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Energy intake and energy balance in male and female adolescent rowers in New Zealand

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

Background Adequate energy intake (EI) is essential for adolescent athletes to support health, performance, and growth. Rowing is a physically demanding sport where intense training begins in adolescence. Research is needed to assess whether current EI is sufficient to support healthy physiological functions and training in adolescent rowers. The aim of this study was to evaluate the energy status (energy availability (EA) or energy balance (EB)) including EI and exercise energy expenditure (EEE) of adolescent rowers in New Zealand.

Methods A total of 35 rowers (23 females, 16.8 ± 1.9 yrs; 12 males, 17.3 ± 1.6 yrs) who had been rowing for at least one season participated. Energy balance for all participants was calculated using estimated body weight (23 females, weight 71.6 ± 9.7 kg; 12 males, weight 72.6 ± 10.7 kg). A bioimpedance analyser measured body composition in 11 participants (8 females, weight 63.0 ± 7.0 kg, fat-free mass (FFM) 50.8 ± 6.5 kg; 3 males, weight 78.5 ± 15.9 kg, FFM 70.7 ± 12.2 kg) enabling calculation of EA. All participants completed four days of food and training diaries, two 'recovery' and two 'hard' training days. EI was determined in FoodWorks10 software using the New Zealand Food Composition Database. For training, metabolic equivalent of tasks (MET) were assigned using body weight, heart rate and rating of perceived effort to estimate EEE. Paired sample t-tests or Wilcoxon Signed Rank test (non-parametric data) were used to determine differences between EI, EEE, EA and EB on the high and low training days for each gender. Significance was set at $p < 0.05$.

Results The average EI for females on hard and recovery days was 2584.6 ± 678.3 kcal and 2492.6 ± 618.7 kcal respectively, and for males was 3655.1 ± 792.5 kcal and 3183.3 ± 1078.2 kcal respectively. No significant differences were found between EI on hard vs. recovery days in both genders. Significant differences between average EEE on hard vs. recovery days were found in both genders (females, hard day 1108.8 ± 541.6 kcal, recovery day 757.3 ± 431.6 kcal, $p < 0.001$; males, hard day 1574.9 ± 686.0 kcal, recovery day 794.9 ± 690.8 kcal, $p = 0.001$). The average EB across hard and recovery training days was 65.5 ± 524.0 kcal for females and 236.4 ± 913.9 kcal for males. Both genders had no significant difference in EB between hard and recovery training days (females $p = 0.341$, males $p = 0.433$). EA on hard and recovery training days was classified as subclinical for both genders at 35.8 ± 12.6 kcal·FFMkg⁻¹·day⁻¹ and 38.2 ± 26.2 kcal·FFMkg⁻¹·day⁻¹ for females and males respectively. No significant difference in EA between hard and recovery days was found in either gender.

(females $p=0.934$, males $p=0.212$). The average carbohydrate (CHO) intake ranged between $2.4\text{-}7.0\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ for females and $2.2\text{-}8.7\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ for males, both beginning below sport nutrition recommendations.

Conclusion The results suggest that adolescent rowers do not adjust their nutritional intake to match EEE. This may increase the risk of adolescent rowers presenting with suboptimal EB or EA.

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List of Abbreviations

Abbreviation	Term
BC	Body Composition
BIA	Bioelectrical Impedance Analysis
BMR	Basal metabolic rate
CHO	Carbohydrate
DXA	Dual-energy X-ray Absorptiometry
EA	Energy Availability
EB	Energy Balance
EEE	Exercise Energy Expenditure
EI	Energy Intake
FFM	Fat-Free Mass
FFQ	Food Frequency Questionnaire
FISA	The International Rowing Federation
GI	Gastrointestinal
IOC	International Olympic Committee
IOC REDs CAT2	International Olympic Committee Relative Energy Deficiency in Sport Clinical Assessment Tool V.2
LEA	Low Energy Availability
MET	Metabolic Equivalent of Task
NRV	Nutrient Reference Value
NZSSSC	School Sport New Zealand
REDs	Relative Energy Deficiency in Sport
RPE	Rate of Perceived Exertion
RMR	Resting Metabolic Rate
SDA	Sports Dietitians Australia
TEE	Total Energy Expenditure

Chapter 1: Purpose

1.1 Purpose

Rowing is a popular sport in New Zealand, with participation from adolescents through to adult elite level and masters programmes. The pinnacle secondary school event within New Zealand, the Maadi Cup, reflects this, with statistics from March 2021 reporting that over 120 schools and approximately 2000 adolescent rowers participated in the weeklong regatta (Rowing New Zealand, 2021). The prominence of elite Rowing New Zealand has been demonstrated by the success had at the 2020 Tokyo Olympic Games, with the squad returning with 12 gold and 11 silver medals. A key focus of Rowing New Zealand across the most recent Olympic Games cycle (2017-2021) was the health and well-being of the athletes in the elite Rowing New Zealand squad. A component was the health and nutrition programme that was launched by athlete health support staff in 2018. Since the implementation of this, elite rowers have publicly spoken about how a change in their mindset and a change in the culture within Rowing New Zealand had supported a shift in their eating behaviours before the Tokyo games. Cumulatively, this was seen as a major contributor to their successful performance outcomes (Newsroom, 2021).

Rowing is a power sport that typically involves a high volume of training, where athletes often complete two or more sessions per day. To sustain training ability and performance, adequate energy intake (EI) is essential for athletes (Stellingwerff et al., 2011). Therefore, the health and nutrition programme implemented by Rowing New Zealand prioritised optimising an athlete's energy availability (EA) through their nutritional intake, to prevent an elite rower from being in a state of problematic low energy availability (LEA) (Mountjoy et al., 2023). Energy availability has been proposed by the scientific literature as a measure of energy status in athletes (Stellingwerff et al., 2019). The calculation of EA is defined as EI minus exercise energy expenditure (EEE), relative to fat-free mass (FFM) e.g., $(EI - EEE) / FFM$. The remaining energy is then suggested to represent the amount of energy available from dietary intake for additional physiological functions, such as reproduction, bone health and growth (Loucks et al., 2011). Recent literature suggests that an appreciable portion of athletes and recreational exercisers may be underfuelling for the exercise they are completing. Consequently, this places them in an unintentional, chronic, and at times severe state of problematic LEA. As a

result, these athletes may present with symptoms associated with suboptimal physiological functioning (Ackerman et al., 2019; Slater et al., 2016). Studies in females have suggested that a possible optimal EA threshold for normal physiological function (e.g., regular menstrual cycles) occurs at an EA of $\sim 45 \text{kcal} \cdot \text{FFMkg}^{-1} \cdot \text{day}^{-1}$. This research has proposed that the probable threshold where physiological dysfunction (e.g., oligomenorrhea or amenorrhea) occurs for females is when EA is at $< 30 \text{kcal} \cdot \text{FFMkg}^{-1}$ per day (Burke & Vicki, 2015; Loucks & Thuma, 2003).

Vulnerable populations at higher risk of problematic LEA include sports with a weight class (e.g., rowing or boxing), endurance sports (e.g., running, cycling, triathlon) and sports with an aesthetic component in the performance objectives (e.g., gymnastics, synchronised swimming, ballet) (Melin et al., 2019; Mountjoy et al., 2014). Chronic or severe states of problematic LEA may arise intentionally, whereby an athlete purposely restricts their EI and/or is overtraining (Wasserfurth et al., 2020). These eating and exercise behaviours may be associated with high levels of body dissatisfaction, creating a belief that being a lower body weight will increase performance, or through societal (social media, coaches) pressures to look and eat a certain way (Heather et al., 2021). Research on New Zealand elite female athletes found that 54% felt pressure to look feminine, while 15% had engaged in disordered eating to achieve a perceived body ideal (Heather et al., 2021). Conversely, problematic LEA may arise unintentionally, especially in high-energy expenditure sports such as rowing. This can occur when the EI of the athlete is not matched to their EEE (Wasserfurth et al., 2020). Research suggests that exercise-induced appetite suppression may be a contributing factor to unintentional problematic LEA in highly trained athletes (Howe et al., 2016). Additionally, inadvertent undereating and lack of nutritional knowledge by athletes have also been proposed as possible contributors to problematic LEA (Torres-McGehee et al., 2021). In 2014 the International Olympic Committee (IOC) released a consensus statement that identified problematic LEA as the main aetiology factor of the syndrome, Relative Energy Deficiency in Sport (REDs) (Mountjoy et al., 2014, 2023). Recognised as an extension of the 'Female Athlete Triad,' REDs is defined as physiological dysfunction attributed to relative energy deficiency and includes, however, is not limited to disruption of metabolic health, hormonal state (e.g., menstruation), bone health (e.g., stress fractures and decreased bone mineral density), immunity, protein synthesis (e.g., poor muscle recovery), gastrointestinal function and

cardiovascular health (Mountjoy et al., 2018). The presence of one or more of these problematic LEA/REDs symptoms acutely or chronically is noted to impact both the physical and mental health of an athlete. Ultimately this can impair an athlete's capacity to compete in their chosen sport, in both daily training and during competition (Ackerman et al., 2019).

Emerging evidence suggests that the distribution of EI across 24 hours can significantly influence the EA status of an individual. It has been reported that both male and female athletes who spend more time in a within-day energy deficit, may pose a higher risk of experiencing the adverse physiological side effects of problematic LEA (even if total EI for the 24 hours is adequate) (Fahrenholtz et al., 2018; Torstveit et al., 2018). More severe restrictive dietary intake practices such as 24 hour fasting, have also been shown to exacerbate the presentation of REDs symptoms, with evidence for this diet showing a reduction in bone turnover in lightweight male rowers (Talbot & Shapses, 1998). Additionally, in line with the REDs research, the increased incidence of rib stress injuries in rowers has been attributed to problematic LEA (Thornton et al., 2016). Conversely, the periodisation of EI within a rowing training cycle has proven a successful tool to optimise an athlete's performance and recovery (Kim & Kim, 2020). Periodisation in a sporting context refers to the intentional sequencing of different training focuses and loads that optimally prepare an athlete for a desired performance (Stellingwerff et al., 2011). Hence, periodisation of nutrition implies that an athlete's EI should reflect the fluctuations in their training load (EEE). This enables adequate EA, optimal physiological function, and performance throughout the athlete's training. Specifically, the periodisation of carbohydrate (CHO) intake appears most important for rowers (Kim & Kim, 2020; Simonsen et al., 1991). Adequate CHO ingestion has been found to increase rowers' energy levels and their readiness to perform at subsequent training sessions (Kim & Kim, 2020). Current evidence suggests that rowers may not be adequately periodising their EI, as demonstrated by a study on the Lithuanian Olympic rowing squad. This study found rowers did not consume sufficient EI to meet their EEE, and specifically their diets lacked carbohydrates, fibre, and omega-3 fatty acids (Baranauskas et al., 2018). This research suggests that there are potential education gaps in the nutritional knowledge of rowers, which ultimately can withhold athletes from optimising their performance across a given training cycle (Heikkilä et al., 2018).

For adolescent athletes, adequate EA is essential to fulfil their growth and development requirements in addition to their high physical activity demands (Matt et al., 2021). Adolescent athletes are exposed to numerous risk factors that may predispose them to enter a problematic LEA state. These include high training loads ranging from 10-18 hours per week, high psychological stress from training or competition and lack of access to nutrition support (Georgopoulos et al., 2010). Additionally, adolescent rowers may lack access to qualified nutrition professionals and therefore rely on nutrition advice from coaches, peers, family, social media, or other media sources (Heather et al., 2021; Wasserfurth et al., 2020). Reliance on the latter has been associated with New Zealand athletes experiencing pressure to achieve a certain physical appearance to perform at their best and to be accepted by society and coaches (Heather et al., 2021). Appearance-related pressure is considered to be detrimental to the physical and mental health of New Zealand athletes. Previously reported outcomes included increases in disordered eating behaviours, menstrual cycle disruption, incidence of stress fractures and diagnosis of nutrient deficiencies (e.g., iron deficiency) (Heather et al., 2021). These findings highlight the need in New Zealand for informed nutritional information to be available for athletes. This may act to reduce the likelihood of athletes entering a state problematic LEA and hence reduce their predisposition to adverse health outcomes. Conversely, it may be considered that the attainment and maintenance of adequate EA allows for adolescent athlete's physiological potential to be achieved, their physiological health to be maintained and could promote longevity in their chosen sport. However, no research has investigated the EA status of New Zealand adolescent athletes or rowers. This area is in need of research as adolescent athletes are exposed to similar performance and societal pressures as elite athletes, although they may not have the means or resources to access support from health and nutrition staff.

The positive performance outcomes upon the implementation of the health and nutrition programme by Rowing New Zealand, along with the relatively young age of the elite squad (23-years median age) have prompted the health support staff to consider the nutritional status of adolescent rowers in New Zealand. Adolescent rowers experience high volumes of training and competition, which makes these developmental years significant for the preceding generation of elite rowers to enter the High Performance Sport and Rowing New Zealand framework. Consequently, an investigation of New Zealand male and female

adolescent rower's EI is required to support these athletes' physiological health and longevity within the sport.

1.2 Aims

The aim of this research is to investigate the EI and energy status of male and female adolescent rowers in New Zealand.

1.2.1 Objectives

The key objectives of this project are to:

- a. Assess the EI of adolescent rowers in New Zealand.
- b. Assess the EEE of adolescent rowers in New Zealand.
- c. Determine any associations or variations between adolescent rowers' EI and their exercise training intensity and volume.
- d. Assess the energy status (EA or EB) of adolescent rowers in New Zealand.
- e. Describe the CHO intake of adolescent rowers in New Zealand in relation to their energy status.

1.2.2 Hypothesis

- a. EI on hard training days will be higher than on recovery training days.
- b. EEE on hard training days will be higher than on recovery training days.
- c. A significant portion of adolescent rowers will not be meeting their estimated energy requirements via daily EI and will be classified as being in a state of LEA.
- d. Energy status of adolescent rowers will on average be suboptimal (subclinical EA, LEA, or negative EB).
- e. CHO intake of adolescent rowers presenting with a suboptimal energy status will be below sports nutrition guidelines.

1.3 Structure of the Thesis

The thesis begins by introducing the concept of EA in rowers. It then describes how being in a state of problematic LEA may result in numerous adverse physiological outcomes that can impact an athlete's health and performance during training and competition. This initial chapter concludes with the aims, objectives, and hypotheses of the thesis. Proceeding this, chapter two provides an in-depth review of the literature, including EI, EA, problematic LEA and REDs in athletes and rowers. It discusses the importance of EI for sporting performance in rowers and identifies the gaps in the current sports nutrition guidelines for the adolescent

population. Chapter three is the research manuscript that presents a complete representation of the study conducted, inclusive of the abstract, introduction, methods, results, discussion, and conclusion. Finally, chapter four concludes the findings of this thesis and assesses the achievement of the aims and objectives of this study. The research's impact and contribution to Rowing New Zealand are also presented, along with the strengths and limitations of the study. The thesis is concluded with recommendations for the future outlined.

