Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults. *Acta Paediatrica Belgica*, *28 Suppl*, 257-265. https://pubmed.ncbi.nlm.nih.gov/4446986/

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191. https://doi.org/10.3758/bf03193146

Fayet-Moore, F., Cassettari, T., Tuck, K., McConnell, A., & Petocz, P. (2018). Dietary fibre intake in Australia. Paper ii: comparative examination of food sources of fibre among high and low fibre consumers. *Nutrients*, *10*(9). https://doi.org/10.3390/nu10091223

Ferraris, C., Guglielmetti, M., Trentani, C., & Tagliabue, A. (2019). Assessment of dietary under-reporting in Italian college team sport athletes. *Nutrients*, *11*(6). https://doi.org/10.3390/nu11061391

Fitó, M., Cladellas, M., de la Torre, R., Martí, J., Alcántara, M., Pujadas-Bastardes, M., Marrugat, J., Bruguera, J., López-Sabater, M. C., Vila, J., & Covas, M. I. (2005). Antioxidant effect of virgin olive oil in patients with stable coronary heart disease: a randomized, crossover, controlled, clinical trial. *Atherosclerosis* *181*(1), 149-158. https://doi.org/10.1016/j.atherosclerosis.2004.12.036

Foo, W., Newbury, J. W., Gough, L. A., Faghy, M. A., & Sparks, A. (2021). The effects of a nutrition education intervention on sports nutrition knowledge during a competitive season in highly trained adolescent swimmers. *Nutrients*, *13*(8). https://doi.org/10.3390/nu13082713

Garner, B. H., Emplaincourt, H. P., Valliant, M. W., & Wenzel, R. K. (2012). Nutrition education by a registered dietitian improves dietary intake and nutrition knowledge of a NCAA female volleyball team. *Nutrients*, *4*(6), 506-516. https://doi.org/10.3390/nu4060506

Ghigiarelli, J., Sell, K., Blum, M., Dagastino, N., & Alfano, P. (2009). The effects of low-fat skim chocolate milk on urinary hydration indices in a sample of Division 1-AA cross country runners during off-season training sessions. *Journal of the International Society of Sports Nutrition*, *6*(1), 10. https://doi.org/10.1186/1550-2783-6-S1-P10

Gibson, J. H., Mitchell, A., Harries, M. G., & Reeve, J. (2004). Nutritional and exercise-related determinants of bone density in elite female runners. *Osteoporosis International*, *15*(8), 611-618. https://doi.org/10.1007/s00198-004-1589-2

Hanley, K. M. (2014). *Dietary analysis of adolescent male rowers assessed using 24-hour food recall* [Master's thesis, D'Youville College]. ProQuest LLC. https://www.proquest.com/openview/4f483278644b71efed14365ff55d15bc/1?pq-origsite=gscholar&cbl=18750

Haralambie, G. (1982). Enzyme activities in skeletal muscle of 13-15 years old adolescents. *Bulletin Européen de Physiopathologie Respiratoire*, *18*(1), 65-74.

Hargreaves, M., McConell, G., & Proietto, J. (1995). Influence of muscle glycogen on glycogenolysis and glucose uptake during exercise in humans. *Journal of Applied Physiology*, *78*(1), 288-292. https://doi.org/10.1152/jappl.1995.78.1.288

Hassapidou, M. (2001). Dietary assessment of five male sports teams in Greece. *Nutrition & Food Science*, *31*(1), 31-35. https://doi.org/10.1108/00346650110362571

Heaney, S., O'Connor, H., Gifford, J., & Naughton, G. (2010). Comparison of Strategies for Assessing Nutritional Adequacy in Elite Female Athletes' Dietary Intake. *International Journal of Sport Nutrition and Exercise Metabolism*, *20*(3), 245-256. https://doi.org/10.1123/ijsnem.20.3.245

Heinemann, L., & Zerbes, H. (1989). Physical activity, fitness, and diet: behavior in the population compared with elite athletes in the GDR. *American Journal of Clinical Nutrition*, *49*, 1007-1016. https://doi.org/10.1093/ajcn/49.5.1007

Helms, E. R., Zinn, C., Rowlands, D. S., & Brown, S. R. (2014). A systematic review of dietary protein during caloric restriction in resistance trained lean athletes: a case for higher intakes. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(2), 127-138. https://doi.org/10.1123/ijsnem.2013-0054

Hill, R. J., & Davies, P. S. W. (2002). Energy intake and energy expenditure in elite lightweight female rowers. *Medicine & Science in Sports & Exercise*, *34*(11), 1823-1829. https://doi.org/10.1097/00005768-200211000-00020

Ho, D., Tseng, S., Wu, M., Shih, C., Atika, A., Chen, Y., & Chang, J. (2020). Validity of image-based dietary assessment methods: a systematic review and meta-analysis. *Clinical Nutrition*, *39*(10), 2945-2959. https://doi.org/10.1016/j.clnu.2020.08.002

