Energy Intake and Energy Balance in New Zealand Elite Female Football Academy Players

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

Nutrition and Dietetics

Massey University, Albany

New Zealand

Josie McConnochie

2024

Abstract

Background: Energy is a fundamental requirement for all biological processes, making adequate dietary energy intake (EI) critical to the health and athletic performance of athletes. Playing football at the elite level is an energetically expensive activity. Research in female footballers is limited; however, due to the negative consequences of being in a state of problematic low energy availability (pLEA), further investigation is needed to assess the adequacy of female footballers' EI in supporting physiological function and demands of training.

Objectives: Determine the energy intake (EI) and energy balance (EB) of elite under 20 female Football Academy players in New Zealand and if low carbohydrate (CHO) intake is a factor that increases the risk of low EB.

Methods: Twenty-four female footballers who were part of the Wellington Phoenix U20 Football Academy team in New Zealand participated in this study. Participants were asked to complete a three-day dietary record on one light training day, one heavy training day, and one pre-game rest day. Energy intake was analysed via Foodworks V.1.0 software. For training, exercise energy expenditure (EEE) was estimated using a human motion tracking device (Playermaker, Israel). Paired sample t-tests or Wilcoxon Signed Rank test (non-parametric data) were utilised for comparisons between EI, EEE and EB on different training days. Significance was determined by a p-value of < 0.05.

Results: The average EI for participants on light training, heavy training, and pre-game rest days was 1758.7 ± 549.5 kcal, 1910.1 ± 611.2 kcal and 1805.8 ± 533.2 kcal respectively, with no significant differences in EI between training days. The average relative carbohydrate intake ranged between 1.4 – 6.7 $g \cdot kg^{-1}$ across all training days, failing to collectively meet sports nutrition recommendations. The average EB across all training days was 297.1 ± 491.6 kcal with no significant differences between days of data collection. Across the three training days, 25.0% of female development players were in a negative EB. A very strong, significant positive correlation was found between average EI and average EB ($R=0.980$, $n=24$, $P=<0.01$). There was no significant correlation found between average EI and average EEE ($p=0.909$) or average EEE and average EB ($p=0.538$).

Conclusion: The results of this study suggest that female footballers fail to match their EI to their EEE, and a high proportion of players at the elite development level in New Zealand are in a negative EB, which could increase their risk of pLEA.

Acknowledgements

Thank you to Claire Badenhorst and Andrew Foskett for being the best supervisors imaginable. Thank you, Claire, for always being so quick to reply to emails and for your efficiency in providing me with any help or feedback that I required at any time. Thank you, Andrew, for all your input and valuable ideas. The consistent support from you both made this project feel like a breeze. It couldn’t have run more smoothly.

Thank you to Isabella Coombes, who assisted in the running of the project, your help during the data collection process was greatly appreciated. Thank you to Courtney Younger, who shared the load of this project with me and continuously provided support, laughs, and accountability.

Thank you to the 2024 Massey University dietetics cohort, who have become my close friends. I wouldn’t have been able to get here without your continual support, and our frequent debriefs, often fueled by our shared, stress-induced loopy states.

Finally, I would like to thank my family for their continual support, encouragement, and willingness to listen to my ideas and worries.

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List of Abbreviations

Abbreviation	**Term**
ACSM	American College of Sports Medicine
CHO	Carbohydrate
DXA	Dual-energy X-ray Absorptiometry
EA	Energy Availability
EB	Energy Balance
EEE	Exercise Energy Expenditure
EER	Estimated Energy Requirements
EI	Energy Intake
FFM	Fat Free Mass
GPS	Global Positioning Systems
IOC	International Olympic Committee
LEA	Low Energy Availability
LEAF-Q	Low Energy Availability in Females Questionnaire
LH	Luteinising Hormone
pLEA	Problematic Low Energy Availability
REDs	Relative Energy Deficiency in Sport
RMR	Resting Metabolic Rate
TDEE	Total Daily Energy Expenditure
UEFA	Union of European Football Association