1.4 Researchers' Contributions

Table 1.1: Summary of researchers' contributions to the study	
Author	Contribution to Thesis
Jessie Speedy MSc (Nutrition and Dietetics) student	Primary author of thesis Food record data entry and analysis Statistical analysis of food records, exercise, and EA Interpreted and presented the results
Dr Claire Badenhorst Primary Supervisor Senior Lecturer School of Sport, Exercise and Nutrition	Primary Supervisor Ethics application Assisted in interpretation of results Assisted in statistical analysis Revised and approved thesis
Dr Kathryn Beck Co-Supervisor Associate Professor School of Sport, Exercise and Nutrition	Co-supervisor Assisted in interpretation of results Assisted in statistical analysis Revised and approved thesis
Rebecca Paul Research Officer School of Sport, Exercise and Nutrition	Primary research officer of the study Assisted in data entry
Samantha Watts Co-researcher MSc (Nutrition and Dietetics) student	Co-researcher Assisted in data entry Assisted in analysis

Chapter 2: Literature review

2.0 Introduction

Adequate energy intake (EI) is important for the health and sporting performance of endurance athletes. The amount of energy that should be ingested by an athlete should primarily be sufficient to support optimal body function, however, it can be adjusted to manipulate body composition as required (Heydenreich et al., 2017). The amount of energy required by an athlete is the sum of individual (e.g., resting metabolic rate (RMR)) and environmental factors related to their chosen sport, with hormonal, social and behavioural factors, as well as the accessibility of food, influencing the amount of energy consumed by an athlete (Holtzman & Ackerman, 2019).

Rowing is a physically demanding sport where intense training (10+ hours/week) typically begins in an athlete's adolescent years. In this population, achieving adequate EI to avoid entering a state of problematic low energy availability (LEA), is vital to support the physiological growth and development of athletes and to promote the sporting longevity of these athletes. A recent qualitative descriptive study investigated why eight high school students in New Zealand had discontinued rowing after three to four seasons. The main reasons were that they felt pressured to leave the sport, they felt incompetent in their ability, and they did not feel a part of the team culture. The study raised concerns about the potential harmful effects of weight-restricted sports in adolescents, the drive for results over physiological function and dissatisfaction in athletes stemming from coaches' comments (Walters et al., 2017).

Based on the available literature, this review aims to highlight the energy requirements for adolescent athletes in New Zealand. This review will provide details on assessing EA in athletes and previous studies' findings on the dietary habits of rowers. The review will also provide details on the implications of both optimal and inadequate nutritional intake on athlete health and sporting performance.

2.1 Adolescent Athletes

Participation in sports in the years of adolescence has been associated with many positive outcomes. These include greater self-esteem, social interaction, increased bone mineral density, better academic performance and increased life satisfaction (Thein-Nissenbaum & Hammer, 2017; Valois et al., 2004). Adolescence is a time of rapid growth and physiological development, regardless of physical activity level. Changes occur in body composition (BC), metabolically and hormonally and organ systems, along with the formation of nutrient deposits, which all influence future health (Sawyer et al., 2012). The nutrient reference values (NRVs) and general community-based nutrition guidelines account for general activity and some sporting involvement of adolescents. However, some adolescents participate in sports with a higher level of commitment and performance which requires additional consideration of the individual's nutritional intake (Desbrow et al., 2014). Therefore, an adolescent athlete's nutrition requirements should ensure dietary EI is sufficient to support physiological development in conjunction with the energy requirements of the developing athlete's training and competition (Desbrow et al., 2014). Additionally, adolescence is an important period that establishes an individual's relationship with food and where lifelong nutrition habits are learned. As such, adolescence is a phase of life where an athlete is most likely to develop their mindset toward diet, physical activity and body image (Desbrow et al., 2014).

Leading sports organisations such as the American Dietetic Association have well-developed sport nutrition guidelines for adult athletes (ADA et al., 2009). However, specialised support and regular delivery of nutrition education are advised for coaches and parents of adolescent athletes (Mountjoy et al., 2008). The Sports Dietitians Australia (SDA) Position Statement, for Sports Nutrition for the Adolescent Athlete (Desbrow et al., 2014), suggests that an athlete's eating pattern should reflect their daily physical activity demands, sporting performance and basal metabolic rate (BMR) to support health and physical performance. Interestingly, New Zealand does not have specific sports nutrition guidelines for adolescents, as such most nutritional and dietetic experts rely on the recommendations provided by Australia. The New Zealand and Australian NRVs provide nutrition recommendations across the lifespan. These values are aimed at the general population rather than those with increased nutrition needs

such as active adolescents whose total energy requirement is influenced by multiple factors such as physical activity levels, growth and physiological development.

2.2 Energy Availability, Energy Balance and Exercise Energy Expenditure

The concept of energy availability (EA) has acquired significant interest by scientific researchers in recent years due to its seemingly crucial role in optimal physiological functioning, and consequently, an individual's sporting performance (Mountjoy et al., 2014). Importantly, EA must be distinguished from the term 'energy balance' (EB). Fundamentally, EB includes all types of energy expenditure and is defined as dietary EI minus TEE ($EB = EI - TEE$) (Loucks, 2013). Whereas EA prioritises exercise energy expenditure (EEE) alone and relates EI only to EEE. Energy availability is calculated as dietary EI minus EEE relative to fat-free mass (FFM) ($EA = EI - EEE/FFM$) (Loucks et al., 2011). The outcome determines the amount of dietary EI left available for other basal physiological functions once the energy used by an individual's skeletal muscle (e.g., FFM) for locomotion has been considered. While both are descriptors of energy status, researchers have suggested that EA is a more useful parameter than EB when assessing the diet of athletes (Loucks et al., 2011). The preference for EA is due to the separation of TEE into energy for exercise and energy left available for basal physiological functioning (Stellingwerff et al., 2019). The term EA acknowledges that dietary EI is required to support multiple physiological processes such as reproduction, cellular maintenance, growth, immunity, and locomotion (Wade & Jones, 2004). When energy is used for one of these processes it is no longer accessible for any other processes (Wade & Jones, 2004). Therefore, EA can be viewed as energy input for the body to use in all the remaining basal physiological processes. Whereas EB may be considered as energy output of exercise and basal physiological processes (Areta et al., 2021).

To define EA in a sporting context and of relevance to this research, EEE, as per the equation previously stated must be known. The EEE of an individual is recognised and measured as the kilojoules required for physical activity, with this being any movement created by skeletal muscles resulting in energy expenditure (Siscovick et al., 1985). An accurate measure of EEE can be made using a well-established and accepted coding system that groups physical activity by rates of energy expenditure. Ainsworth et al., (1993), devised this system which

corresponds each physical activity with a five-digit code, thus classifying it by purpose and the type of activity. Each activity is then allocated a metabolic equivalent (MET) which can be used to determine the energy expenditure over time. A MET is a ratio of the energy expended during an activity to the rate of energy expended during rest. One MET represents the oxygen uptake while sitting at rest, which equates to 3.5ml of oxygen per kilogram body weight in a minute and represents the RMR per minute (Jetté et al., 1990). This coding system allows for greater comparability of results across studies that use self-reported physical activity (de Oliveira Goulart et al., 2022). The limitation of this method of measuring EEE is that it doesn't consider the individual variability associated with differing levels of skill, fitness, and intensity, as well as environmental factors (Mielgo-Ayuso et al., 2015). However, the rating of perceived exertion (RPE) can be a useful measure to help correctly identify an activity within the MET compendium (Jetté et al., 1990). The MET activity list contains low to high intensity exercise, as such the use of the RPE is likely to support the correct selection of an activity for a MET calculation (Jetté et al., 1990). Other measures of EEE include direct calorimetry, which measures heat production, and indirect calorimetry which measures gas production and other factorial methods (e.g., prediction equations and activity tables). Factorial methods may be used when access to heart rate monitoring information is unavailable and when the physical activity of participants is generalised.

For adolescent athletes, adequate EA is essential given their energy requirements for growth and development, as well as the physical activity they are completing (Aerenhouts et al., 2011; Matt et al., 2021; Petrie et al., 2004). However, it is difficult to provide an exact daily energy requirement for adolescent athletes due to the great variability in growth and physical activity (Petrie et al., 2004). From a dietetics perspective, this demonstrates the need to individualise nutrition strategies for each athlete which ensure that a state of problematic LEA is not being implemented and maintained for a long period of time. It has been recognised that the energy requirements of growth have less of an influence on TEE than the energy requirements for physical activity (Torun, 2010). Hence this reinforces the idea that EA may be a better tool than EB when measuring the energy status of an individual. Therefore, an adolescent athlete's daily EI should provide energy for both the amount of sport and activity they are completing and for healthy growth and development (Desbrow et al., 2014).

2.3 Low Energy Availability

Research in recent years suggests that an appreciable number of athletes and recreational exercisers may be underfuelling the physical activity they are doing. Consequently, this places this population at high risk of entering a state of problematic LEA (Ackerman et al., 2019). In a problematic state of LEA an individual does not have enough energy to maintain 'normal' (homeostasis) physiological functions after accounting for EEE (Logue et al., 2018). The result of being in this state combined with additional sporting pressures can pose a multitude of adverse physiological, psychological, and behavioural outcomes. In such instances, an individual could experience disturbances to cognitive function (mood, depression, eating disorders), cardiovascular health, bone health, gastrointestinal health, immune function, reproductive health, muscle recovery and synthesis, and concentration (Logue et al., 2018). The most researched consequences of problematic LEA are menstrual dysfunction and low bone mineral density in female athletes. Impairment to bone metabolism is particularly relevant for adolescent athletes as this may be associated with an increased risk of stress fractures given that 50% of adult bone mineral density is accumulated between the onset of puberty and 18 years old (Loucks, 2006). It has been highlighted in more recent years that males are also at risk of problematic LEA and more research is required to understand the psychological and physiological consequences of problematic LEA for this sex (Logue et al., 2018).

Based on the results of clinical trials in sedentary females, the literature has proposed three thresholds of EA, these being optimal, subclinical, and problematic LEA (Burke & Vicki, 2015; Loucks & Thuma, 2003; Mountjoy et al., 2023). Optimal EA is considered to occur at approximately $45\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$ and is recommended to maintain normal physiological functions (e.g., regular menstrual cycle). Subclinical EA is suggested to be between the range of $30\text{-}45\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$. This is considered within the allowable range for athletes who are aiming to achieve weight loss as part of an overseen structured diet and exercise program for a short or set period (e.g., adaptable LEA (Mountjoy et al., 2023)). For a dietitian, an adaptable state of LEA can be a useful tool, which can occasionally be necessary for an athlete to achieve a certain weight class and can enable them to peak for a particular competition. However, following this phase of adaptable LEA for competition preparation, an athlete must resume

eating and exercise behaviours to promote a state of optimal EA (Wasserfurth et al., 2020). Finally, the threshold for problematic LEA has been defined as an EA of less than $30\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$. At this level physiological functions may become disrupted, with numerous researchers proposing that sporting performance will become compromised if this state is sustained for a prolonged period (Logue et al., 2018; Mountjoy et al., 2023). The applicability of these thresholds to the adolescent population has been accepted in the literature (Bass & Inge, 2010), however extensions are recognised. The SDA position statement states that EA calculated in adolescents must be matched to markers of growth and physiological development to decide whether an individual's EI is meeting their activity level and health needs (Desbrow et al., 2014). The statement also poses that the presentation of problematic LEA in adolescence should include other factors such as self-reported fatigue, delayed onset of puberty, menstrual cycle irregularities and low bone mineral density (Desbrow et al., 2014).

Athletic populations which are vulnerable to entering a state of problematic LEA include weight-sensitive sports (e.g., rowing, weightlifting), sports with an aesthetic component (e.g., dancing, gymnastics, synchronised swimming) and endurance sports (e.g., running, cycling, triathlon) (Melin et al., 2019; Mountjoy et al., 2023). Research has noted that problematic LEA may arise through inadequate dietary EI, an increase in physical activity (EEE), or a combination of these two factors. It is recognised that problematic LEA may be caused intentionally or unintentionally by an individual. Intentional causes of problematic LEA may be due to disordered eating behaviours, clinical eating disorders, or obsessive exercise (Mountjoy et al., 2023). Therefore, it is recommended that the psychological status of an individual, independent of their EI and EEE, should be considered as it may be a risk factor for the progression or development of problematic LEA (Mountjoy et al., 2023). Conversely, research in adolescent athletes and sedentary students has indicated that this cohort may be prone to entering states of unintentional problematic LEA. In a cohort of athletes and sedentary individuals who were in a problematic LEA state, it was found that all participants had satisfactory eating attitude test scores, therefore, no student was considered to be presenting with an eating disorder or disordered eating characteristics that would contribute to an intentional energy deficit (Hoch et al., 2009). However, an individual may unintentionally enter a state of problematic LEA due to a lack of awareness of their energy

requirements, or due to a sudden increase in training demands with little dietary upregulation (Logue et al., 2018). Additionally, research suggests that acute exercise may have an appetite-suppressing effect in individuals through hormonal pathways (e.g., suppressed ghrelin) (Holtzman & Ackerman, 2019). This effect may unintentionally put those who exercise regularly (e.g., athletes) at risk of problematic LEA due to these individuals potentially consuming less energy due to the hormonal suppressive effect on appetite. This highlights the unique nutritional challenges experienced by adolescent athletes of which problematic LEA may be a potential outcome.

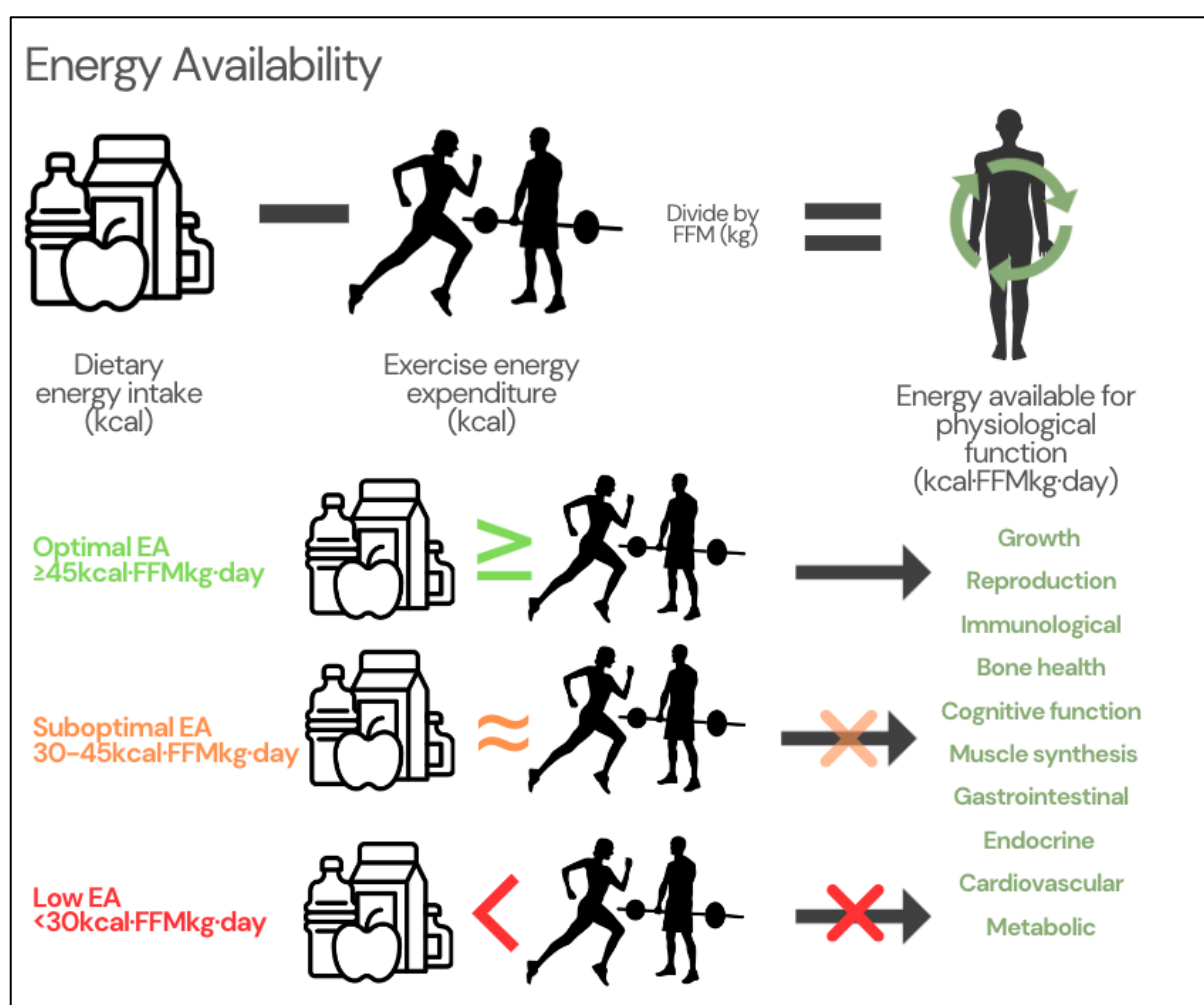


Figure 2.1. Low energy availability (Logue et al., 2018; Loucks & Thuma, 2003)