Holtzman, B., & Ackerman, K. E. (2021). Recommendations and nutritional considerations for female athletes: health and performance. *Sports Medicine*, *51*(Suppl 1), 43-57. https://doi.org/10.1007/s40279-021-01508-8

Howe, S. M., Hand, T. M., Manore, M. M., Larson-Meyer, D. E., Austin, K. J., & Alexander, B. M. (2016). No effect of exercise intensity on appetite in highly-trained endurance women. *Nutrients*, *8*(4). https://doi.org/10.3390/nu8040223

Iguchi, J., & Kuzuhara, K., et al. (2020). Seasonal changes in anthropometric, physiological, nutritional, and performance factors in collegiate rowers. *Journal of Strength and Conditioning Research*, *34*(11), 3225-3231. https://doi.org/10.1519/JSC.0000000000002521

Ioanna, K., & Tonia, V. (2021). Nutritional risks among adolescent athletes with disordered eating. *Children*, *8*(715), 715-715. https://doi.org/10.3390/children8080715

Ivy, J. L. (1998). Glycogen resynthesis after exercise: effect of carbohydrate intake. *International Journal of Sports Medicine*, *19 Suppl 2*, S142-145. https://doi.org/10.1055/s-2007-971981

Jagim, A. R., Kerksick, C., Luedke, J., Erickson, J., Fields, J. B., Magee, M., & Jones, M. T. (2021). The influence of sport nutrition knowledge on body composition and perceptions of dietary requirements in collegiate athletes. *Nutrients*, *13*(7). https://doi.org/10.3390/nu13072239

James, L. J., Clayton, D., & Evans, G. H. (2011). Effect of milk protein addition to a carbohydrate-electrolyte rehydration solution ingested after exercise in the heat. *British Journal of Nutrition*, *105*(3), 393-399. https://doi.org/10.1017/s0007114510003545

Jenner, S. L., Buckley, G. L., Belski, R., Devlin, B. L., & Forsyth, A. K. (2019). Dietary intakes of professional and semi-professional team sport athletes do not meet sport nutrition recommendations: a systematic literature review. *Nutrients*, *11*(5). https://doi.org/10.3390/nu11051160

Jensen, M., Stellingwerff, T., & Klimstra, M. (2015). Carbohydrate mouth rinse counters fatigue related strength reduction. *International Journal of Sport Nutrition and Exercise Metabolism*, *25*(3), 252-261. https://doi.org/10.1123/ijsnem.2014-0061

Jentjens, R. L., & Jeukendrup, A. (2003). Determinants of post-exercise glycogen synthesis during short-term recovery. *Sports Medicine*, *33*(2), 117-144. https://doi.org/10.2165/00007256-200333020-00004

Jentjens, R. L., Van Loon, L. J. C., Mann, C. H., Wagenmakers, A. J., & Jeukendrup, A. E. (2001). Addition of protein and amino acids to carbohydrates does not enhance postexercise muscle glycogen synthesis. *Journal of Applied Physiology (1985)*, *91*(2), 839-846. https://doi.org/10.1152/jappl.2001.91.2.839

Jeukendrup, & Killer, S. C. (2010). The myths surrounding pre-exercise carbohydrate feeding. *Annals of Nutrition and Metabolism*, *57 Suppl 2*, 18-25. https://doi.org/10.1159/000322698

Jeukendrup, A. (2014). A step towards personalized sports nutrition: carbohydrate intake during exercise. *Sports Medicine*, *44* (Suppl 1), S25-33. https://doi.org/10.1007/s40279-014-0148-z

Kabasakalis, A., Kalitsis, K., Tsalis, G., & Mougios, V. (2007). Imbalanced nutrition of top-level swimmers. *International Journal of Sports Medicine*, *28*(9), 780-786-786. https://doi.org/10.1055/s-2007-964907

Kaufman, M., Nguyen, C., Shetty, M., Oppezzo, M., Barrack, M., & Fredericson, M. (2023). Popular dietary trends' impact on athletic performance: a critical analysis review. *Nutrients*, *15*(16), 3511. https://doi.org/10.3390/nu15163511

Kerksick, C. M., Arent, S., Schoenfeld, B. J., Stout, J. R., Campbell, B., Wilborn, C. D., Taylor, L., Kalman, D., Smith-Ryan, A. E., Kreider, R. B., Willoughby, D., Arciero, P. J., VanDusseldorp, T. A., Ormsbee, M. J., Wildman, R., Greenwood, M., Ziegenfuss, T. N., Aragon, A. A., & Antonio, J. (2017). International society of sports nutrition position stand: nutrient timing. *Journal of the International Society of Sports Nutrition*, *14*(1), 1-21. https://doi.org/10.1186/s12970-017-0189-4

Kerksick, C. M., Wilborn, C. D., Roberts, M. D., Smith-Ryan, A., Kleiner, S. M., Jäger, R., Collins, R., Cooke, M., Davis, J. N., Galvan, E., Greenwood, M., Lowery, L. M., Wildman, R., Antonio, J., & Kreider, R. B. (2018). ISSN exercise & sports nutrition review update: research & recommendations. *Journal of the International Society of Sports Nutrition*, *15*(1), 38. https://doi.org/10.1186/s12970-018-0242-y