Chapter 1: Purpose

1.0 Introduction

Energy is a fundamental requirement for all biological processes, making adequate dietary energy intake (EI) critical to the health and athletic performance of athletes. Maintaining an appropriate energy balance (EB), where EI matches total daily energy expenditure (TDEE), ensures adequate energy availability (EA). Energy availability has been defined as the amount of dietary energy available from EI to sustain normal physiological function, inclusive of growth, immune function, locomotion, and thermoregulation (Nattiv et al., 2007), after removing exercise energy expenditure (EEE) of skeletal muscles (Areta et al., 2021). Low energy availability (LEA) occurs in athletes who have a dietary EI that fails to account for their current TDEE. As a result, after energy has been used by skeletal muscle for movement, exercise, and locomotion (EEE), the amount of energy left available for other physiological processes is inadequate (Mountjoy et al., 2023). Low energy availability exists on a continuum where effects are benign (adaptable LEA) to substantial (problematic LEA) and have been defined in depth in the recent IOC Relative Energy Deficiency in Sport (REDs) Consensus Statement (Mountjoy et al., 2023). Adaptable LEA refers to a temporary reduction in EA, such as during periods of purposeful body composition manipulation in an acute and prescribed manner with professionals, such as a dietitian, to achieve high performance goals or during scheduled periods of intensified training or competition. Adaptable LEA is associated with benign effects, including reversible changes in biomarkers such as oestrogen and cortisol. This benign state of LEA is indicative of adaptive energy distribution and typically has minimal impact on long-term health, wellbeing, or performance. Conversely, problematic LEA (pLEA) is exposure to LEA that is proposed to be associated with greater and potentially persistent disruption of various body systems, such as the gastrointestinal, immunological, haematological, and endocrine systems. H, owever, the specific risk factors, individual mediators and health and performance outcomes of these disruptions to the various body systems are still being investigated. Problematic LEA is observed to often present with signs and/or symptoms and represents a maladaptive response. As such, pLEA is the noted causal factor of REDs and the associated adverse health and performance consequences (Mountjoy et al., 2023).

Initial research suggested a LEA threshold of <30 kcal·kg^{-1} FFM (fat free mass) where health implications, such as the onset of reproductive dysfunction, were reported to occur in a small sample of sedentary females (Ihle & Loucks, 2004; Loucks & Heath, 1994; Loucks & Thuma, 2003; Loucks et al., 1998). However, more recent research has identified significant individual variability in physiological responses to LEA thresholds, with differences observed between individuals and across various body systems (Lieberman et al., 2018; Salamunes et al., 2024). Reproductive function impairments, such as menstrual irregularities and amenorrhea, are recognised for their adverse impacts on female athletes, secondary to the disruptions to reproductive endocrine function caused by pLEA. While there is not yet a clear consensus on the causative factors for reproductive dysfunction, current evidence suggests a LEA-associated disruption of gonadotropin releasing hormone (GnRH) pulsatility at the hypothalamus is likely to contribute to alterations of luteinising hormone (LH) and follicle stimulating hormone release from the pituitary. Subsequently, there are decreases in oestradiol and progesterone levels, resulting in menstrual irregularities, of which the most severe form is functional hypothalamic amenorrhoea (FHA) (Mountjoy et al., 2018). Of note, impairments to reproductive function, endocrine pathways and body systems are coupled with a range of other health consequences including, but not limited to, decreases in energy metabolism, musculoskeletal health, immunity, glycogen synthesis and cardiovascular and haematological health (Mountjoy et al., 2023). These outcomes of pLEA occur over different timeframes with different severity and significance to the individual athlete, which is now acknowledged to be due to various moderating factors such as gender, age, genetics, environment, or behaviours (Mountjoy et al., 2023).