2.4 Relative Energy Deficiency in Sport

In 2014 the International Olympic Committee (IOC) consensus statement recognised that problematic LEA was the main aetiological factor of the syndrome, relative energy deficiency

in sport (REDs) (Mountjoy et al., 2014). The IOC proposes that REDs is an extension of the female athlete triad (which focuses on bone health, menstrual function and EA (Sangenis et al., 2005)), which now also encompasses male relative energy deficiency and multiple other physiological systems impacted by problematic LEA. The syndrome is defined as the adverse physiological functioning related to relative energy deficiency, including but not limited to metabolism, immunity, protein synthesis, bone health, menstrual function, cardiovascular health and psychological health (Mountjoy et al., 2014). The IOC updated their initial REDs consensus statement in 2018, with results from recent research that investigated the adverse impacts of problematic LEA states in both males and females (Mountjoy et al., 2018). Factors contributing to male athletes entering a state of problematic LEA were noted to be diverse. Sporting populations identified at higher risk for entering this state in males include rowers, cyclists, runners, jockeys and weight-class combat sports (Barrack et al., 2017; Berkovich et al., 2016; Burke et al., 2018). More recently, the IOC has updated their consensus statement which recognised the expanding literature on REDs (Mountjoy et al., 2023). This has led the IOC to create a physiological model that displays the complications associated with adaptable or problematic LEA and their effect on health and sporting performance. Additionally, the advancement of problematic LEA exposure in males, and on mental health has been refined. Moreover, the understanding of low CHO availability is appearing to be a prevailing factor associated with problematic LEA in the literature (Mountjoy et al., 2023).

Almost all the major physiological systems in the body can be affected by REDs (Mountjoy et al., 2023). The related effects on the endocrine system have primarily been studied in females, with only more recent studies undertaken in men. The current literature suggests that from a biological standpoint, males and females may respond differently to a state of problematic LEA (Mountjoy et al., 2018). Common findings in female athletes who are in a problematic state of LEA (determined by the IOC REDs CAT2 Severity/Risk Assessment tool (Mountjoy et al., 2023)) include disturbance to the hypothalamic-pituitary-gonadal axis, changes in thyroid function, alterations to appetite-regulating hormones (e.g., increased ghrelin, decreased leptin), increases in cortisol and growth hormone, and decreases in insulin and insulin-like growth factor-1 (Allaway et al., 2016; Ihle & Loucks, 2004; Logue et al., 2018; Loucks & Thuma, 2003; Mountjoy et al., 2023). Currently, changes in male endocrine systems are less well understood and are an active area of research. Available research amongst male

marathon runners, a group at high risk of problematic LEA, reported decreased luteinising hormone pulsatility and amplitude (MacConnie et al., 1986). However, these results do appear to be inconsistent between studies (Hackney et al., 1988). More recently, a review of the endocrine system implications of REDs in both males and females suggested that some similarities exist between both sexes. These similarities are related to the impact of exercise on reproductive hormones, basal metabolic rate and growth hormone resistance (Dipla et al., 2020). Although, it was noted that there is a high degree of individual variability among endocrine system changes. Thus, the physiological changes associated with problematic LEA are likely to be unique to each individual regardless of sex.

The REDs model has expanded the physiological systems that may be impacted by problematic LEA exposure. Specifically, research in females presenting with REDs symptoms, including decreases in oestrogen, and irregular menstrual cycles, were also reported to have an increased risk of cardiovascular disease (Dipla et al., 2020; Solomon et al., 2002). The gastrointestinal (GI) system has also been cited as a system impacted by problematic LEA. A study on elite and pre-elite female athletes found that 47% of the individuals identified with having GI symptoms (e.g., delayed gastric emptying, flatulence, and persistent bloating) (Rogers et al., 2021). However, when interpreting these results caution is needed as this 47% included all athletes, not only those who were in a state of problematic LEA (hence, the exclusion of other causes of GI distress must be made before the diagnosis of REDs) (Rogers et al., 2021). However, in anorexia nervosa, which is an extreme and chronic state of problematic LEA, delayed gastric emptying, constipation and increased intestinal transit time have been reported (Norris et al., 2016). This finding would support the rationale for this symptom being considered in the REDs model.

Finally, immunosuppression is a well-recognised consequence of exposure to problematic LEA (Drew et al., 2017). Before the 2002 and 2004 Olympic Games, Swedish endurance athletes and sports where leanness was emphasised, were reported to incur almost double the number of respiratory illnesses than athletes competing in other sports (Hagmar et al., 2008). Similarly, periods of overtraining have also been associated with compromised immune function which can increase illness incidence (Walsh, 2019). This was illustrated by a study of elite female Japanese college runners which found that a higher incidence of upper

respiratory symptoms occurred in amenorrhoeic athletes compared to eumenorrhoeic athletes. These athletes also showed decreased secretion levels of immunoglobulin A, an antibody of the immune system (Shimizu et al., 2012). Additionally, this study found that oestrogen deficiency associated with athletic amenorrhea accelerated the downregulation of mucosal immune function. This suggests that susceptibility to infection may be higher for females who are in a state of problematic LEA. The regular occurrence of illness may increase an athlete's time away from training and reduce training intensity, and this becomes important when considering their sporting performance.

Psychological issues can arise prior to or as a result of an athlete being in a state of problematic LEA (Mountjoy et al., 2023). Multiple studies have associated that being in a state of problematic LEA may increase the risk of an athlete developing depression, lower self-esteem, body dysmorphia and decreased stress tolerance. Numerous studies have identified that eating disorders and disordered eating behaviours are risk factors for an athlete entering a state of problematic LEA (Bomba et al., 2007; Marcus et al., 2001; Mountjoy et al., 2023).

The independence, or the accumulation of these consequences reveals the importance of adequate EI for the health, sporting performance and subsequently longevity of adolescent athletes' participation in sport.

2.5 Sporting Performance in Rowers

After considering the physiological and psychological consequences of problematic LEA, it is important to consider how these impact sporting performance and competition, which is the main goal of training and physical activity for an athlete. The effects of suppressed bone formation, impaired protein synthesis and increased protein breakdown can increase the likelihood of both neuromuscular and bone stress injuries occurring. In addition, decreases in concentration and a poor psychological state can impair an athlete's cognitive function. If this occurs during competition, it may contribute to a decrease in an athlete's sporting performance.

Rowing is an energetically demanding sport that requires a high aerobic capacity (Di Prampero et al., 1971; Hagerman et al., 1978). The energy cost of simulated rowing has been calculated at $5\text{kcal}\cdot\text{l}^{-1}$ of oxygen consumption in elite oarsmen, with aerobic metabolism contributing between 70-86% of total energy production and the remainder by anaerobiosis (Di Prampero et al., 1971; Messonnier et al., 1997; Steinacker, 1993). Rowing races are typically 2000m in length and last approximately six to eight minutes in duration (Martin & Tomescu, 2017). It has been estimated that 70% of skeletal muscle mass is used during rowing, as all extremities act to help propel the boat forward (Mäestu et al., 2005). The training regime involved in rowing tends to be intensive, with multiple water, land, and strength sessions occurring on the same or consecutive days (Mäestu et al., 2005). Therefore, the periodisation of rowers' nutrition becomes an important factor in managing training stress and adaption.

Recently, it has been acknowledged that male lightweight rowers may have a higher risk of being in a state of problematic LEA given the weight-category component of their sport (Burke et al., 2018). These rowers, relative to open-weight rowers, have been shown to have lower testosterone levels and bone mineral density, along with a higher risk of developing rib stress fractures (Vinther et al., 2006). Studies have also shown that female lightweight rowers are more likely to engage in disordered eating habits and weight manipulation strategies, which place these rowers at a higher risk of entering a state of problematic LEA (Dimitriou et al., 2014; Walsh et al., 2020). However, open-weight rowers may not be exempt from symptoms associated with REDs due to their high volume and intensity of training, high muscularity and low body fat percentages, all of which predispose rowers (open-weight and lightweight) to potentially problematic states of LEA (Burke et al., 2018). Additionally, the opportunities for rowers to consume energy are dictated by the time of a session, the type of training being completed and the time before the next session. This may make it difficult for rowers to consume sufficient energy to meet their training demands, especially if sessions are early in the morning and an athlete prioritises sleep over digestion time (Burke et al., 2018). This situation is reflected in a study on elite rowers that found four weeks of intense training decreased RMR and BC, and created substantial fatigue, with these outcomes likely related to this group entering an unintentional problematic state of LEA (Woods et al., 2017). These rowers also experienced decreased performances in their 1800m on-water time trial, 30-

minute ergometer and 5km on-water time trial. This indicates possible negative sporting performance consequences associated with being in an unintentionally problematic state of LEA (Woods et al., 2017).

Insights from previous research demonstrates that the causation of REDs may differ between the two weight classes, specifically depending on whether EI and EEE behaviours are intentional or unintentional. However, it is important to note that the lightweight rowing category has started to be phased out from junior and elite levels of competition. The IOC and the International Rowing Federation (FISA) ruled to exclude the male lightweight four from the Tokyo 2020 Olympic Games (Giesbrecht, 2023). This was followed by Rowing New Zealand and School Sport New Zealand (NZSSSC) supporting FISA's medical commission decision to disallow junior lightweight rowing, resulting in this category being removed from school regattas in 2016 within New Zealand (NZSSSC, 2016).

Rib stress injuries are recognised as the injury with the highest burden in rowing (Trease et al., 2020). This injury involves chest wall pain that occurs in the 'drive phase' of every stroke made, with an average three to eight-week recovery period, and results in decreased opportunities to train. However, the role of nutrition in the onset of rib stress injuries remains poorly described (Lundy et al., 2022). A recent study found that diet restriction, menstrual dysfunction and weight category were associated with an increased incidence of rib stress fractures (Lundy et al., 2022). Additionally, the Great Britain Rowing Team's guidelines for the management of such an injury identify REDs as a risk factor (Evans & Redgrave, 2016). This suggests that EA and problematic LEA could play a significant role in the onset of rib stress injuries in the rowing population. While the consequences of problematic LEA and REDs are noted and recognised in research to significantly impact the sporting performance of endurance athletes and rowers, these athletes may still be required to compete in weight classes or at a certain weight. Adaptable LEA is a method dietitians may use to manipulate body weight in this instance. Periodised nutrition for these athletes and how it might be used to achieve both adequate EA and desired BC to optimise sporting performance is needed.

Table 2.1 Summary of Research on Dietary Intake of Rowers in General

Authors, year	Study design	Participants	Relevant methods	Key Results relevant to this study	Comments
Dimitriou et al., 2014	Cross-sectional	21 Female lightweight rowers, 12 active, 9 retired	EAT-26 questionnaire. Self-reported questionnaires (menstrual cycle history, training history, intentional weight loss, rib pain). DEXA scan.	Active rowers with disordered eating (DE) symptoms had started rowing at a significantly younger age (10.6+/- 3.1 years) than those without DE (18.3+/- 4.9 years).	Limitations: small sample size of active rowers' limits generalisation in all female light-weight rowers.
Walsh et al., 2020	Cross-sectional	158 female collegiate rowers, 78 lightweight, 80 openweight	Electronic survey; diet and eating habits and body image.	Higher prevalence of history of an eating disorder in lightweight rowers (25.7%) v. openweight (13%)	Limitations: Survey was taken during off-season, lightweight rowers have less training volume at this time, hence limiting data quality and application to in-season training.
Talbott & Shapses, 1998	Case-control	27 Male lightweight colligate rowers	Acute 24-hr fast vs usual 24-hr dietary intake. Bone turnover measured by serum osteocalcin, urinary excretion pyridinium cross-links.	Fasting over a 24-hr reduced bone turnover in male lightweight rowers. Suggestive of adequate dietary energy intake having a role in regulating bone turnover in this population.	Fasting for 24-hrs may be significant enough to impair bone remodelling.
Lundy et al., 2022	Cross-sectional	133 international level Australian rowers, 77 male, 56 females.	Online questionnaire (diet restriction, menstrual background). SCQ2002 habitual calcium intake DXA.	Diet restriction was inversely related to both spine and rib BMD.	Suggests that restricted EI may be related to stress fracture injuries in both male and female rowers.

2.6 Periodisation of Nutrition

The term 'periodisation' has been most notably associated with exercise training and refers to the intentional programming of different training phases so that athletes are at an optimal level of fitness to perform at targeted competitions and events (Stellingwerff et al., 2019). However, it is becoming more recognised that the periodisation of nutrition may be just as important as that of the exercise training phases due to the intricacies of what individuals are exposed to (both genetic, emotional, and physical) (Stellingwerff et al., 2019). The first formal theoretical guidelines for nutrition periodisation were provided by the 2007 International Association of Athletics Federations Nutrition Consensus (Stellingwerff et al., 2007). This proposed that the approximate matching of macronutrients (notably carbohydrate (CHO) availability) to energetic demands should occur across the different training phases within a yearly training plan (Stellingwerff et al., 2007). In recent times, nutrition periodisation has been defined as "the planned, purposeful, and strategic use of specific nutritional interventions to enhance the adaptations of individual exercise sessions or periodic training plans, or to obtain other effects that will enhance performance in the longer term" (Jeukendrup, 2017, P. 53). Periodisation of nutrition aims to match an athlete's nutrition to the phase of their training cycle, with this theoretically enabling an athlete to achieve an adequate EI for the training that is being completed. The result of implementing such a nutrition approach has been shown to enhance sporting performance and to assist athletes to continuously perform at a high level (Hawley & Burke, 2010). The periodisation of EI within a rowing training cycle has proven to enhance rowing performance and increase a rower's energy levels and their readiness for the next training session or competition (Kim & Kim, 2020). Specifically, this is achieved when glycogen replenishment is prioritised by the rower, with the adequate form, and amount of CHO consumed post-training. The amount of CHO is determined by the intensity and duration of their training (Kim & Kim, 2020) (Table 2.2). This is evidenced by Simonsen et al., (1991) who found rowers consuming $10\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ of CHO increased their mean power output by 10.6% over four weeks, compared to the 1.6% increase by rowers who consumed half this amount. Likewise, Cornford & Metcalfe (2018), reported that the omission of a CHO-rich breakfast impaired an afternoon 2000m ergometer time trial performance and was associated with an increased RPE. Conversely, evidence suggests that lightweight rowers or those aiming to lose body mass to obtain lightweight status may engage

in restrictive eating behaviours and/or increase their EEE through training to create a negative EB. This often occurs at the cost of attaining their optimal performance. A case report by Slater et al., (2006) found this to be a successful method for heavyweight male rowers to move towards being lightweight rowers. However, these efforts also resulted in a decrease in lean muscle mass, RMR, and consequently rowing performance. Therefore, the implications of being in a state of problematic LEA on performance, muscle mass and RMR may need to be taken into consideration. Despite the research suggesting periodised nutritional intake in rowers may promote optimal sporting performance, it is not known whether in practice rowers are adequately periodising their EI to match their training demands. Previous research on the Lithuanian Olympic rowing squad found athletes were not consuming enough energy to compensate for their training demands. These athletes' diets were found to be low in CHO, fibre and omega-3 fatty acids (Baranauskas et al., 2018), however it should be noted that dietary habits of one nation may not be representative of another. Similarly, Woods et al., (2017) found that rowers did not increase their EI when EEE increased in response to higher training loads and subsequently, rowers' 500m split times had decreased at the end of the training block. Therefore, nutritional support that is provided to rowers, parents or coaches, that focuses on periodised EI and the potential impact it may have on sporting performance needs to be considered. This is crucial for adolescent rowers who may be training intensely for the first time in their lives.