Kim, J. (2020). Pre-sleep casein protein ingestion: new paradigm in post-exercise recovery nutrition. *Phys Act Nutr*, *24*(2), 6-10. https://doi.org/10.20463/pan.2020.0009

Kim, J., & Kim, E. K. (2020). Nutritional strategies to optimize performance and recovery in rowing athletes. *Nutrients*, *12*(6), 1-13. https://doi.org/10.3390/nu12061685

King, J. A., Miyashita, M., Wasse, L. K., & Stensel, D. J. (2010). Influence of prolonged treadmill running on appetite, energy intake and circulating concentrations of acylated ghrelin. *Appetite*, *54*(3), 492-498. https://doi.org/10.1016/j.appet.2010.02.002

Kölling, S., Steinacker, J. M., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016). The longer the better: sleep-wake patterns during preparation of the World Rowing Junior Championships. *Chronobiology International*, *33*(1), 73-84. https://doi.org/10.3109/07420528.2015.1118384

Kumar, V., Atherton, P., Smith, K., & Rennie, M. J. (2009). Human muscle protein synthesis and breakdown during and after exercise. *Journal of Applied Physiology*, *106*(6), 2026-2039. https://doi.org/10.1152/japplphysiol.91481.2008

Lee, T. C., Ivester, P., Hester, A. G., Sergeant, S., Case, L. D., Morgan, T., Kouba, E. O., & Chilton, F. H. (2014). The impact of polyunsaturated fatty acid-based dietary supplements on disease biomarkers in a metabolic syndrome/diabetes population. *Lipids in Health and Disease*, *13*(1), 261-283. https://doi.org/10.1186/1476-511X-13-196

Levy, E., & Chu, T. (2019). Intermittent fasting and its effects on athletic performance: a review. *Current Sports Medicine Reports*, *18*(7), 266-269. https://doi.org/10.1249/JSR.0000000000000614

Lewis, N. A., Daniels, D., Calder, P. C., Castell, L. M., & Pedlar, C. R. (2020). Are there benefits from the use of fish oil supplements in athletes? A systematic review. *Advances in Nutrition*, *11*(5), 1300-1314. https://doi.org/10.1093/advances/nmaa050

Li, Y., Hruby, A., Bernstein, A. M., Ley, S. H., Wang, D. D., Chiuve, S. E., Sampson, L., Rexrode, K. M., Rimm, E. B., Willett, W. C., & Hu, F. B. (2015). Saturated fats compared with unsaturated fats and sources of carbohydrates in relation to risk of coronary heart disease: a prospective cohort study. *Journal of the American College of Cardiology*, *66*(14), 1538-1548. https://doi.org/10.1016/j.jacc.2015.07.055

Longland, T. M., Oikawa, S. Y., Mitchell, C. J., Devries, M. C., & Phillips, S. M. (2016). Higher compared with lower dietary protein during an energy deficit combined with intense exercise promotes greater lean mass gain and fat mass loss: a randomized trial. *The American Journal of Clinical Nutrition*, *103*(3), 738-746. https://doi.org/10.3945/ajcn.115.119339

Lust, C. A. C., Mountjoy, M., Robinson, L. E., Oliver, J. M., & Ma, D. W. L. (2020). Sports-related concussions and subconcussive impacts in athletes: incidence, diagnosis, and the emerging role of EPA and DHA. *Applied Physiology, Nutrition & Metabolism*, *45*(8), 886-892. https://doi.org/10.1139/apnm-2019-0555

MacKenzie-Shalders, K. L., Byrne, N. M., Slater, G. J., & King, N. A. (2015). The effect of a whey protein supplement dose on satiety and food intake in resistance training athletes. *Appetite*, *92*, 178-184. https://doi.org/10.1016/j.appet.2015.05.007

Maier, S. P., Lightsey, H. M., Galetta, M. D., Usoro, A. O., & Oh, L. S. (2023). Plant-based diets and sports performance: a clinical review. *Sport Sciences for Health*, *19*, 1059–1081. https://doi.org/10.1007/s11332-023-01074-8

Manore, M. M., Patton-Lopez, M. M., Meng, Y., & Wong, S. S. (2017). Sport Nutrition Knowledge, Behaviors and Beliefs of High School Soccer Players. *Nutrients*, *9*(4). https://doi.org/10.3390/nu9040350

Martin, S. A., & Tomescu, V. (2017). Energy systems efficiency influences the results of 2,000 m race simulation among elite rowers. *Clujul Medical*, *90*(1), 60-65. https://doi.org/10.15386/cjmed-675

Masson, G., & Lamarche, B. (2016). Many non-elite multisport endurance athletes do not meet sports nutrition recommendations for carbohydrates. *Applied Physiology, Nutrition and Metabolism* *41*(7), 728-734. https://doi.org/10.1139/apnm-2015-0599