Moreover, pLEA has been reported to have a significant impact on athletic performance. Over time, pLEA may result in a reduction in training response and recovery (Mountjoy et al., 2023). These changes may occur as a result of acute impairment of glycogen storage (Tarnopolsky et al., 2001) or protein synthesis (Areta et al., 2014), or by reducing the consistency and quality of training due to the increased risk of injury and illness (Drew et al., 2018; Drew et al., 2017). Subsequently, female athletes may experience decreased muscle strength, power and endurance performance (Mountjoy et al., 2023). Research has reported a 10% decline in performance over a 400m time trial after a 12-week training period in elite female swimmers who presented with an energy deficiency that resulted in ovarian suppression (VanHeest et al., 2014). Changes in cognitive performance and skill, and motivation may also contribute to poor performance in periods of pLEA (Mountjoy et al., 2023). In amenorrheic elite endurance athletes, reaction time was found to be 7% longer than in their eumenorrheic counterparts (Tornberg et al., 2017), while another study in female athletes found that those classified as having pLEA were more likely to self-report impaired judgement and decreased coordination and concentration (Ackerman et al., 2019).

Research in this field has primarily been completed in sports where athletes are considered at a higher risk of pLEA, including endurance, aesthetic, and weight dependent sports (Logue et al., 2020). Therefore, a considerable amount of the available research on prevalence, symptoms and risk factors has focused on individual and endurance athletes. Limited research has been conducted specifically on female athletes participating in team sports, where unique training and performance dynamics may influence dietary choices and, subsequently, the EI, EB, and EA of the athletes. The demands of team sports, characterised by intermittent and high-intensity activities, as well as the collaborative nature of training and competition, may introduce variables not fully captured in studies investigating pLEA in individual athletes. As a result, the reported prevalence of pLEA/REDs in female athletes across sports ranges widely from 23%-79.5% (Mountjoy et al., 2023).

Despite the popularity of football as a sport, research on pLEA in female footballers remains notably sparse compared to other sports, such as endurance running, cycling, gymnastics and swimming, representing a critical gap in the literature. In the current body of research on female footballers, the prevalence of pLEA ranges from 12% (Reed et al., 2013) to 66.7% (Magee et al., 2020). Despite the increasing recognition of the importance of nutrition in athletic performance, there is a lack of research into the specific challenges faced by female footballers. The unique physical demands of the sport, such as frequent sprinting every 40 seconds (Datson et al., 2019), ~1350-1650 activity changes, including sudden changes in direction and sustained periods of high-intensity activity, mean a distance of up to 8-12 km may be covered by a player in any given match (Datson et al., 2014). These demands require a nuanced understanding of EI, EB, and EA in female players that isn’t covered in the broader range of research that has been done, for the most part in endurance and individual athletes. Additionally, CHO intake plays a crucial role in meeting energy demands and supporting performance, yet within the available research on female footballers, details on how carbohydrate (CHO) availability contributes to EI, EB, and EA has not yet been addressed, requiring future investigations. Furthermore, few studies have been done on late adolescent and elite development athletes which may be helpful in supporting health and sporting longevity for these female athletes.

While much of the current research on energy status in female footballers focuses on LEA, accurately measuring EA in applied settings can be challenging due to the need for precise estimations of TDEE and fat-free mass over time. In contrast, EB offers a more practical and measurable outcome that can provide insight into whether an athlete may be at risk of pLEA. Given that EB is closely related to EA, this study will use EB as a proxy while drawing from existing EA research to interpret findings. Therefore, this study will examine EI, EB, and CHO intake to assess whether dietary intake sufficiently supports the demands of training and competition in female footballers.

1.1 Aims

The aim of this research is to determine the EI and EB of elite under 20 female Football Academy players in New Zealand and if low CHO intake is a factor that increases the risk of low EB for players.

1.1.1 Objectives

a. Determine and describe the EI of female footballers in New Zealand during competition season.
b. Determine if CHO intake meets sport nutrition guidelines, reflecting adequate CHO availability for performance in a competitive season in female footballers in New Zealand.
c. Determine the EB of female footballers in New Zealand and determine the relative risk of pLEA.