Table 2.2 Nutrition Periodisation in Rowers (in relation to EA)

Authors, year	Study design	Participants	Relevant methods	Key Results relevant to this study	Comments
Kim & Kim, 2020	Systematic review	21 original articles, 11 literature reviews and 2 case reports.	Nutrition related articles which evaluated rowing performance and recovery in athletes.	CHO should be periodised around training intensity. Lightweight rowers may use strategies (increasing training volume or limiting energy intake) to undergo heavy weight loss prior to competition.	Recommendations for CHO intake before training/competition to be periodised according to intensity, duration, and type of training. During training nutrition is consistent with simple CHO intake. Recovery nutrition considers adequate energy intake via CHO ($1.2\text{g}\cdot\text{kg}^{-1}$), protein (20-40g)
Slater et al., 2006	Case report	3 male heavyweight oarsmen competing in the Australian Rowing Championships	16 week program, with 3 data collection days (8 weeks apart). Athletes worked with a psychologist, dietitian, and physiologist. Maximal rowing performance, peak oxygen uptake, RMR and body composition were assessed.	Periodised, well-planned energy restriction can be a successful strategy for heavyweight rowers to transition to lightweight status. Energy restriction resulted in a decrease in muscle mass, especially if an athlete had low body fat levels to begin with, concededly decreasing rowing performance.	Heavyweight rowers can transition to lightweight status; however, this involves energy restriction, subsequent loss of muscle mass and disruption of RMR which may impair rowing performance. Limitations: case study design, small sample size (n=3), all male therefore sex differences are not accounted for.
Baranauskas et al., 2018	Observational	24 rowers 18.2 ± 2.3 years, 9 male 3 female, 12.8 ± 0.4 years' experience, 6 workouts per week, average training time per day 104.0 ± 19.4 minutes.	Dietary intake, food recall method. BC: BIA	Inadequate total energy (75.5% male, 70.8% female) and CHO intake ($4.5\text{g}\cdot\text{kg}^{-1}$ male, $4.6\text{g}\cdot\text{kg}^{-1}$ female, recommended $7\text{-}10\text{g}\cdot\text{kg}^{-1}$) for estimated energy requirements.	Elite rowers may not optimally periodise their nutrition to training loads. Limitations: food recall method unspecified and physical activity coefficient.
Cornford & Metcalfe, 2018	Randomised and counter balanced cross-over	10 competitive rowers (2 male, 8 female)	Two trials; Individualised CHO-rich breakfast (831 ± 67 kcal) eaten before 0900 or no-breakfast, fast till 1200.	Omission of CHO breakfast significantly ($P < 0.05$) impaired afternoon 2000m row time trial result (469.2 ± 43.4 vs. 465.7 ± 43.3 s)	Suggestive of positive benefits of within-day adequate EI for sport performance. Limitations: small sample size.

			Afternoon 2000m time trial on ergometer.	Higher RPE of participants (17.8 ± 0.9 vs. 16.7 ± 0.9).	
Simonsen et al., 1991	Randomised controlled trial	22 collegiate rowers (12 male, 10 female)	Diet: high CHO ($10\text{g}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$) or moderate CHO ($5\text{g}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$). Training: 4wks, 2-a-day/ 6 days/wk. BC: hydrostatic weighing.	High CHO diet promotes greater glycogen content and greater mean power output in training. 10.7% increase in power by day 26 vs 1.6% in the moderate CHO group (207W vs 192W).	Periodisation of CHO's is effective for optimal performance during intense training. High efficiency in the diet, breakfast and dinner were eaten under supervision, and lunch provided.
Woods et al., 2017	Longitudinal	17 elite rowers (10 male, 7 female), 21-30 years	Four-week intensified training. RMR, BC and EI measured pre and post via indirect calorimetry, DXA and 3-day food diary. Performance; 5km on-water time trial pre and post.	Decreased RMR, BC and substantial fatigue whilst EI remained unchanged and EEE increased. Suggests energy imbalance likely impacted recovery shown by increased 5km split times (the final two split times being 3.1% and 7.1% greater post intervention), hence decreased performance.	Suggests that elite athletes may not periodise their EI when training increases. Short-term problematic LEA may directly impact sporting performance and physiological health.
Morris, 1996	Cross-sectional	18 lightweight rowers (6 female, 12 male)	Data collected four times across a 10-month period (once pre-season, twice during the season, once post season). BC: DXA and skinfolds. Weight control techniques; questionnaire prior to regattas.	Seasonal body weight control was achieved by energy restriction and reduced fat intake, 73.3% of participants achieved this by; increased exercise, 71.4% food restriction, 62.9% fluid restriction.	Suggests lightweight rowers manipulate their EI to control weight in-season. Limitations: validity of questionnaire and skinfold method.
<i>BC – bod composition; BIA- bioelectrical impedance analysis; CHO – carbohydrate; DXA- Dual energy x-ray absorptiometry; EEE- exercise energy expenditure; EI- energy intake; LEA- low energy availability; RMR- resting metabolic rate</i>					

2.7 Within-day Energy Balance

Recent studies have suggested the importance of within-day EB for maintaining hormonal balance, bone turnover and metabolism. The gold standard method for assessing this is through the measurement of EI and EE at one-hour intervals, with the suggestion that this will provide a further understanding of biomarker change related to energy deficiency as well as specific changes to the endocrine system (Logue et al., 2020). Two studies have examined within-day energy deficits, one on male and the other on female endurance athletes (Fahrenholtz et al., 2018; Torstveit et al., 2018). In males, it was found that those who spent a longer time in an energy deficit greater than 400kcal across 24 hours (21 hours vs. 11 hours) presented with a suppressed RMR. In this group, a within-day energy deficit was also associated with higher levels of blood cortisol and a lower testosterone-to-cortisol ratio (Torstveit et al., 2018). The study on females highlighted similar associations, with higher levels of cortisol reported in addition to menstrual cycle dysfunction in those who spent a longer amount of time across 24 hours in an energy deficit (22 hours vs. 18 hours) greater than 300kcal (Fahrenholtz et al., 2018). As previously mentioned, rowing training typically occurs at either extreme of the day (sunrise/sunset), with the potential for a cross-training session(s) during the day. This training schedule may limit the fuelling opportunities for athletes (Burke et al., 2018). These factors may predispose rowers to within-day energy deficits and the potential adverse physiological outcomes associated with this. This suggests that the EB of an athlete across the entire day may be just as important for performance as an athlete's EI immediately before and after training or competition. However, further research is needed to verify this proposal.

2.8 Dietary Behaviours of Rowers and Energy Availability Status

More recently, the dietary practice of intermittent fasting has gained significant momentum especially in the space of social media and functional medicine to enable weight loss, decreased blood pressure and improved metabolic biomarkers (Levy & Chu, 2019; Patterson & Sears, 2017). However, the effect of intermittent fasting on athletic performance may increase the chance of an individual being in a state of problematic LEA. Particularly, it may increase the within-day energy deficit and consequently this may result in both physiological

and performance impacts associated with REDs. One study found that the omission of a CHO-rich breakfast before an evening 2000m rowing time trial impaired performance by an average of 3.5 seconds, with a significant difference in power output, even though EI was not restricted in the afternoon (Cornford & Metcalfe, 2018). Total energy and CHO intake were lower in those who had omitted the CHO breakfast suggesting that lower energy and/or CHO availability may impair exercise performance. However, this study was unable to determine if energy or CHO availability was associated with declines in performance, therefore more research in this area is required. Additionally, another study on cyclists who skipped breakfast, also reported decreases in performance (4.5%) during an afternoon VO₂ (maximal oxygen consumption) session compared to those who ate breakfast. It was noted that cyclists who skipped breakfast reported a larger intake at lunch and dinner, but still consumed less energy throughout their day (Clayton et al., 2015). These results may suggest that in addition to ensuring adequate EA and periodising EI to reflect training demands, athletes may need to consider adequate intake of macronutrients such as CHO, to optimise their sporting performance.

The rise in social media platforms (e.g., TikTok and Instagram) in recent years has most likely contributed to creating unrealistic body image ideals for athletes and active individuals. A study on elite female athletes in New Zealand reported that 73% of athletes felt pressure from their sport to manipulate their physical appearance to conform to the gender ideals associated with their sport and that 15% of these individuals used disordered eating practices to achieve this (Heather et al., 2021). The main source of appearance-related pressure was found to be social media (80%), closely followed by the individuals themselves (77%), then the general public (54%) and other media (53%). Interestingly, appearance-related pressure (54%) was reported to be greater than sporting performance-related pressure (48%) (Heather et al., 2021). Disordered eating habits such as restricting CHO intake have been found to contribute to menstrual cycle disruption in the female athlete population and this is a commonly reported symptom of problematic LEA (Manore, 2002). Previously, barriers that have been identified in communicating female health issues (e.g., appearance-related pressure, menstrual cycle disruption, GI symptoms) include the gender of staff with namely male coaches, doctors, strength and conditioning coaches and support staff. Additionally, the lack of support staff knowledge, the perceived stigma surrounding the topic of menstrual

health and the fear of impacting their position within the team were reported as barriers that may prevent an athlete from raising these concerns before adverse physiological and performance symptoms manifest (Heather et al., 2021). Such results would suggest a need for education and support for female athletes in New Zealand to prevent disordered eating behaviours, support their menstrual health and to proactively reduce the incidence of problematic LEA and its associated symptoms in this population.

Furthermore, adolescence is a period where traits such as impulsivity and the importance of social groups along with other psychological aspects can influence food choice and behaviour (Munno et al., 2016). The connection between an adolescent's personal food system (e.g., what they have control of) and their external food environment (e.g., marketing, peer influences and social norms) must be considered when assessing this population's EI (Daly et al., 2022).

Elite lightweight female rowers may lack nutritional support to achieve the physical requirements for their competition season (Dimitriou et al., 2014). Results from previous research suggest that these athletes who begin high-level training at a young age (e.g., adolescence) are at an increased risk of exposure to problematic LEA (Desbrow et al., 2014; Thein-Nissenbaum & Hammer, 2017). Recently, Rowing Australia has delivered a REDs program by an accredited sports dietitian where the recognised barriers to the implementation of REDs education were found to be limited time and resources, and a lack of existing REDs knowledge by coaches (Hamer et al., 2021). The cumulative results from this previous research in rowers would suggest a need for a multi-disciplinary approach to sports and nutritional science education. Resources which are developed to educate on problematic LEA and REDs may address the entire rowing environment, with this including coaches, athletes, parents and support staff.

2.9 Measuring Energy Intake

Measuring the dietary intake of individuals in research poses multiple challenges in relation to error, both random and systematic. Traditional methods of measuring dietary intake include 24-hour recalls, food records, food frequency questionnaires (FFQ) and screening

tools (Bailey, 2021). However, the validity of dietary assessment tools used in the athlete population faces unique challenges, such as frequent eating patterns, erratic eating patterns, the participant burden of reporting large food intakes and estimating these amounts, as well as determining the nutrient value of sports foods and supplements (Capling et al., 2017). However, recent methodologies that incorporate the use of technology (e.g., taking photographs of food consumed and various online tools) can reduce participant burden and increase the accuracy of data collected (Stumbo, 2013).

Food frequency questionnaires are better suited for measuring dietary intake over a long period of time. They investigate how often an individual consumes food items or food groups, with often, multiple foods that have a similar nutrient composition being categorised together (Capling et al., 2017). The strengths of FFQs are that they are cost-effective and reduce participant burden by portion sizes being assumed, however, this assumption of portion sizes also acts as a key limitation of this method along with the limited scope of food items that can be investigated. Additionally, screening tools can be used to measure dietary intake. These tools are often used when there is a particular nutrient of interest and must be tested and validated before use and be specific to the population of interest.

A 24-hour recall is a dietary assessment method where an individual's intake over the past 24 hours (ideally on multiple non-consecutive days) is assessed. Strengths of this method include the use of probing questions by the interviewer which can increase the accuracy of dietary information collected. An experienced interviewer can mean that participant nutrition literacy is not required, and the method can capture a wide variety of foods (representative of total energy and macronutrient intakes). Limitations of 24-hour recalls include under-reporting by participants (either intentionally or due to lack of nutrition-related awareness), the need for interviewer or administrator training (e.g., probe questions and to build rapport) and unreliable vitamin and mineral intakes.

A food record encompasses all food and fluids ingested over a set period, with items ideally measured or weighed. This method has a high participant burden and is associated with a high risk of under-reporting of intake (Bailey, 2021). However, this can be mitigated by

photographs being taken of all items consumed and timely follow-up by the research team on each record (Stumbo, 2013).

Ultimately, the method of measuring dietary intake that is used by a researcher depends upon the study design, the study's objectives, the sample population and the sample size in question, with hybrid methods that combine multiple methodologies becoming more popular. The use of technologies (e.g., photographs of food intake) may be better suited to adolescent athletes due to the reduced food literacy required by athletes and the reduced participant burden (e.g., convenience in a school or training environment). This method in combination with timely follow-up of food records may act to more accurately measure dietary intake reported in an adolescent athlete population.

2.10 Conclusion

The pathway to elite rowing is one where the phase of adolescence is vital in both the development of sport-specific skills and physical development. Thus, EI must be sufficient to support these key functions in adolescent athletes. This review has summarised the importance of EA for the adolescent population and has aimed to highlight the key limitations and gaps in the literature regarding the specific recommendations for adolescent rowing athletes' nutritional requirements. Whilst New Zealand does not have any current nutrition guidelines specific to adolescent athletes, the SDA position statement for this population serves to fill this need.

The thresholds of subclinical and severe problematic LEA appear to be variable amongst the active population. This raises the question of individual discrepancies in EA amongst athletes and how valid an EA threshold is for the adolescent population. The research on EA and problematic LEA in male athletes is less well-described. While evidence suggests similarities between both sexes, the physiological outcomes at an endocrine level appear to differ. Emerging research into factors affecting EI (e.g., within-day EB and disordered eating behaviours) has proven to have an important role in the EA status of an athlete, which appears especially relevant to rowing training. The amount of time spent in an energy deficit within 24 hours has proven to be a factor that predisposes athletes to the risk of problematic

LEA even when adequate total EI is consumed throughout the day. Therefore, diet trends such as intermittent fasting and low CHO diets could pose imminent risks to the adolescent athlete population.