Maughan, R., Burke, L. M., International Olympic Committee, & Medical and Scientific Commission. (2012). *Nutrition for athletes: A practical guide to eating for health and performance*. International Olympic Committee. https://library.olympics.com/Default/doc/SYRACUSE/74010/nutrition-for-athletes-a-practical-guide-to-eating-for-health-and-performance-based-on-an-internatio?_lg=en-GB

Mazzulla, M., Volterman, K. A., Packer, J., Wooding, D. J., Brooks, J. C., Kato, H., & Moore, D. R. (2018). Whole-body net protein balance plateaus in response to increasing protein intakes during post-exercise recovery in adults and adolescents [article]. *Nutrition & Metabolism*, *15*(1), 1-11. https://doi.org/10.1186/s12986-018-0301-z

Mettler, S., Mitchell, N., & Tipton, K. D. (2010). Increased protein intake reduces lean body mass loss during weight loss in athletes. *Medicine & Science in Sports & Exercise*, *42*(2), 326-337. https://doi.org/10.1249/MSS.0b013e3181b2ef8e

Ministry of Health, & University of Otago. (2011). *A focus on nutrition: Key findings of the 2008/2009 New Zealand Adult Nutrition Survey.* Ministry of Health. https://www.health.govt.nz/system/files/documents/publications/a-focus-on-nutrition-v2.pdf

Miyamoto, M., Hanatani, Y., & Shibuya, K. (2021). Relationship among nutritional intake, anxiety, and menstrual irregularity in elite rowers. *Nutrients*, *13*(10), 3436. https://doi.org/10.3390/nu13103436

Monteyne, A., Martin, A., Jackson, L., Corrigan, N., Stringer, E., Newey, J., Rumbold, P. L. S., Stevenson, E. J., & James, L. J. (2018). Whey protein consumption after resistance exercise reduces energy intake at a post-exercise meal. *European Journal of Nutrition*, *57*(2), 585-592. https://doi.org/10.1007/s00394-016-1344-4

Moore, D. R. (2019). Maximizing post-exercise anabolism: the case for relative protein intakes. *Frontiers in Nutrition*, *6*. https://doi.org/10.3389/fnut.2019.00147

Moore, D. R., Churchward-Venne, T. A., Witard, O., Breen, L., Burd, N. A., Tipton, K. D., & Phillips, S. M. (2015). Protein ingestion to stimulate myofibrillar protein synthesis requires greater relative protein intakes in healthy older versus younger men. *The Journals of Gerontology: Series A*, *70*(1), 57-62. https://doi.org/10.1093/gerona/glu103

Moore, D. R., Robinson, M. J., Fry, J. L., Tang, E., Glover, I., Wilkinson, S. B., Prior, T., Tarnopolsky, M. A., & Phillips, S. M. (2009). Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. *The American Journal of Clinical Nutrition*, *89*(1), 161-168. https://doi.org/10.3945/ajcn.2008.26401

Morris, F. L., & Payne, W. R. (1996). Seasonal variations in the body composition of lightweight rowers. *British Journal of Sports Medicine*, *30*(4), 301-304. https://doi.org/10.1136/bjsm.30.4.301

National Health and Medical Research Council, Australian Government Department of Health and Ageing, & New Zealand Ministry of Health. (2006). *Nutrient reference values for Australia and New Zealand*. National Health and Medical Research Council. https://www.nhmrc.gov.au/about-us/publications/nutrient-reference-values-australia-and-new-zealand-including-recommended-dietary-intakes

New Zealand Olympic Committee. (2023). *Rowing*. NZOC. https://www.olympic.org.nz/sports/rowing/

Noll, M., De Mendonça, C. R., De Souza Rosa, L. P., & Silveira, E. A. (2017). Determinants of eating patterns and nutrient intake among adolescent athletes: a systematic review. *Nutrition Journal*, *16*(1). https://doi.org/10.1186/s12937-017-0267-0

Nowak, D., & Jasionowski, A. (2016). Analysis of consumption of energy drinks by a group of adolescent athletes. *International Journal of Environmental Research and Public Health*, *13*(8), 768. https://doi.org/10.3390/ijerph13080768

Oshima, S., Takehata, C., Sasahara, I., Lee, E., Akama, T., & Taguchi, M. (2017). Changes in stress and appetite responses in male power-trained athletes during intensive training camp. *Nutrients*, *9*(8), 912. https://doi.org/10.3390/nu9080912

Pasiakos, S. M., Vislocky, L. M., Carbone, J. W., Altieri, N., Konopelski, K., Freake, H. C., Anderson, J. M., Ferrando, A. A., Wolfe, R. R., & Rodriguez, N. R. (2010). Acute energy deprivation affects skeletal muscle protein synthesis and associated intracellular signaling proteins in physically active adults. *The Journal of Nutrition*, *140*(4), 745-751. https://doi.org/10.3945/jn.109.118372

Petersen, S. R., Gaul, C. A., Stanton, M. M., & Hanstock, C. C. (1999). Skeletal muscle metabolism during short-term, high-intensity exercise in prepubertal and pubertal girls. *Journal of Applied Physiology*, *87*(6), 2151-2156. https://doi.org/10.1152/jappl.1999.87.6.2151