1.1.2 Hypotheses

a. Energy intake on heavy training days will not vary from EI on light training days.
b. Energy balance on heavy training days will be negative compared to the EB on pre-game rest days.

c. Players with CHO intakes that do not meet the sports nutrition guidelines, reflecting inadequate CHO availability for performance in a competitive season in female footballers in New Zealand will be more likely to be at risk of negative EB.

1.2 Structure of Thesis

The thesis begins by introducing the concept of negative EB and pLEA in female athletes, along with the associated health and performance consequences, followed by the study aims, objectives and hypotheses. Chapter two follows this, providing a comprehensive review of the current literature available on pLEA and EB in collegiate, professional, youth and international female footballers, as well as the additive effects of low CHO intake on pLEA and the associated symptoms. Chapter three, the manuscript, summarises the details of the methodology and results of this research. The thesis concludes with chapter 4, with a discussion on the findings and implications of this study, the strengths and limitations, and practical takeaways for New Zealand football and the elite development female footballers, as well as future directions for research looking at pLEA, EI and EB in female footballers.

1.3 Researcher's Contributions

Table 1.1: Summary of Researcher's Contributions to the Study

Author	Contribution to Thesis
Josie McConnochie MSc Nutrition and Dietetics student	Primary author of thesis Designed research Data collection Statistical analysis Interpreted and presented results
Dr Claire Badenhorst Primary Supervisor Senior Lecturer School of Sport, Exercise and Nutrition	Primary Supervisor Ethics application Revised and approved thesis
Associate Professor Andrew Foskett Co-Supervisor	Co-supervisor Ethics application Revised and approved thesis

Head of School of Sport, Exercise and Nutrition	
Isabella Coombes PhD Candidate Wellington Phoenix Female Academy Sport Scientist	Assisted in data collection
Courtney Younger Co-researcher MSc Nutrition and Dietetics student	Co-researcher Assisted in data collection Assisted in statistical analysis

Chapter 2: Literature Review

2.0 Introduction

Optimal performance and health in female footballers relies on adequate energy intake (EI) to support the demands of training and match play. In a state of problematic low energy availability (pLEA), there is a negative energy balance (EB) that is inadequate for optimal body function (Logue et al., 2018). Problematic low energy availability is the noted causal factor of relative energy deficiency in sport (REDs), defined by the International Olympic Committee (IOC) in 2023 as exposure to low energy availability (LEA) that is associated with greater and potentially persistent disruption of various body systems such as the gastrointestinal, immunological, haematological, and endocrine systems – all of which contribute to unfavourable health and performance consequences (Mountjoy et al., 2023).

Playing football at the elite level is an energetically expensive activity. For optimal player performance, footballers need to consider the energy expenditure of both training and matches (Thomas et al., 2016). Elite female football players will typically partake in 1-2 matches and 4-6 training sessions across a week (Moss et al., 2021), though this varies depending on the time of the year and playing position (Mara et al., 2015). During a football match, it is typical for elite female football players to cover distances of 8-12 km incorporated with up to 1.68 km of high intensity running efforts and ~1400 activity changes in match play across a range of heart rate zones and intensities (Andersson et al., 2010; Datson et al., 2014; Krustrup et al., 2005). There are, however, differences in daily and exercise energy expenditure (EEE) between individual days of the week, training sessions and individual players with reference to their playing positions (Mara et al., 2015). Female footballers should therefore ensure that they have an EI that supports their EEE to allow for adequate EB and energy availability (EA) and in turn facilitate optimal training adaptations, physiological function and athletic performance (Mountjoy et al., 2023).

The popularity of Football as a sport is indisputable, with the female game growing at a high rate, with 73% of member associations having an active senior women's national team, which is up from 55% in 2015 (FIFA, 2019). The growing numbers of female footballers, and particularly the increasing number of full-time professional footballers who have the greatest demands on them, calls for a deeper understanding of how their EI and EB is impacting their risk of pLEA and the associated consequences on performance and health. This review aims to outline the current understanding of pLEA within female footballers across a range of high-performance levels. Additionally, this review will investigate the carbohydrate (CHO) intake of female footballers and how this may result in changes in EA, EI, and EB and or contribute to LEA states across the competitive and training seasons. In turn, this review will aim to highlight gaps in the literature where future research should be directed so that female footballers can be supported to enhance performance and mitigate the risk of pLEA.