Whilst the literature in recent years has made significant progress in the realm of EA, problematic LEA and REDs, it appears that research on adolescent athletes and sport-specific investigations are still requiring thorough investigation. The current evidence suggests that a significant portion of rowers may not be meeting adequate EA thresholds to optimise their training, performance and physiological health. This may be due to limited food and nutrition knowledge, lack of nutrition periodisation or other factors that influence a rower's EI and EEE such as body image, weight class-related psychology and compensatory behaviours (e.g., restrictive eating or excessive EEE). However, evidence in the adolescent rowing population remains unclear. This highlights the need to address these gaps in future research. This will assist in promoting a pathway for improved health, well-being, and longevity in adolescent athletes' sporting endeavours.

Chapter 3: Manuscript

3.0 Abstract

Background Adequate energy intake (EI) is essential for adolescent athletes to support health, performance, and growth. Rowing is a physically demanding sport where intense training begins in adolescence. Research is needed to assess whether current EI is sufficient to support healthy physiological functions and training in adolescent rowers. The aim of this study was to evaluate the energy status (energy availability (EA) or energy balance (EB)) including EI and exercise energy expenditure (EEE) of adolescent rowers in New Zealand.

Methods A total of 35 rowers (23 females, 16.8 ± 1.9 yrs; 12 males, 17.3 ± 1.6 yrs) who had been rowing for at least one season participated. Energy balance for all participants was calculated using estimated body weight (23 females, weight 71.6 ± 9.7 kg; 12 males, weight 72.6 ± 10.7 kg). A bioimpedance analyser measured body composition in 11 participants (8 females, weight 63.0 ± 7.0 kg, fat-free mass (FFM) 50.8 ± 6.5 kg; 3 males, weight 78.5 ± 15.9 kg, FFM 70.7 ± 12.2 kg) enabling calculation of EA. All participants completed four days of food and training diaries, two 'recovery' and two 'hard' training days. EI was determined in FoodWorks10 software using the New Zealand Food Composition Database. For training, metabolic equivalent of tasks (MET) were assigned using body weight, heart rate and rating of perceived effort to estimate EEE. Paired sample t-tests or Wilcoxon Signed Rank test (non-parametric data) were used to determine differences between EI, EEE, EA and EB on the high and low training days for each gender. Significance was set at $p < 0.05$.

Results The average EI for females on hard and recovery days was 2584.6 ± 678.3 kcal and 2492.6 ± 618.7 kcal respectively, and for males was 3655.1 ± 792.5 kcal and 3183.3 ± 1078.2 kcal respectively. No significant differences were found between EI on hard vs. recovery days in both genders. Significant differences between average EEE on hard vs. recovery days were found in both genders (females, hard day 1108.8 ± 541.6 kcal, recovery day 757.3 ± 431.6 kcal, $p < 0.001$; males, hard day 1574.9 ± 686.0 kcal, recovery day 794.9 ± 690.8 kcal, $p = 0.001$). The average EB across hard and recovery training days was 65.5 ± 524.0 kcal for females and 236.4 ± 913.9 kcal for males. Both genders had no significant difference in EB between hard and recovery training days (females $p = 0.341$, males $p = 0.433$). EA on hard and recovery training days was classified as subclinical for both genders at $35.8 \pm$

12.6kcal·FFMkg⁻¹·day⁻¹ and 38.2 ± 26.2kcal·FFMkg⁻¹·day⁻¹ for females and males respectively. No significant difference in EA between hard and recovery days was found in either gender (females p=0.934, males p=0.212). The average carbohydrate (CHO) intake ranged between 2.4-7.0g·kg⁻¹·day⁻¹ for females and 2.2-8.7g·kg⁻¹·day⁻¹ for males, both beginning below sport nutrition recommendations.

Conclusion The results suggest that adolescent rowers do not adjust their nutritional intake to match EEE. This may increase the risk of adolescent rowers presenting with suboptimal EB or EA.

3.1 Introduction

New Zealand has an extensive history of rowing. The Nation's accumulative medal count from the past Summer Olympic Games (2022) in the sport was 29 (Rowing New Zealand, 2023), whilst 50 gold medals have been won at the annual World Rowing Championships by New Zealand between 1982 and 2022 (Ministry for Culture and Heritage, 2022). Domestically, Lake Karapiro and Lake Ruataniwha are the most renowned settings for regattas in New Zealand, and both (biannually) host the week-long annual secondary school Maadi Cup Regatta. This regatta typically has over 2,000 student rowers, making it the largest in the southern hemisphere.

Rowing is a physically demanding power sport that often requires multiple training sessions in one day. The high EEE associated with this training requires adequate EI to support a rower's health and performance (Stellingwerff et al., 2011). However, if an athlete fails to meet their energy requirements via dietary EI, they risk entering a state of problematic LEA and subsequently may experience symptoms related to relative energy deficiency in sport (REDs) (Mountjoy et al., 2018). The current literature on rower's EI suggests some athletes may not be consuming enough energy to account for the energy expended during training (Baranaukas et al., 2018). Insights from this previous research have demonstrated common themes that hinder rowers' ability to achieve adequate EI and include the lack of periodisation of CHO, intentional and unintentional under-eating, and barriers to eating such as training timings (e.g., early morning and late into the evening). For adolescent rowers, achieving adequate EI is crucial for not only having energy available for training and performance but also for growth and development (Desbrow et al., 2014). It is difficult to provide detailed EI requirements for this age group of athletes due to the inter variability in growth and physical activity (Petrie et al., 2004). As a result, little research has investigated adolescent athletes' energy requirements or alignment of EI with sport-specific nutrition guidelines. Therefore, individualised nutrition needs are required to ensure adequate EI is achieved, to mitigate the risk of problematic LEA exposure and athletes potentially experiencing adverse side effects of REDs. Adolescent rowers in New Zealand are on a direct pathway to high-performance rowing, therefore if their EI can be matched to their individual needs it may help promote longevity in the sport and overall health and well-being.

Thus, the aim of this study is to investigate the EI, EEE, and energy status of male and female adolescent rowers in New Zealand. This study will assess the EI and EEE of adolescent rowers in New Zealand, as well as determine associations and variations between adolescent rowers' EI and their exercise training intensity and volume. In addition, the energy status (EA or EB) of adolescent rowers in New Zealand will be described.

3.2 Methodology

This study was a cross-sectional study conducted on male and female adolescent rowers in New Zealand. Data collection occurred between February and July 2022, with the extended data collection period required due to the COVID-19 pandemic restrictions in New Zealand.

3.2.1 Participants

To be included in this study participants needed to have completed a minimum of one season rowing (e.g., competing since the start of 2020), be aged 14-21 years, be actively rowing and not coxswains, male and female athletes, and proficient in English. Participants were recruited throughout New Zealand by researcher contacts, rowing clubs, and Rowing New Zealand social media. The study received ethics approval from Massey University Human Ethics Committee: Southern A (21/70) and written informed consent was provided by all participants and parents (if under the age of 16 years) before taking part in this study.

A sample size was calculated using G*power sample size calculation software. For four repeated data collection points obtained during the study from a single cohort, an effect size of 0.25, α probability set at 0.05, and power set at 0.95, a total sample size of 36 was determined sufficient to determine statistical differences within the collected data.

3.2.2 Study Design

This study had four data collection points. Participants were asked to provide dates for two recovery days and two heavy training days. In each of the days identified, the participant was asked to provide training details. On each data collection day, participants completed a visual 24-hour food recall, where all food and drink consumed in 24 hours was photographed,

described, and sent to the research officer. Once all food data had been completed, the food recall was verified by the research officer with a phone call or email to each participant. This ensured accurate food intake for each of the 24-hour data collection points collected across the trial. The training week in which data collection commenced was determined by participant availability. The verified food recalls were analysed using FoodWorks 10 software (Xyris, 2023) to assess dietary EI. Data input via FoodWorks was completed by three researchers with this process being standardised by the use of a food code book spreadsheet for consistency across the foods being input. The food code book enabled cross-checking of entries to occur which increased the accuracy of the data entered.

Data from each training session was collected from participants, this included heart rate (if available), training duration, training intensity, and rate of perceived exertion (RPE). Researchers then assigned a metabolic equivalent (MET) to each training session (Ainsworth et al., 1993). The estimated oxygen utilisation and EEE for each training session within the data collection period was then calculated upon the assignment of the training sessions MET.

Body composition (BC) data via BIA was collected on 16 participants at Massey University to-benedict equation (Harris & Benedict, 1919) was used to calculate BMR as this method has been justified for use in athletic populations (Mackay et al., 2019; Schofield et al., 2019). The BMR was then combined with each MET to derive estimated energy requirements (EER).

Energy availability was calculated for the n=11 participants whose BC was determined by BIA. On training days, EA was calculated by subtracting total estimated exercise energy expenditure from their total energy intake, relative to their fat-free mass. Participants who did not complete the BIA scan had their EB calculated and presented (EB = estimated EI-EER).

The timeframe of EI pre- and post-training sessions was reviewed in accordance with recommendations by clinical guidelines (Burke & Vicki, 2015). These guidelines state that adequate EI is required 4 hours prior to an exercise session, and CHO and protein should be consumed as soon as possible after a training session (e.g., within 1 hour). Therefore, analysis of EI pre- and post-training sessions in this study has considered the EI 4 hours prior to training and the EI in the first 1 hour after training. This encompasses both the CHO and protein

ingestion recommendations for best practice sports nutrition, expressed in kcal·kg⁻¹ for comparability to these guidelines.

3.2.3 Statistical Analysis

IBM SPSS Statistics 25 for Mac was used for statistical analysis (IBM Corp, 2022). Data was tested for normality using Kolmogorov Smirnov and Shapiro-Wilk tests. Normally distributed data are represented as mean $\pm$ standard deviation, and non-normally distributed data as median (25%, 75% percentiles), occasionally both are shown for comparative purposes. Categorical data is shown as the percentage and number of participants per gender (EA and EB). The EI, EEE, EER, EA and EB of each participant were averaged by training day or across the four days for statistical analysis, except for reported maximum and minimum values which are a distinct day. The CHO intake is presented as a range (minimum-maximum) in g·kg⁻¹. For data that was parametric, comparison between individuals was conducted through either paired-sample t-test or independent samples t-test depending on whether the analysis required comparison between hard and training days or between genders. Non-parametric data was compared using the Wilcoxon signed ranks test. A p-value of <0.05 was considered significant. Pearson's correlation coefficient was used to analyse the bivariate correlations between EI, EEE, EB and EA.

3.3 Results

3.3.1 Participant Characteristics

The study recruited 51 rowers, with a mean age of 16.9 ± 1.9 years. The final analysis included 35 rowers (female n=23, male n=15). Table 3.1 summarises the characteristics of the participants. Thirteen rowers withdrew from the study at various stages. Three rowers had to be removed from this data analysis due to incomplete records with a single day having to be removed for one participant due to it being incomplete. One rower's 'hard day' was removed due to them completing a 12-hour endurance event. Therefore, 35 adolescent rowers (23 female, 12 male) have been included in this data analysis. In addition, a sub-analysis of EI throughout the day excluded four singular days of data where a rower took a complete rest from exercise or only went for a light walk (n=35).

Table 3.1: Participant Characteristics (n=35)				
	mean ± SD			
Characteristics	Female (n=23)		Male (n=12)	
Age (years)	16.8 ± 1.9		17.3 ± 1.6	
Average training duration (minutes)	107.0 ± 47.7		107.2 ± 44.6	
<i>Anthropometrics</i>				
Height (cm)	173.8 ± 5.4		186.4 ± 4.9	
Weight (kg)	67.7 ± 8.1		81.2 ± 9.0	
*Fat Free Mass (kg)	50.8 ± 6.5		70.7 ± 12.2	
Body Mass Index (kg·m ²)	22.4 ± 2.1		23.3 ± 1.9	
<i>Dietary</i>				
Energy intake (kcal·day ⁻¹)	2538.6 ± 643.6		3419.2 ± 956.2	
Carbohydrate (g·kg ⁻¹ ·day ⁻¹)	4.3 ± 1.4		4.6 ± 2.0	
Protein (g·kg ⁻¹ ·day ⁻¹)	1.5 ± 0.6		2.0 ± 0.8	
Fat (g·kg ⁻¹ ·day ⁻¹)	1.5 ± 0.6		1.7 ± 0.7	
	Min.	Max.	Min.	Max.
EEE (kcal)	155.7	3702.3	0	4547.7
<i>*FFM n=8 females, n=3 males</i>				
<i>EEE = exercise energy expenditure; Min = minimum value; Max = maximum value</i>				

3.3.2 Energy Intake and Exercise Energy Expenditure

Average EI and EEE on hard and recovery days, as well as ranges for EI and EEE on both days for the group of participants, are presented in Table 3.2. No significant differences were found between EI on hard vs. recovery training days in both genders (females $p=0.451$, males $p=0.100$).

Both genders' average EEE was significantly higher on hard training days vs. recovery training days (Table 3.2). The single highest EEE for females was 3702.3kcal and for males 4547.7kcal. The lowest EEE for females was 155.7kcal and for males was 0kcal (with three male participants each taking complete rest from exercise on a recovery day).

Table 3.2: Average Energy Intake and Estimated Energy Requirements						
	Females (n=23)			Males (n=12)		
Kcal	Hard Day	Recovery Day	P	Hard Day	Recovery Day	P
EI	^a 2584.6 ± 678.3	2492.6 ± 618.7	0.451	3655.1 ± 792.5	3183.3 ± 1078.2	0.100
EI Range	1085.5 - 5393.1	1422.8 - 4291.8		2264.3 - 6258.8	1535.5 - 6136.0	
EER	^a 2653.8 ± 587.9 ^b 2521.7 (2240.9, 3029.8)	2302.3 ± 486.3 2139.5 (2025.9, 2548.3)	< 0.001 0.001	3572.8 ± 674.3 [†] 3427.3 (3180.3, 4002.0)	2792.9 ± 611.2 2562.1 (2345.3, 3264.6)	0.011 0.019
EER Range	2059.6 - 4662.1	1585.2 - 3782.5		2544.9 - 5103.1	2057.5 - 4116.7	
EEE	^a 1108.8 ± 541.6 ^b 930.3 (749.3, 1434.5)	757.3 ± 431.6 603.9 (461.0, 995.2)	<0.001 0.001	1574.9 ± 686.0 1397.9 (1172.5, 1902.3)	794.9 ± 690.8 656.9 (318.8, 1214.2)	0.011
EEE Range	478.2 - 2944.2	239.6 - 2146.4		539.0 - 3199.5	147.0 - 2135.3	
^a Mean ± standard deviation ^b Median (25 th , 75 th percentiles) P= P-value is a test for differences conducted within each gender as assessed by paired-sample t-test, Wilcoxon signed ranks test (non-parametric continuous data) EEE: exercise energy expenditure; EER: estimated energy requirements; EI: energy intake EER calculated as RMR + EEE (as determined by METS) Range represented as (min-max)						

Figures 3.1 and 3.2 display the average EI and EEE by training day type for females and males respectively. No significant difference was found between hard and recovery day EI, despite a significant difference in EEE observed.

In females, a significant strong positive correlation was found between average EI and average EEE ($R=0.541$, $n=23$, $P=0.008$), and between average EI and average EB ($R=0.627$, $n=23$, $P=0.001$). No correlation was found between, average EI and average EA, average EEE and average EB, or average EEE and average EA in females. In males, a significant strong positive correlation was found between average EI and average EB ($R=0.860$, $n=12$, $P<0.001$), and between average EI and average EA ($R=0.998$, $n=3$, $P=0.040$). No significant correlation was found between, average EI and average EEE, average EEE and average EB, or average EEE and average EA in males.