Petrie, H. J., Stover, E. A., & Horswill, C. A. (2004). Nutritional concerns for the child and adolescent competitor. *Nutrition*, *20*(7), 620-631. https://doi.org/10.1016/j.nut.2004.04.002

Phillips, S. M., Atkinson, S. A., Tarnopolsky, M. A., & MacDougall, J. D. (1993). Gender differences in leucine kinetics and nitrogen balance in endurance athletes. *Journal of Applied Physiology*, *75*(5), 2134-2141. https://doi.org/10.1152/jappl.1993.75.5.2134

Riddell, M. C., Jamnik, V. K., Iscoe, K. E., Timmons, B. W., & Gledhill, N. (2008). Fat oxidation rate and the exercise intensity that elicits maximal fat oxidation decreases with pubertal status in young male subjects. *Journal of Applied Physiology (1985)*, *105*(2), 742-748. https://doi.org/10.1152/japplphysiol.01256.2007

Rogerson, D. (2017). Vegan diets: practical advice for athletes and exercisers. *Journal of the International Society of Sports Nutrition*, *14*(1), 36. https://doi.org/10.1186/s12970-017-0192-9

Rowing NZ. (2021). Aon Maadi Cup event programme. In. Cambridge: Rowing NZ.

Rumbold, P. L. S., St Clair Gibson, A., Stevenson, E., & Dodd-Reynolds, C. J. (2011). Agreement between two methods of dietary data collection in female adolescent netball players. *Appetite*, *57*(2), 443-447. https://doi.org/10.1016/j.appet.2011.06.013

Sabato, T. M., Walch, T. J., & Caine, D. J. (2016). The elite young athlete: strategies to ensure physical and emotional health. *Open Access Journal of Sports Medicine*, *7*, 99-113. https://doi.org/10.2147/OAJSM.S96821

Schoenfeld, B. J., Aragon, A., Wilborn, C., Urbina, S. L., Hayward, S. E., & Krieger, J. (2017). Pre- versus post-exercise protein intake has similar effects on muscular adaptations. *PeerJ*, *5*, e2825. https://doi.org/10.7717/peerj.2825

Schoenfeld, B. J., Aragon, A. A., & Krieger, J. W. (2013). The effect of protein timing on muscle strength and hypertrophy: a meta-analysis. *Journal of the International Society of Sports Nutrition*, *10*(1), 53. https://doi.org/10.1186/1550-2783-10-53

School Sport New Zealand. (2016). NZSSSC removes saction for lightweight rowing. Retrieved Sept 15 2023, from https://www.schoolsportnz.org.nz/newsarticle/47799

Sherman, W. M., Costill, D. L., Fink, W. J., & Miller, J. M. (1981). Effect of exercise-diet manipulation on muscle glycogen and its subsequent utilization during performance. *International Journal of Sports Medicine*, *2*(2), 114-118. https://doi.org/10.1055/s-2008-1034594

Short, S. H., & Short, W. R. (1983). Four-year study of university athletes' dietary intake. *Journal of American Dietetic Association*, *82*(6), 632-645.

Simonsen, J. C., Sherman, W. M., Lamb, D. R., Dernbach, A. R., Doyle, J. A., & Strauss, R. (1991). Dietary carbohydrate, muscle glycogen, and power output during rowing training. *Journal of Applied Physiology*, *70*(4), 1500-1505. https://doi.org/10.1152/jappl.1991.70.4.1500

Sims, S. T., Kerksick, C. M., Smith-Ryan, A. E., Janse de Jonge, X. A. K., Hirsch, K. R., Arent, S. M., Hewlings, S. J., Kleiner, S. M., Bustillo, E., Tartar, J. L., Starratt, V. G., Kreider, R. B., Greenwalt, C., Rentería, L. I., Ormsbee, M. J., VanDusseldorp, T. A., Campbell, B. I., Kalman, D. S., & Antonio, J. (2023). International society of sports nutrition position stand: nutritional concerns of the female athlete. *Journal of the International Society of Sports Nutrition*, *20*(1). https://doi.org/10.1080/15502783.2023.2204066

Spadine, M., & Patterson, M. S. (2022). Social influence on fad diet use: a systematic literature review. *Nutrition and Health*, *28*(3), 369-388. https://doi.org/10.1177/02601060211072370

Sports Dietitians Australia. (2023a). *Nutrition for the adolescent athlete*. Sports Dietitians Australia,. https://www.sportsdietitians.com.au/factsheets/across-the-lifespan/nutrition-for-the-adolescent-athlete/

Sports Dietitians Australia. (2023b). *Rowing*. Sports Dietitians Australia,. https://www.sportsdietitians.com.au/factsheets/food-for-your-sport/rowing/

Spriet, L. L. (2014). New insights into the interaction of carbohydrate and fat metabolism during exercise. *Sports Medicine*, *44* (Suppl 1), S87-96. https://doi.org/10.1007/s40279-014-0154-1

Steen, S. N., & Brownell, K. D. (1990). Patterns of weight loss and regain in wrestlers: has the tradition changed? *Medicine & Science in Sports & Exercise*, *22*(6), 762-768. https://doi.org/10.1249/00005768-199012000-00005

Steen, S. N., Mayer, K., Brownell, K. D., & Wadden, T. A. (1995). Dietary intake of female collegiate heavyweight rowers. *International Journal of Sport Nutrition*, *5 3*, 225-231.