2.1 Low energy availability in athletes

The concept of LEA originated from the development of the female athlete triad, which proposed the negative consequences that pLEA may have on a female's bone density and reproductive function (Nattiv et al., 1994). Over time, the phenomenon has evolved to better encompass the outcomes of pLEA beyond reproductive function and bone density (Mountjoy et al., 2014). With this development has come a growing body of research and awareness in the field, with >170 original academic publications advancing the field of REDs research since 2018 (Mountjoy et al., 2023). The research spans largely across sports where the risk of pLEA in athletes is considered to be high, including endurance, aesthetic, and weight dependent sports (Logue et al., 2020). Current research suggests that pLEA is more common in female athletes than male athletes (Mountjoy et al., 2018). There is evidence that shows female athletes consistently fail to meet their EI with a higher EEE that may occur during periods of high training loads and intensity within a competitive season (Dobrowolski & Włodarek, 2020; Gibson et al., 2011; Magee et al., 2020; Moss et al., 2021). Low energy availability may arise as a result of inadequate dietary EI and/or an increase in EEE resulting from physical activity. While an inadequate dietary EI could be a symptom of unintentional causes, for instance, periods of intensified training or competition, lack of previous nutrition education (Costill et al., 1988), or post-exercise appetite suppression (Howe et al., 2016), it is noted that for some athletes it may be a purposeful decision. In these cases, inadequate EI may be secondary to disordered eating behaviours, clinical eating disorders, and choosing to restrict EI to enhance sports performance, meet aesthetic demands of the sport, or perceived societal pressures (Mountjoy et al., 2023; Mountjoy et al., 2018). In New Zealand, 73% of elite female athletes in the high-performance sport environment felt pressure to embody specific traits related to physical appearance and that these pressures did not align with positive overall health outcomes. Of these women, 33% reported falling into habits of disordered eating to achieve the perceived ideal body for their sport (Heather et al., 2021). Consequently, in the study of EA and EB, the psychological status and possible risk of disordered eating habits should be considered in research investigating dietary intake in athletes.

The reported prevalence of pLEA/REDs in female athletes across the full spectrum of sports ranges widely from 23-79.5% (Mountjoy et al., 2023). Research methodologies/design have commonly used both direct assessments of physiological or psychological signs/symptoms of pLEA (e.g. blood hormone concentrations, bone mineral density (BMD), menstrual dysfunction, presence of clinical eating disorders or disordered eating habits) and indirect assessments typically in the form of a validated screening survey tool (e.g. the Low Energy Availability in Females Questionnaire - LEAF-Q) to determine the EB and subsequently the EA of participants and or the relative risk of pLEA (Ackerman et al., 2023). Therefore, the large variability in pLEA prevalence may be attributed to the challenges of measuring EB and/or EA accurately and, subsequently, the range of methodologies used in the absence of a gold standard assessment tools or standardisation between studies (Ackerman et al., 2023).