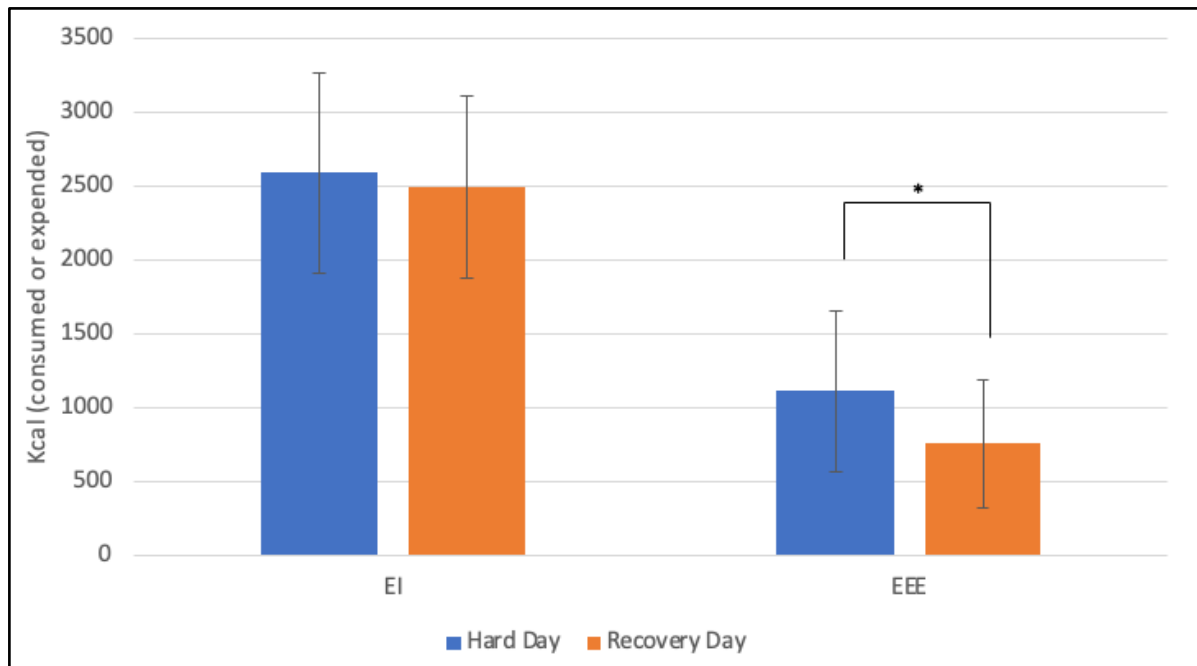


Figure 3.1. Female Average Energy Intake and Exercise Energy Expenditure by Training Day

Note: EEE: exercise energy expenditure; EI: energy intake

*statistically different from recovery day

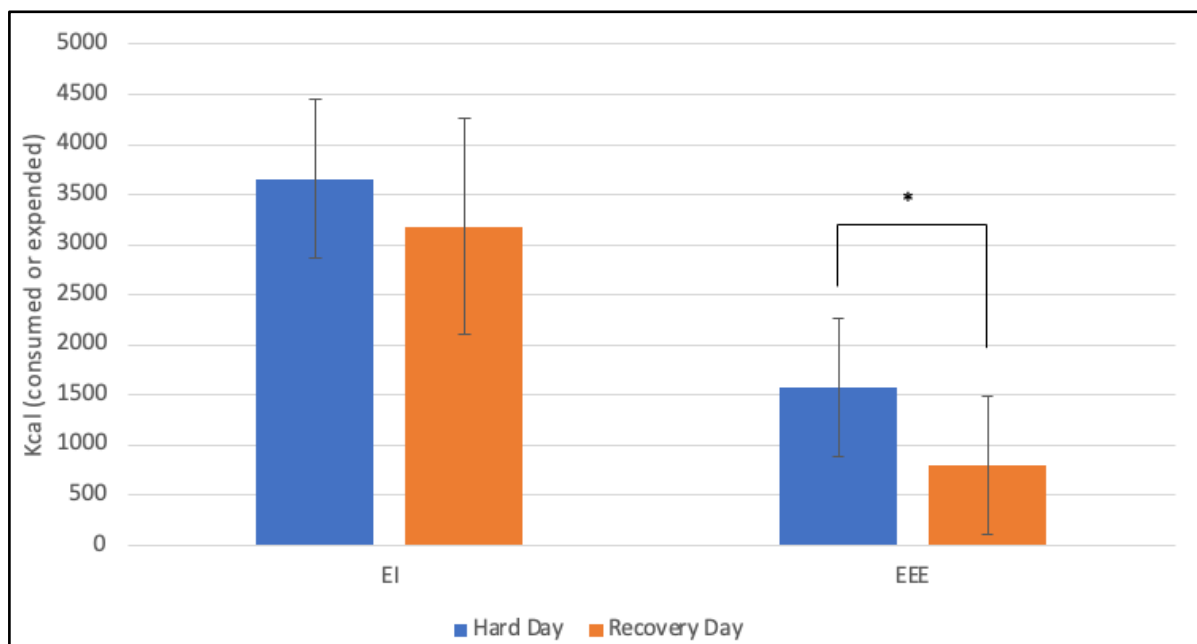


Figure 3.2. Male Average Energy Intake and Exercise Energy Expenditure by Training Day

Note: EEE: exercise energy expenditure; EI: energy intake.

*Statistically different from recovery day

3.3.3 Energy Balance and Energy Availability

Energy balance was analysed for all participants (Table 3.3). On average across all training days, the proportion of females in a negative EB was greater than that of males (60.9%, and 36.4% respectively). No difference was found between females' or males' hard and recovery

day average EB ($p=0.341$ and $p=0.433$, respectively). Similarly, no difference was found in average CHO intake between hard and recovery training days for both genders (females $P=0.904$, males $P=0.089$). The percentage of rowers not meeting the minimum guidelines for CHO intake across all training days ($6\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$) was on average found to be, 95.7% of females and 91.7% of males.

Table 3.3: Energy Balance and Carbohydrate Intake						
	Female (n=23)			Male (n=12)		
	Average across all training days					
^a EB (kcal)	65.5 ± 524.0			236.4 ± 913.9		
- CHO(g·kg ⁻¹)	2.4-7.0			2.2-8.7		
EB positive (%)	39.1%			63.6%		
- CHO(g·kg ⁻¹)	3.2-7.0			3.6-8.7		
EB negative (%)	60.9%			36.4%		
- CHO(g·kg ⁻¹)	2.4-5.7			2.2 - 5.3		
	Hard day	Recovery day	P	Hard Day	Recovery day	P
^a EB (kcal)	-16.1 ± 693.2	137.2 ± 600.3	0.341	82.3 ± 1037.6	390.5 ± 1206.4	0.433
- CHO(g·kg ⁻¹)	2.1-7.3	2.6-7.0	0.904	3.0-7.7	1.5-9.7	0.089
EB positive (%)	39.1%	60.9%		50.0%	58.3%	
- CHO(g·kg ⁻¹)	3.5-7.3	3.2-7.0		4.1-7.7	2.8-9.7	
EB negative (%)	60.9%	39.1%		50.0%	41.7%	
- CHO(g·kg ⁻¹)	2.1-4.9	2.6-5.5		3.0-4.8	1.5-5.8	
^a Mean ± standard deviation Percentages which are expressed as n% per gender CHO presented as a range (min-max) P= P-value is a test for differences conducted within each gender as assessed by paired-sample t-test CHO: carbohydrate; EB: energy balance						

For the rowers who were able to complete a BIA scan, an analysis of this group's EA ($n=11$) was undertaken and displayed in Table 3.4. Both female and male rowers had an average EA classified in the sub-clinical range ($30\text{-}45\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$) across the four distinct training days. The average CHO intake per day ranged between $3.6\text{-}5.8\text{g}\cdot\text{kg}^{-1}$ for females and $2.2\text{-}8.7\text{g}\cdot\text{kg}^{-1}$ for males. No difference was found for females' average EA ($p= 0.934$) or CHO ($p = 0.799$) intake on hard or recovery training days.

The breakdown of EA by classification (Figure 3.3) found that on hard days 87.5% of females were either in a state of sub-clinical or problematic LEA, compared to only 75% on recovery days. The majority of female participants in a sub-clinical state reported a CHO intake between $4.0\text{-}5.9\text{g}\cdot\text{kg}^{-1}$, while female participants meeting the problematic LEA classification ingested only $3.1\text{-}4.7\text{g}\cdot\text{kg}^{-1}$ of CHO. A single female participant with an optimal EA had a CHO intake of $7.2\text{g}\cdot\text{kg}^{-1}$.

A large variation in the EA of males is seen partly due to the small sample size ($n=3$). No significant difference was found between the average EA and CHO intake on hard and recovery days ($p=0.212$ and 0.804 , respectively). On hard days, one rower was noted to have optimal EA with a CHO intake of $7.7\text{g}\cdot\text{kg}^{-1}$. The other two rowers met the classification of problematic LEA and were ingesting between $3.0\text{-}4.0\text{g}\cdot\text{kg}^{-1}$ CHO (Figure 3.4). On recovery days, one male was classified in each of the three EA thresholds, with reported CHO intake of $9.7\text{g}\cdot\text{kg}^{-1}$, $4.3\text{g}\cdot\text{kg}^{-1}$, and $1.5\text{g}\cdot\text{kg}^{-1}$ for each male (optimal, subclinical, and problematic LEA respectively).

Table 3.4: Energy Availability and Carbohydrate Intake						
	Female (n=8)			Male (n=3)		
	Average across all training days					
^a EA (kcal·FFMkg ⁻¹ ·day ⁻¹)	35.8 ± 12.6			38.2 ±26.5		
- CHO(g·kg ⁻¹)	3.6-5.8			2.2-8.7		
^a Optimal EA (n=1)	48.1			67.1		
- CHO(g·kg ⁻¹)	5.3			8.7		
^a Subclinical EA (n=5)	38.3 ± 6.5			-		
- CHO(g·kg ⁻¹)	4.3-5.8			-		
^a LEA (^b n=2)	23.4 ± 3.1			23.8 ± 8.0		
- CHO(g·kg ⁻¹)	3.6-4.3			2.2-4.2		
	Hard Day	Recovery Day	P	Hard Day	Recovery Day	P
^a EA (kcal·FFMkg ⁻¹ ·day ⁻¹)	35.6 ± 14.4	36.1 ± 11.4	0.934	28.7 ± 19.5	47.7 ± 33.2	0.212
- CHO(g·kg ⁻¹)	3.1-7.2	3.5-7.0	0.799	3.0-7.7	1.5-9.7	0.804
Optimal EA (%)	12.5%	25%		33%	33%	
- CHO(g·kg ⁻¹)	7.2	6.5-7.0		7.7	9.7	
Subclinical EA (%)	50%	50%		-	33%	
- CHO(g·kg ⁻¹)	4.0-5.9	3.5-4.3		-	4.3	
LEA (%)	37.5%	25%		67%	33%	
- CHO(g·kg ⁻¹)	3.1-4.7	4.7-5.4		3.0-4.0	1.5	
^a Mean ± standard deviation						
^b n=2 per gender						
Percentages are expressed as n% per gender						
CHO presented as a range (min-max)						
P= P-value is a test for differences conducted within each gender as assessed by paired-sample t-test						
CHO: carbohydrate; EA: energy availability; LEA: low energy availability						



Figure 3.3. Female Energy Availability by Training Day
 Note: LEA: low energy availability

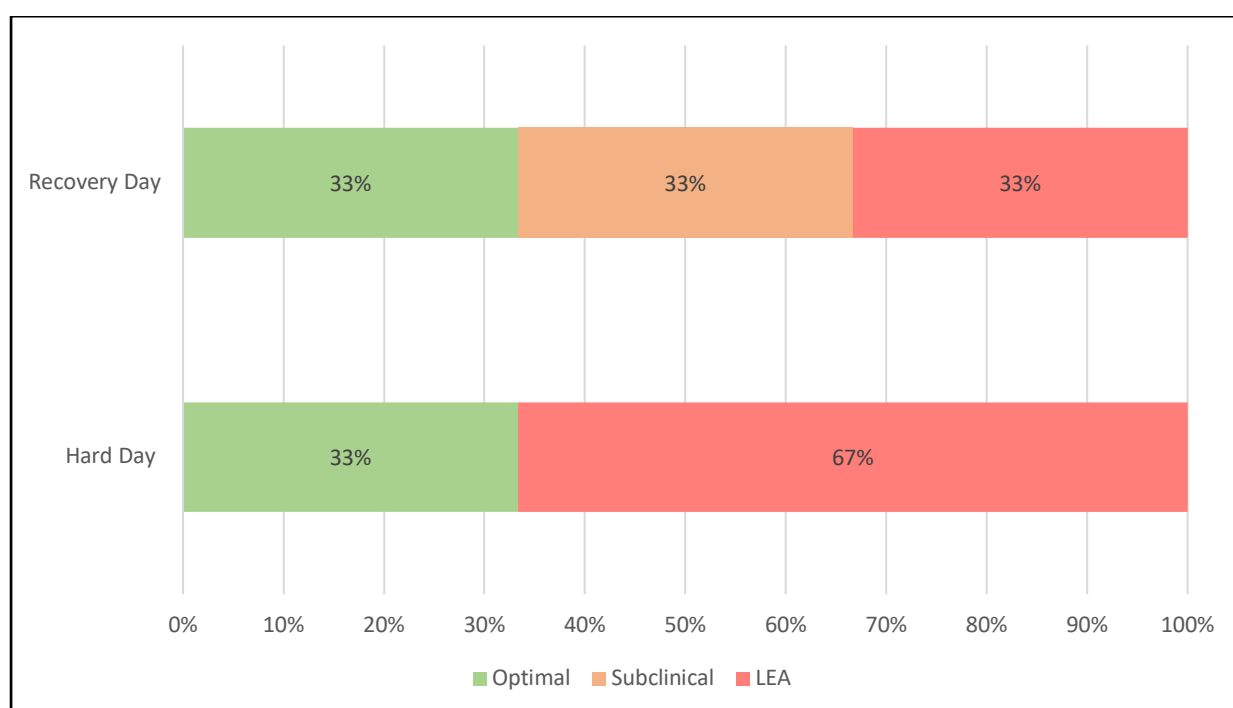


Figure 3.4. Male Energy Availability by Training Day
 Note: LEA: low energy availability

3.3.4 Energy Intake Before and After Training Sessions

The EI consumed before and after training sessions is shown in Table 3.5. The average EI consumed 4 hours before training for females was $7.5 \pm 3.4 \text{ kcal} \cdot \text{kg}^{-1}$ and CHO intake was 0.9

$\pm 0.4\text{g}\cdot\text{kg}^{-1}$, whereas for males EI was $7.9 \pm 2.7\text{kcal}\cdot\text{kg}^{-1}$ and CHO intake was $0.9 \pm 0.3\text{g}\cdot\text{kg}^{-1}$ respectively. The average EI consumed in the first hour after training was $4.8 \pm 2.3\text{kcal}\cdot\text{kg}^{-1}$ and $5.8 \pm 4.2 \text{ kcal}\cdot\text{kg}^{-1}$ for females and males respectively. The post-training CHO for females was $0.5 \pm 0.2\text{g}\cdot\text{kg}^{-1}$ and $0.6 \pm 0.5\text{g}\cdot\text{kg}^{-1}$ for males. The longest time taken to consume food after a training session was 210 minutes (3.5 hours) for the females and 330 minutes (5.5 hours) for the males.