Stellingwerff, T. (2013). Contemporary nutrition approaches to optimize elite marathon performance. *International Journal of Sports Physiology and Performance*, *8*(5), 573-578. https://doi.org/10.1123/ijspp.8.5.573

Stellingwerff, T., Jonkers, R. A. M., Senden, J. M., Koopman, R., Van Loon, L. J. C., Boon, H., & Spriet, L. L. (2007). Significant intramyocellular lipid use during prolonged cycling in endurance-trained males as assessed by three different methodologies. *American Journal of Physiology, Endocrinology and Metabolism*, *292*(6), E1715-E1723. https://doi.org/10.1152/ajpendo.00678.2006

Stellingwerff, T., Maughan, R. J., & Burke, L. M. (2011). Nutrition for power sports: middle-distance running, track cycling, rowing, canoeing/kayaking, and swimming. *Journal of Sports Sciences*, *29*, S79-S89. https://doi.org/10.1080/02640414.2011.589469

Tarnopolsky, L. J., MacDougall, J. D., Atkinson, S. A., Tarnopolsky, M. A., & Sutton, J. R. (1990). Gender differences in substrate for endurance exercise. *Journal of Applied Physiology (1985)*, *68*(1), 302-308. https://doi.org/10.1152/jappl.1990.68.1.302

Taylor, D. J., Kemp, G. J., Thompson, C. H., & Radda, G. K. (1997). Ageing: effects on oxidative function of skeletal muscle in vivo. *Molecular and Cellular Biochemistry: An International Journal for Chemical Biology in Health and Disease*, *174*(1-2), 321-324. https://doi.org/10.1023/a:1006802602497

Thomas, D. T., Erdman, K. A., & Burke, L. M. (2016). Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. *Journal of the Academy of Nutrition and Dietetics*, *116*(3), 501-528. https://doi.org/10.1016/j.jand.2015.12.006

Timmons, B. W., Bar-Or, O., & Riddell, M. C. (2003). Oxidation rate of exogenous carbohydrate during exercise is higher in boys than in men [Article]. *Journal of Applied Physiology*, *94*(1), 278-284-284. https://doi.org/10.1152/japplphysiol.00140.2002

Tinline-Goodfellow, C. T., West, D. W. D., Malowany, J. M., Gillen, J. B., & Moore, D. R. (2020). An acute reduction in habitual protein intake attenuates post exercise anabolism and may bias oxidation-derived protein requirements in resistance trained men. *Frontiers in Nutrition*, *7*, 55. https://doi.org/10.3389/fnut.2020.00055

Tipton, K. D., Ferrando, A. A., Phillips, S. M., Doyle, J., David, & Wolfe, R. R. (1999). Postexercise net protein synthesis in human muscle from orally administered amino acids. *American Journal of Physiology-Endocrinology and Metabolism*, *276*(4), E628-E634. https://doi.org/10.1152/ajpendo.1999.276.4.E628

Torun, B. (2005). Energy requirements of children and adolescents. *Public Health Nutrition*, *8*(7a), 968-993. https://doi.org/10.1079/PHN2005791

Trommelen, J., & Van Loon, L. J. C. (2016). Pre-sleep protein ingestion to improve the skeletal muscle adaptive response to exercise training. *Nutrients*, *8*(12), 763. https://doi.org/10.3390/nu8120763

Ueda, S. Y., Yoshikawa, T., Katsura, Y., Usui, T., & Fujimoto, S. (2009). Comparable effects of moderate intensity exercise on changes in anorectic gut hormone levels and energy intake to high intensity exercise. *Journal of Endocrinology*, *203*(3), 357-364. https://doi.org/10.1677/joe-09-0190

Van Erp-Baart, A. M., Saris, W. H., Binkhorst, R. A., Vos, J. A., & Elvers, J. W. (1989). Nationwide survey on nutritional habits in elite athletes. Part I. Energy, carbohydrate, protein, and fat intake. *International Journal of Sports Medicine*, *10* (Suppl 1), S3-10. https://doi.org/10.1055/s-2007-1024947

Van Loon, L. J., Saris, W. H., Kruijshoop, M., & Wagenmakers, A. J. (2000). Maximizing postexercise muscle glycogen synthesis: carbohydrate supplementation and the application of amino acid or protein hydrolysate mixtures. *American Journal of Clinical Nutrition*, *72*(1), 106-111. https://doi.org/10.1093/ajcn/72.1.106

Vatansever-Ozen, S., Tiryaki-Sonmez, G., Bugdayci, G., & Ozen, G. (2011). The effects of exercise on food intake and hunger: relationship with acylated ghrelin and leptin. *Journal of Sports Science & Medicine*, *10*(2), 283-291. https://pubmed.ncbi.nlm.nih.gov/24149873/

Wallin, A., Di Giuseppe, D., Orsini, N., Patel, P. S., Forouhi, N. G., & Wolk, A. (2012). Fish consumption, dietary long-chain n-3 fatty acids, and risk of type 2 diabetes: systematic review and meta-analysis of prospective studies. *Diabetes Care*, *35*(4), 918-929. https://doi.org/10.2337/dc11-1631

Wang, L., Tao, L., Hao, L., Stanley, T. H., Huang, K.-H., Lambert, J. D., & Kris-Etherton, P. M. (2020). A moderate-fat diet with one avocado per day increases plasma antioxidants and decreases the oxidation of small, dense LDL in adults with overweight and obesity: a randomized controlled trial. *Journal of Nutrition*, *150*(2), 276-284. https://doi.org/10.1093/jn/nxz231

Witard, O. C., Garthe, I., & Phillips, S. M. (2019). Dietary protein for training adaptation and body composition manipulation in track and field athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(2), 165-174. https://doi.org/10.1123/ijsnem.2018-0267

World Health Organisation. (2015). *Guideline: sugars intake for adults and children*. https://www.who.int/publications/i/item/9789241549028

Xyris Pty Ltd. (2019). *FoodWorks 10 Professional*. In (Version v10.0) Xyris Pty Ltd.

Ziegler, P., Sharp, R., Hughes, V., Evans, W., & Khoo, C. S. (2002). Nutritional status of teenage female competitive figure skaters. *Journal of the American Dietetic Association*, *102*(3), 374-379. https://doi.org/10.1016/S0002-8223(02)90086-6

Zorn, S. P. (2017). *Body composition, dietary habits, and rowing performance of male collegiate club rowers* [Master's thesis, Ohio State University]. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=osu149269022744971

Chapter 5 : Appendices

Dietary intake of adolescent rowers within New Zealand

Information Sheet

Invitation to participate.

We would like to invite you to participate in this study investigating dietary intake in New Zealand Rowers. The purpose of this research is to understand how young rowers are eating and fuelling their training and competitions. Increasing our understanding of current dietary intake habits of young rowers will help us to build nutrition education resources for athletes, parents and coaches that may support athletes in achieving optimal rowing performance.

Please read the information sheet provided here in full before deciding whether to participate. If you are under the age of 16 years, then please ensure that your parents read this information sheet with you and decide together if you wish to participate.

For further details on the study please feel free to contact the lead researcher:

Dr Claire Badenhorst
Lecturer
School of Sport, Exercise and Nutrition
College of Health
Massey University
Email: C.Badenhorst@massey.ac.nz
Phone: (09) 414 0800 ext 43410

Why are we doing this research?

Rowing is one of the key sports within New Zealand, in 2021 more than 2500 school aged rowers participated in the largest sporting event in the southern hemisphere, the Maadi Cup. More recently the elite Rowing New Zealand squad returned from the Tokyo Olympic Games with 3 gold and 2 silver medals. Athlete health and wellbeing was a key focus for Rowing New Zealand in the preceding Olympic cycle (2017-2021), with the athlete health support staff initiating a health and nutrition programme in 2018. Rowing New Zealand's health and nutrition programme focused on optimising nutritional intake and avoiding chronic low energy availability states in elite rowers. The success of the health and nutrition programme in Rowing New Zealand, and the relatively young age of the elite squad (median age of 23 years) has prompted the health support staff to investigate nutritional intake in adolescent rowers.

Therefore, the aim of this research is to investigate the current dietary intake of adolescent male and female rowers within New Zealand. Results from this research will be used to build national nutritional education resources for this age group of athletes, coaches, and parents to address nutritional concerns that are identified throughout the research. These resources will help in upskilling the athletes and their support network on nutritional practices that promote longevity in rowing and sport in general.

Who are we looking for?

We are looking to recruit 40 adolescent rowers to participate in this study. To take part in the study you should:

- Be between the ages of 14-21 years.
- Have participated in rowing for at least 1 season (start of 2020) and be actively rowing and not a coxswain.
- Be proficient in English.
- Male and female athletes are all welcomed to participate.
- Not pregnant

What is going to happen?

If you decide to take part in this study after you have read and had time to consider the information contained within this information sheet, the researchers will then set up a time for your first session. This will take place at Massey University Auckland Campus or at a researcher approved School/Rowing Club facility.

During this first session (email, phone call or zoom) the researchers will ensure informed consent has been collected from yourself and/or parental guardian if you are under the age of 16 years before completing any data collection. You will complete a short online questionnaire that will collect information about; age, ethnicity, medical history (last 12 months), choice of dietary pattern, supplement use, years of rowing experience, preferred rowing format (sweep or scull) and which boat your training/racing is predominantly completed in (e.g., single, four, quad, eight).