Table 3.5: Energy Intake 4 hours Prior and 1 hour After Training Sessions				
	Females (n=23)		Males (n=12)	
	EI (kcal·kg ⁻¹)	CHO (g·kg ⁻¹)	EI (kcal·kg ⁻¹)	CHO (g·kg ⁻¹)
^a Average intake 4 hours before	7.5 ± 3.4	0.9 ± 0.4	7.9 ± 2.7	0.9 ± 0.3
^a Average intake 1 hour after	4.8 ± 2.3	0.5 ± 0.2	5.8 ± 4.2	0.6 ± 0.5
^a Average minutes until EI post exercise	114.2 ± 42.7		118.3 ± 79.6	
^a Mean ± SD. EI: energy intake; Average minutes until EI: if 0kcal had been consumed in the first 1 hour after training, this is the average minutes until any EI				

By grouping each gender by energy status (Table 3.6) no significant differences in EI or CHO intake before or after training sessions were found in either gender for those in a positive EB or optimal EA state compared to those in a negative EB or subclinical EA/problematic LEA state.

Table 3.6: Energy Status and Energy Intake Before and After Training Sessions								
	Females (n=23)				Males (n=12)			
Energy Status	Average intake 4 hours before		Average intake 1 hour after		Average intake 4 hours before		Average intake 1 hour after	
	EI (kcal·kg ⁻¹)	CHO (g·kg ⁻¹)	EI (kcal·kg ⁻¹)	CHO (g·kg ⁻¹)	EI (kcal·kg ⁻¹)	CHO (g·kg ⁻¹)	EI (kcal·kg ⁻¹)	CHO (g·kg ⁻¹)
^a Negative EB or subclinical EA/ LEA	6.8 $\pm$ 2.4	0.8 $\pm$ 0.3	5.1 $\pm$ 2.5	0.5 $\pm$ 0.3	7.7 $\pm$ 3.3	0.9 $\pm$ 0.4	4.4 $\pm$ 4.2	0.4 $\pm$ 0.4
^a Positive EB or optimal EA	10.0 $\pm$ 5.4	1.1 $\pm$ 0.6	4.0 $\pm$ 1.5	0.5 $\pm$ 0.2	8.2 $\pm$ 2.2	1.0 $\pm$ 0.3	7.2 $\pm$ 4.0	0.7 $\pm$ 0.5
Significance	0.063	0.083	0.184	0.615	0.751	0.627	0.266	0.238
^a Mean $\pm$ standard deviation P= P-value is a test for differences conducted within each gender as assessed by paired-sample t-test EA: energy availability; EB: energy balance								

3.4 Discussion

To the best of our knowledge, this is the first study to consider EI, EEE, and energy status in adolescent rowers in New Zealand. Our research suggests that adolescent rowers in New Zealand do not periodise their EI to match their EEE. It was found that whilst total EI in adolescent rowers appeared to meet their EERs, upon calculation of energy status, 78.3% of

females and 50.0% of males were classified with suboptimal energy status (EA subclinical or problematic LEA or negative EB).

3.4.1 Energy Intake and Exercise Energy Expenditure

This study found that the EI of both female and male adolescent rowers did not differ between hard and recovery training days. However, the EEE of both female and male rowers did differ significantly across the two types of training days. This suggests that adolescent rowers in this study did not adjust their EI based on their daily training load. Interestingly, females' EI on hard training days compensated for 97.3% of calculated EERs and exceeded EERs (108.3%), on recovery days. Of note, the male rowers in this study exceeded their EERs on both training days, achieving an EI of 102.3% of their EERs on hard days and 114.0% of their EERs on recovery days. The results from the current study would suggest that our cohort of adolescent rowers compensated for a greater proportion of their EEE with their EI when compared to elite rowers. In a previous study within the Lithuanian Olympic team, both female and male rowers did not match EI with expended EEE, with the elite females' EI compensating for only 70.8% of their EEE, and the elite males' EI compensating for only 75.5% of EEE (Baranauskas et al., 2018). Despite the differences to previous research on total compensation of EEE via reported EI, the current study and that of Baranauskas et al., (2018) found that rowers may not periodise their nutrition to match training loads. Both Baranauskas et al., (2018) and this study used the Harris-Benedict equation to determine BMR, however, the derivation of physical activity differed. A 24-hour activity diary was used by Baranauskas et al., (2018), whereas the current study used only training sessions that were recorded. These differences in EEE reporting may have influenced the total EEE reported, with the potential of under-reporting in our study due to daily walking or unreported activities outside of rowing training not being accounted for. Additionally, the likely differences in training load between adolescent rowers and elite rowers may explain the differences in EEE between studies. These factors would directly impact the calculated energy status and EEE average values. However, it is noted that the current study's method of recording EI via a photographed food recall and follow-up may be viewed as more credible than the 24-hour recall method used by Baranauskas et al., (2018). Despite both strengths and limitations noted in the data collection of this study, the result of inadequate periodisation in adolescents through to elite rowers in New Zealand is still evident.

When reviewing the results of our study to that of a similar aged athletic group, similarities can be found in inadequate EIs. Matt et al., (2021) found that both female and male adolescent endurance runners did not meet their energy requirements, a result similar to our study on hard training days. The results of this study and previous research expose a potential lack of knowledge and/or awareness of nutrition in the adolescent rowing population. A proposition which is supported by previous research that has demonstrated a lack of dietary awareness (Torres-McGehee et al., 2021), and a lack of coaching staff education (Heikkilä et al., 2018) may contribute to inadequate EI in young athletes. Cumulatively, the research in this age group of athletes may suggest that sport-specific guidelines or education may be needed in the adolescent population. These nutritional guidelines or education should consider addressing existing dietary concerns within each sport, especially since different sports have unique variations of volume, intensity, and type of training being required. When considering adolescent rowers' nutritional guidelines, nutritional strategies to optimise performance and recovery may include athletes periodising their EI according to the type of training session taking place, with a particular emphasis on the periodisation of carbohydrates (Kim & Kim, 2020). As such, the results of this study add to the literature on the importance of providing nutritional strategies and support to help young rowers tailor their EI for their training.

This study found that there was a difference between the EEE on hard and recovery training days for both female and male adolescent rowers. Of note, the range of the data within both genders showed large variations, this demonstrated a large interindividual variability in EEE. The high inter variability in EEE may mean that those with higher EEE may be at risk of being in a suboptimal or problematic LEA state, especially when considering the results for EI showed no variation between hard and recovery days. Similarly, a study on 17 elite rowers from Australia found that after four weeks of intensified training (increased EEE), these rowers failed to increase their EI accordingly. Subsequently, in this short period (four weeks) these elite rowers had started to present with adverse consequences related to problematic LEA. These included decreased RMR, changes in BC, increased levels of reported fatigue, and decreased performance in 5km split times (Woods et al., 2017). The presentation of problematic LEA in adolescent groups may not only be detrimental to performance, but

physiological health too. Desbrow et al., (2014) highlights the unique nutritional requirements of this group, with growth and development needing to occur simultaneously with training demands. However, the impact of inadequate periodisation of EI on health outcomes is an area requiring investigation in adolescent rowers. Another factor to consider is the effect exercise has on appetite, both on the day of hard training and on subsequent days. Appetite suppression is a known side effect of acute aerobic exercise (Howe et al., 2014; Stensel, 2011), providing a possible reason for the relatively higher EI observed in rowers in this study on their recovery training days. Future research should consider an investigation of exercise-induced appetite suppression and the influence on EI of a population over time, especially in cohorts that regularly participate in exercise. Such groups, like the adolescent rowing population in New Zealand, may be at a higher risk of entering a negative EB (Howe et al., 2014) due to their frequent training sessions. Therefore, future research may consider measuring EI and EEE over multiple weeks to assess whether EI compensation occurs. Moreover, improved measures of EEE in adolescent studies which account for daily activities in addition to training sessions may influence the EERs of this population.

In females, a significant strong positive correlation was found between average EI and average EEE. This suggests that female adolescent rowers tend to have higher EI on days when there is high EEE. Whereas, in males, no correlation was found between average EI and average EEE, suggesting that this group of adolescent rowers in our study did not tend to increase their EI when EEE increased. Interestingly, our results indicated that in both genders, average EI and average EB are positively correlated. This suggests that adolescent rowers in this study who have a higher EI may have a more positive EB. Furthermore, it appears that male adolescent rowers with a higher EI may achieve a more optimal EA classification. Therefore, support through nutrition prescription or education that enables athletes to achieve a higher EI is likely to assist the attainment of a positive EB and EA in adolescent rowers. However, the small sample size ($n=3$) of this sub-analysis should be noted when interpreting these results and as such should be investigated further in future research.

3.4.2 Energy Balance and Energy Availability

The average EB for females and males was positive ($> 0\text{kcal}$), however, 60.9% of females and 36.4% of males were found to be in an average negative EB. The average EA for both female and male adolescent rowers in this study was classified as subclinical ($30\text{--}45\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$). A possible explanation for these findings may be due to the skewedness of the data, where those in a positive EB have a substantially higher EI than the remaining 60% of females. As such, average data has been impacted by the extreme ranges in EI between individuals in the study. This would explain why on average female rowers reported an average positive, but over half of females were found to be in a negative EB. No other studies in New Zealand have assessed the EA or EB of adolescent rowers or athletes. Regardless, the results of the current study align with those that have evaluated the EA of adolescent endurance runners (Matt et al., 2021) which reported that the mean EA for males was classified as subclinical ($35.8 \pm 14.4\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$), and for females was problematic LEA ($29.6 \pm 17.4\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$). Previous research has shown that female endurance runners on average had a lower EI ($\text{kcal}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$) than male endurance runners, with 60% of adolescent females meeting the criteria for problematic LEA compared to 30% of adolescent males (Matt et al., 2021). In comparison, the current study found that 37.5% and 25% of females met the criteria for problematic LEA on hard and recovery training days (respectively). Whereas 67% and 33% of males met the criteria for problematic LEA on hard and recovery training days (respectively). In this study, the higher prevalence of problematic LEA in males was likely due to the small sample size. Both our study and Matt et al., (2021) had a significant proportion of adolescent athletes who met the criteria for problematic LEA, however, the prevalence in adolescent female runners was almost twice that of rowers in our study. This may be due to the difference in physical attributes required for each of these sports, specifically runners may have a greater focus on their power-to-weight ratio as compared to rowers who are weight supported and as such have a lesser focus on power-to weight (Stefani et al., 2014). In addition, the different environmental factors such as the nutrition ‘culture’ related to each sport. Alternatively, it may be due to the difference in methods used to calculate EEE and EI, with Matt et al., (2021) using Actiheart HR monitors for EEE and food frequency questionnaires (FFQs) for measurement of EI. Nonetheless, both studies indicate the high prevalence and subsequent high risk of problematic LEA in the adolescent athlete population.

It is crucial to minimise the exposure of problematic LEA in adolescent athletes to prevent adverse health and performance consequences. A case report on a 15-year-old cross-country runner who presented with symptoms related to problematic LEA for two years (absent menstrual cycles, disordered eating, low BMD) demonstrates the importance of detecting problematic LEA early in the adolescent population. During adolescence peak bone mass is accrued, however, as demonstrated by this case study, failure in the detection of problematic LEA and appropriate support may result in stress fractures, or possible diagnosis of osteoporosis (Goolsby et al., 2012). From a rowing perspective, adequate EA may be considered important for the prevention of rib stress injuries, which comprise approximately 10% of all rowing injuries (Hosea & Hannafin, 2012). Previously, lightweight male rowers were found to be at higher risk of rib stress injuries, low testosterone, and decreased RMR (Vinther et al., 2006), likely due to decreased EI, and being in a subclinical or problematic LEA state. Similarly, a study on 40 women endurance athletes exercising 11.4 ± 4.5 hours/week found that athletes with an EA classified as subclinical or problematic LEA ($<45\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$) and/or menstrual dysfunction, had a lower RMR and 45% of these athletes had impaired bone health (Melin et al., 2015). Cumulatively, the prior research in this area demonstrates the importance of achieving adequate EA ($>45\text{kcal}\cdot\text{FFMkg}^{-1}\cdot\text{day}^{-1}$) as a means of reducing the risk of adverse physiological outcomes that may arise in those individuals meeting the classification of subclinical and problematic LEA states for prolonged periods. In alignment with this recommendation, it is noted that the Great Britain Rowing Team has identified risk factors (such as problematic LEA) for bone stress injuries and subsequently provided guidelines for the management of weight loss, low bone density, and REDs (Evans & Redgrave, 2016).

When assessing the energy status of adolescent athletes, thought must be given to unintentional suboptimal EA and EB, and the likelihood of this group being prone to such states. A study on adolescents, both sedentary and athletes, who were in a problematic LEA state found that both groups had satisfactory eating attitude scores and no characteristics of disordered eating behaviour (Hoch et al., 2009). Although no validated tests on eating behaviours were carried out in this study, associated questions on how much nutritional knowledge and awareness adolescent rowers in New Zealand have around their EI are

needed. Tools such as the Athlete Food Choice Questionnaire, Platform to Evaluate Athlete Knowledge of Sports – Nutrition Questionnaire, and the Athlete Diet Index may be useful to address this issue if future research, however, may require adjustment to New Zealand foods and for an adolescent age group. This information may be used to enable changes in their eating behaviours on hard days and may be a consideration for future research.

3.4.4 Carbohydrate Intake and Energy Intake around Training Sessions

This study reported average CHO intake that ranged across the four days between 2.4-7.0g·kg⁻¹·day⁻¹ for females and 2.2-8.7g·kg⁻¹·day⁻¹ for males. Both these CHO ranges are below the recommended 6-10g·kg⁻¹·day⁻¹ for activities of moderate to high intensity (Thomas et al., 2016). The failure of adolescent rowers in our study to meet current nutritional CHO guidelines is similar to those of Baranauskas et al., (2018), who found elite female and male rowers (18.2 ± 2.3 years old) had an average CHO intake of 4.6 ± 0.8g·kg⁻¹·day⁻¹ and 4.6 ± 1.3g·kg⁻¹·day⁻¹, respectively. Interestingly, Matt et al., (2021) reported CHO intakes for females to be below recommended amounts (4.9 ± 2.1g·kg⁻¹·day⁻¹), however, males in their study cohort met CHO intakes (6.1 ± 2.5g·kg⁻¹·day⁻¹). This differs from this study where both female and male adolescent rowers appear to be achieving CHO intakes on the low end of sport nutrition guidelines. Adequate EI through CHO ingestion has proven important for sporting performance (Simonsen et al., 1991), not only as part of the total daily EI but also how CHO is spread across the day. A study on 10 competitive rowers found that the omission of a CHO-rich breakfast impaired afternoon performance, even if adequate energy was consumed at the lunchtime meal (Cornford & Metcalfe, 2018). This suggests that nutritional guidelines should not only focus on energy requirements and enhancing nutritional knowledge on how to compensate for EEE, but they should also consider CHO intake, as this is needed to support adolescent rowers' EI, health, and performance.