Following this, the researcher will provide details and instructions on how to collect a food record. The researchers and participants will then identify 4 days in the next 3-4 weeks, specifically they will identify, two days in a light/recovery training week and the remaining two days will be in the build 3/ heavy training week. This first session will take ~30-45 minutes.

On selected data collection days, participants will be asked to complete visual and written 24-hour food records of all food and drink consumed on these days. For the visual food record, participants will take photos of all their ingested food and drink and will write down a description of the food and meals consumed. At the completion of a data collection day, food records (pictures and written) will be sent through to the researchers. Within 48 hours of receiving the food record the researchers will contact the participants via a phone call. The timing of this call will be selected by the participants to ensure it occurs at a time that best suits them. During this call researchers will look to answer and clarify any questions that participants may have on food and drink entry and discuss any difficulties that they may have encountered during the data collection period. These calls will only last ~20 minutes. Data available for each training session completed during the data collection days including heart rate (if available), training duration, training intensity and rating of perceived exertion, will be collected from the coaches and participants. This too may be checked on the phone call at the end of the data collection day.

Total time for data collection over the 1-2 months will be:

- ~45-60 minute first sessions for informed consent, questionnaire completion and body composition assessment
- 4 x 24-hour food record with no restriction on daily activity or social interactions
- 4 x ~20 min phone calls within 48 hours after day of data collection

Data Management

The data will be used only for the purposes of this project and no individual will be identified. Only the investigators and administrators of the study will have access to personal information, and this will be kept secure and strictly confidential. At the first session participants will be assigned a study identification number. All data will then be stored under this identification number to ensure that all data is stored in a confidential manner. Results of this project will be presented as group averages to ensure that no individual will be able to be identified from the data set. The overall summary of the results may be published or presented at conferences or seminars to both and academic and general population audiences. At the end of this study the list of participants and their study identification number will be disposed of. Any raw data on which the results of the project depend will be retained in secure storage for 10 years, after which it will be destroyed. A summary of the project findings will be available to all study participants. All participants will be sent this information via email or a personal letter.

Participants Rights

You are under no obligation to accept this invitation. Should you choose to participate, you have the right to:

- Withdraw from the study at any time, even after signing a consent form (if you choose to withdraw you cannot withdraw your data from the analysis after the data collection has been completed)
- Ask any questions about the study at any time during participation.
- Provide information on the understanding that your name will not be used unless you give permission to the researcher.
- Be given access to a summary of the project findings when it is concluded.
- Be given access to any data (body composition and food records) at any time point throughout the study.
- Your participation is completely voluntary and will not be shared with coaches, clubs, or sporting organisations (e.g., Rowing New Zealand)
- Your participation will not affect your crew selection as individual information will not be shared with coaches or clubs/schools.
- If the participant is interested in receiving nutritional support, details for registered dietitians will be provided to athletes at study completion.

What are the benefits and risks of taking part in this study?

You will receive a report providing a summary of the main findings of the project via email. In addition, as koha for your participation all participants will receive a $50 voucher.

The principal benefit of the study is that you are contributing to our understanding of nutritional habits in young rowers throughout New Zealand. This will provide insight on whether the nutritional intake of adolescent rowers is sufficient to support their health, training, and competition performance. We will then be able to utilise the results to build evidence-based educational resources for yourself and fellow athletes to ensure that young rowers throughout New Zealand are achieving nutritional requirements for health and sport performance.

We do acknowledge that there are some potential psychological risks associated with participation. This may include psychological discomfort with body composition and dietary intake assessments. To ensure minimal risk to the participant:

- Dietary assessment verification calls will be set at a time where the individual can complete the call in a private location of their choice (e.g., at home in the evening). This information will be stored under the participants identification number and will not be shared with coaches, parents or sporting clubs/schools/organisations or selectors.
- All presented results will be overall study results and no individual data will be presented or be able to be identified.
- Participation in the study will not be shared with coaches or sporting clubs/schools/organisations or selectors, this is to ensure that participation does not influence crew selection for the individual.
- Any physical risk of COVID-19 will be controlled for by ensuring all researchers and participants are fully vaccinated for COVID-19. All body composition assessment equipment will be thoroughly sanitized before each participant. Researchers will ensure they are abiding by any current COVID-19 restrictions at the time of data collection, including social distancing, frequent hand and equipment sanitation and use of face masks.

Support process

If the participant wishes to receive dietary support or counsel during the study, the researchers will provide details of registered dietitian/s at the study completion. All results (body composition and food records) will be provided to the participant so that they may obtain additional dietary advice from a registered dietitian. Usual fees for dietary analysis support will likely apply and participants will need to consult with the dietitian on their pricing.

Project Contacts

If you have any questions regarding this study, please do not hesitate to contact either of the following people for assistance:

Principal Researchers:

Dr Claire Badenhorst (School of Sport, Exercise and Nutrition)

C.Badenhorst@massey.ac.nz

(09)414 0800

Rebecca Paul

R.Paul@massey.ac.nz

021 2200092

Dr Kathryn Beck

K.L.Beck@massey.ac.nz

(09)414 0800

Ethics Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 21/70. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email humanethicsoutha@massey.ac.nz.