While the findings from this study regarding EI before and after training sessions were mainly descriptive, the importance of EI prior to or immediately post-training is becoming more well-recognised in the literature (Kim & Kim, 2020). Of particular interest is the periodisation of CHO around training sessions. Our study found that in the 4 hours prior to a training session female rowers on average consumed 0.9 ± 0.4g·kg⁻¹ CHO, and males 0.9 ± 0.3g·kg⁻¹ CHO, this

is below the current sports nutrition guidelines of the recommended CHO ingestion before exercise (Thomas et al., 2016). Aandahl et al. (2021), reported that pre-event CHO ingestion of $3\text{g}\cdot\text{kg}^{-1}$ increased time to exhaustion in elite male athletes (aged 24.6 ± 2.3) compared to intakes of $0.5\text{g}\cdot\text{kg}^{-1}$ or those training in a fasted state. For our cohort of rowers, their CHO intake pre-training may suggest that they are at risk of decreased sporting performance. In the first hour after training both genders did not reach recovery CHO targets of $1\text{g}\cdot\text{kg}^{-1}$ (Burke & Vicki, 2015), instead averaging $0.5 \pm 0.2\text{g}\cdot\text{kg}^{-1}$ for females, and $0.6 \pm 0.5\text{g}\cdot\text{kg}^{-1}$ for males. Glycogen resynthesis is at its highest in the first two hours after exercise (Ivy et al., 1988). Therefore, it is important for rowers to ingest enough CHO after a session, especially with multiple training sessions in one day (Burke et al., 2017). Possible explanations for the delay in or insubstantial EI after training sessions could be due to, this population's schedule (e.g., going from morning training straight to school), the limited windows of opportunity to eat (e.g., fixed times for morning tea and lunch) and an adolescent's accessibility to food (e.g., self-provided snacks and lunch must be packed ahead of time for the day). All of which may need to be investigated or considered in future research within this age group. The inability to periodise CHO intake and total EI around training may adversely impact performance and ultimately may disrupt a rower's energy status. This may put rowers at risk of entering a state of problematic LEA which over time may result in the unfavourable health outcomes associated with REDs. Therefore, nutritional guidelines for adolescent rowers should consider the timing of nutritional intake.

3.4.5 Strengths and Limitations

The adolescent population is underrepresented in research, particularly in a sporting context. This study is unique in that it not only assessed EI in this population group but also their energy status across two days of differing training intensities. This study involved an in-depth dietary assessment where multiple strategies were used to ensure the accuracy of data obtained (such as written diary, photography, and timely researcher follow-up). This study recruited rowers of both genders, with unusually more participants being female ($n=23$) than male ($n=12$). This allowed for results to be reported by gender which considers the differing physiologies of each sex. Furthermore, data input in this study was another strength, with

few researchers handling the data set. This allowed for extensive cross-checking and consistency in inputting methods.

The relevance of the EA calculation and determining EB as a means of measuring energy status in the adolescent population remains topical due to the growth and physiological development that occur in this period. The presentation of problematic LEA in adolescents such as self-reported fatigue, the delayed onset of puberty, irregular menstrual cycles, and low bone mineral density have been recognised by Desbrow et al., (2014), however, these measures in-field can be difficult to quantify and were not investigated in this study. The calculation of rowers' EERs in this study is likely to be an underestimation of the rowers' actual EER due to physical activity outside of rowing training not being accounted for (e.g., incidental activity and other school sports). Additionally, EEE was self-reported by rowers, where measurement of HR was taken from a rower's personal activity tracking device, hence, variation between HR measurements may have occurred (Martín-Escudero et al., 2023). Finally, data on EI and EEE was collected only on four days, although effort was made to ensure these days were as representative of a rower's daily habitats as possible. The COVID-19 pandemic (e.g., physical contact restrictions) meant that not all participant's FFM was able to be measured via BIA analysis. This resulted in male participants being less represented in this data.

3.6 Conclusion

The result of this study provides insight into the energy status of adolescent rowers in New Zealand and the differences between males and females in this population. Our results suggest that up to 78% of female, and 50% of male adolescent rowers may be classified with a negative EB, or in a subclinical or problematic LEA state. These results may be due to distinct differences in both genders' EEE, despite no differences found in either gender's EI between hard and recovery training days. This implies that adolescent rowers may not be periodising their EI to match their EEE. This can ultimately impact a rower's energy status and could have potential adverse effects on physiological health and sporting performance. The average CHO intake for both genders was below the sports nutrition CHO intake guidelines. Given that CHOs are the foundation of an athlete's EI, inadequate consumption of this macronutrient

may put an adolescent rower at risk of entering a suboptimal energy state. These findings suggest that adolescent rowers do not adjust their nutritional intake to match EEE. This may increase the risk of adolescent rowers presenting with either a suboptimal EB or EA status, a result that future nutritional guidelines or education should consider for this age group.

Chapter 4: Conclusions and Recommendations

4.1 Achievement of Aims and Hypotheses

The overall aim of this study was to investigate the EI and energy status of current male and female adolescent rowers in New Zealand. Our results suggest that adolescent rowers in New Zealand may not be periodising their EI to match their EEE from rowing training. The EI of adolescent rowers in New Zealand in this study would seem to meet their EERs, a result that contrasts with previous research which identified that elite rowers did not meet their EERs through their daily EI (Baranauskas et al., 2018). A potential reason for this difference found in our rower's EERs against the previous literature may be due to the underestimation of EERs in this study due to the study not collecting incidental and other exercise, only rowing specific training. However, when analysing the energy status of adolescent rowers, this study revealed that overall, there was a potential risk of these athletes being in a suboptimal energy state (e.g., subclinical EA, problematic LEA or negative EB), a finding that aligns with existing literature on adolescent athletes (Matt et al., 2021). If an athlete is in a suboptimal energy state for a prolonged period (both intentionally and unintentionally), or as a result of very low EI, this can have numerous adverse physiological and performance outcomes (Mountjoy et al., 2023). Adverse health outcomes noted in the research include adverse disruptions to, metabolic processes, protein synthesis, hormonal balance, cardiovascular function, cognition, mood, and concentration (Mountjoy et al., 2023). It is particularly important for adolescent athletes to prevent entering a state of suboptimal energy, either with severe inadequacy in EI or for a prolonged period due to their growth and development needs during adolescence (Desbrow et al., 2014).

Ultimately, the EA and EB of rowers calculated in this thesis, each provide a unique insight into adolescent rowers' energy status. The calculation of EB measures total EI against TEE (including BMR). The limitation of EB calculations is that TEE is difficult to quantify accurately (e.g., incidental activity and the use of predictive equations is often necessary). Whereas EA may calculate the energy status in an individual more accurately given that FFM is accounted for, and the EEE used in its derivation is solely from exercise. However, when the limitations

and derivation of both EA and EB are known and acknowledge, the use of these measures in research can be used synergistically to build an overall awareness of a rower's energy status.

It was hypothesised that EI on hard training days would be higher than EI on recovery training days. However, our study found that there was no significant difference in EI between training days for both females and males, despite differences found in EEE between the two training days. This suggests that adolescent rowers in New Zealand are not periodising their dietary EI to match their training loads. This is important as Kim & Kim (2020), have demonstrated that periodisation of EI within a rowers training cycle can improve performance, increase energy levels, and increase an athlete's readiness to carry out subsequent training sessions. Additionally, the implications of problematic LEA and REDs due to increased EEE without matched EI can start to manifest in as short a period as four weeks in rowers (Woods et al., 2017). Furthermore, we expected that a significant portion of adolescent rowers would on average be classified with a suboptimal energy status. Our results suggest that on average across both training days, up to 78% of females and 50% of the male adolescent rowers may be classified with either, a negative EB, or subclinical EA, or problematic LEA. This highlights that the energy status of adolescent rowers may be best measured in terms of EA or EB rather than EI vs. EER. This confirms our hypothesis that the energy status of adolescent rowers will on average be suboptimal (a negative EB, or subclinical EA, or problematic LEA). The consequences of having a suboptimal energy status on performance and health outcomes was not measured in the current study and is an area to consider in future investigations.

The EI of adolescent rowers in the 4 hours preceding training and in the first hour after training revealed that these athletes did not meet their recommended CHO intakes. Due to the frequency of rowing training, the accumulation of not meeting these requirements may predispose adolescent rowers to enter a state of suboptimal energy status. This finding reinforces our hypothesis that adolescent rowers on average will have a suboptimal energy status. The current study did not examine the extent of EB per hour as Fahrenholtz et al., (2018) did in female endurance athletes, where it was found a deficit greater than 300kcal was associated with greater metabolic disturbances. Similarly, Torstveit et al., (2018) found that male endurance athletes who had a within-day deficit greater than 400kcal more readily presented with a suppressed RMR and increased catabolic biomarkers. Such a method was

not used in this study due to the participant burden associated with this method, and the high participant compliance required to maintain detailed food diaries and physical activity tracking, particularly in an adolescent population. Future research may consider this, and the role hourly EB plays in adolescent energy status measurements.

4.2 Strengths

To our knowledge, this is the first study in New Zealand examining the EI, EEE and energy status in adolescent rowers. It was unique as we looked at the energy status of this population (EA or EB) and collected data on days with two differing training intensities (hard and recovery days).

One of the study's strengths was the method of collecting dietary intake. A hybrid method was used where both the written amounts of food and photographs of food consumed was recorded by each rower. Each record was then verified by a researcher promptly to ensure that all details recorded were complete and correct. The use of photography was used to reduce participant burden and accounted for participants who may have low food literacy and may not be able to describe food (proportions and type) accurately (Stumbo, 2013). Ultimately, this method increased the accuracy of our food records and the results for EI in this cohort of participants.

Moreover, this study recruited both genders, resulting in the analysis of females (n=23) and males (n=12). This allowed for data to be represented by gender which is more valuable given the differing physiologies of females and males.

A final strength of this study was the consistency of data input. Three researchers were involved in the input of rowers' food records into FoodWorks10. A food code book was used to ensure that common items consumed by participants were entered under the same food item in the software. Food records were then cross-checked by each researcher. Similarly, only one researcher assigned the METs to each rower's recorded training sessions, this created consistency in the values obtained, and the subsequent data set that was used in this analysis.

4.3 Limitations

Due to the restrictions imposed by the COVID-19 pandemic, specifically physical distancing, and travel restrictions, not all participants' BC was able to be measured. This means that EB has been calculated for all participants, and EA has been calculated as a smaller subset of participants (n=11). It is possible that EB may be a less useful indicator of energy status as it does not consider a rower's FFM. Additionally, the determination of energy status in an adolescent population is questionable given the recognised need to consider other factors such as growth, the onset of puberty, self-reported fatigue, and menstrual cycle irregularities (Desbrow et al., 2014). Therefore, such results in this study may be considered estimates of the energy status of a rower, and not direct measurements.

The EERs of rowers calculated in this study are likely to underestimate these rowers' energy requirements due to additional activity (incidental e.g., walking, or intentional e.g., school physical education class or participation in other sports and activities) not being accounted for. The accuracy of self-reported heart rate (HR) and RPE at training sessions is an additional limitation. Participants used personal activity tracking devices, including smartwatches and HR monitors to record their HR for each training session. However, these devices have varying degrees of accuracy, especially when the intensity of training changes (Martín-Escudero et al., 2023), and participants may not use or interpret such technologies correctly. Thus, calculations of METs may have been influenced by this, and again this confirms that the EEE and EERs in this study should be considered estimates and not direct measures of these variables.

Finally, it must be noted that only four days of EI and EEE data was collected for each participant. Whilst effort was made to ensure that these days were as representative as possible of a participant's daily habits, this cannot be guaranteed. The nature of inputting food diaries is also subject to human error, this was mitigated as much as possible but not all errors can be eliminated. Thus, the interpretation of EI for other populations may need to be considered with caution.

4.4 Recommendations and Future Direction for Research

The average EA of adolescent rowers in this study was classified as subclinical and a large proportion of rowers had an average negative EB. Given this, it is evident that the EI of this population may not be fulfilling their training and growth requirements through nutritional intake. Moreover, adolescent rowers in this study display a lack of periodisation of their EI to match their EEE. Rowing New Zealand (the sport's governing body) may play an active role in future research and implementation of nutrition initiatives. This would align with Rowing New Zealand's purpose which is to provide leadership and support that facilitates an environment for success to occur for the rowing community in New Zealand, from secondary school to elite, through to master's level in the sport (Rowing New Zealand, 2023). For Rowing New Zealand to achieve their aim, support staff and researchers may consider the following recommendations for future research and athlete support.

Future research recommendations

- Review and development of sport-specific nutritional guidelines for adolescent athletes should be considered in future research and nutritional guidelines. Our study's results displayed several differences in EI and EA to that of adolescent distance runners (Matt et al., 2021). This highlights the need for sport-specific requirements to be considered.
- Since this study only assessed four individual days of EI and EEE, further investigation assessing how adolescent rowers periodise their nutrition to their training load over multiple weeks would enable a better representation of whether adolescent rowers are periodising their EI over a training and competition season. This is important as failure to periodise EI to match EEE may adversely affect energy status as well as physiological health and sporting performance during a competitive season.
- This study assessed EI four hours prior to exercise and one hour post-exercise, future research should consider within day EB/EA on an hourly basis. This will allow for deficits within a 24-hour period to be identified in line with Fahrenholtz et al., (2018) and Torstveit et al., (2018) which may be more valuable to address EI inadequacies in adolescent rowers.

- Future research should consider the validity of measuring energy status in the adolescent athlete population. Adolescence is a unique time where growth and development occur at different times for individuals. With these additional physiological processes taking place (and hence energy being needed for these processes) the validity of calculating EA or EB in this population should be considered. Rather a screening tool such as the IOC REDs CAT2 (Mountjoy et al., 2023) may be used to assess exposure to problematic LEA in this population.
- Given disordered eating can be a major factor influencing EI and hence energy status, future research should consider nutritional behaviour and nutritional knowledge questionnaires for the determination of problematic LEA risk. This will provide additional insights into eating behaviours and awareness in adolescent rowers and if this contributes to being in a suboptimal energy state.

Practical recommendations for athlete support staff and sporting organisations to consider

- Implementation of a health and nutrition programme targeted at adolescent rowers, similar to the campaign launched before the Tokyo 2020 Olympics for New Zealand's elite rowing squads. This will target the next generation of rowers and promote continuity in the sport by teaching the skills of periodisation of nutritional intake and consuming adequate EI for differing training demands.
- Our study demonstrates that adolescent athletes require an individualised approach to nutrition based on their physiological development, training volume and intensity, and socio-environmental factors. Athlete support staff, parents, coaches, and sporting organisations must be made aware of this to support adolescent athletes as required at an individual level.
- Our study indicates a need for nutrition education for adolescent rowers. This education should focus on the need to fuel and recover from training, with a focus on rowers consuming sufficient EI in an appropriate timeframe given this population's often limited opportunities to eat around training times. For example, educating both athletes and their caregivers about the importance of packing a breakfast for the time between before-school training and class beginning. Additionally, the dissemination

of resources to schools and rowing clubs with appropriate examples of food to eat before and after training sessions should be considered.

- Compulsory screening of potential problematic LEA in athletes. Achieved using the IOC REDs CAT2 tool (Mountjoy et al., 2023). This will allow staff to proactively support rowers presenting with factors associated with problematic LEA. Additionally, staff and organisations should refrain from undertaking body composition assessments on rowers, particularly those under 18 years of age, this will minimise extreme pressure on a rower's body weight.
- Psychological health frameworks and values should be implemented and upheld in rowing clubs (e.g., to promote a positive sporting environment), with the option of receiving individual psychological help if required. Recent research highlights the importance of psychological health in preventing symptoms associated with REDs (Mountjoy et al., 2023).

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Appendices

Appendix A: Participant Information Sheet

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 or not 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

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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 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:

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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.