2.2 Measurement and determination of LEA

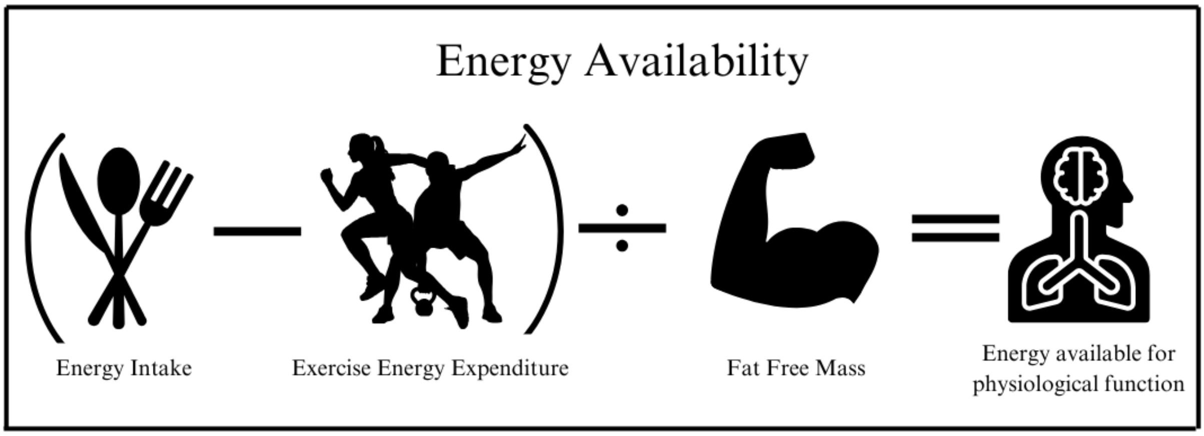

Figure 1.1 EA is the dietary energy left over for physiological processes after EEE has been accounted for.

In the absence of standardised methodologies for direct and indirect assessment of pLEA, research has used a combination of validated and practical methods to determine EI and anthropometry. Methods such as Dual-Energy X-ray Absorptiometry (DXA) and Doubly Labelled Water (DLW) are reliable and valid for assessing body composition and energy expenditure; however, they are costly and, at times, impractical. Doubly Labelled Water, though useful for the accurate measurement of resting metabolic rate, is still somewhat prone to methodological flaws (Heikura et al., 2022) and is unfeasible during football matches. Conversely, anthropometry has been successfully self-reported in females, offering a feasible approach to collecting height and weight data that may be comparable to clinical and lab-based measures in terms of reliability (Seijo et al., 2018).

Methods such as food diaries, remote food photographic methods and 24-hour dietary recalls may be considered more feasible when collecting dietary data of female athletes. Despite their practicality, these methods are more vulnerable to measurement errors and bias. Assessments of EI introduce large sources for error and bias, especially if participants forget to record all food/drink occasions and items, intentionally or unintentionally change dietary behaviour due to the conscious act of recording, they may fail to quantify food intake accurately, and if completed over several days, it could contribute to a large participant burden (Bailey, 2021). Self-reported EI has been found to have errors of both under and over reporting, yet the 24-hour dietary recall tends to have the lowest rates of misreporting due to prompts that help to facilitate the reduction of recall bias. The recent and short time frame over which participants must recall improves the quality of the reported EI (Burrows et al., 2019). Despite this, the measurement error that presents in self-reported EI and EEE remains a significant challenge that impacts the reliability and validity of the conclusions developed from research using these methods. Therefore, careful consideration is required when choosing a methodology to implement within a research study investigating dietary intake. Under-reporting can be reduced when dietary intake is recorded alongside photographs of items and meals consumed and when discrepancies in the dietary records are followed up by researchers in real time (Stumbo, 2013).

Field-based testing for EI, EB and EA can be conducted; however, it often proves unreliable, leading to discrepancies of up to 600 kcal·day^{-1} (Burke et al., 2018). A feasible methodology for assessing the EEE and training load of players may be through the use of Global Positioning System (GPS) based devices (Buchheit et al., 2015), though their accuracy may be limited by the intermittent nature of football and the associated training, which GPS algorithms are less effective at covering (Cummins et al., 2013). Despite these challenges, recent recommendations by Ackerman et al. (2023) advocate for a combination of valid and reliable indirect and direct assessments for the most accurate data, taking into account participant burden when deciding on the degree to which each is employed. The measurement of EI and EEE in the assessment of EA falls under the direct measurement category. By calculating the difference between both EI and energy expenditure, EA can consequently be determined by the net EB. Thus, the inclusion of direct assessments of EI and EEE may allow for more accuracy in the study of EA.

The LEAF-Q is frequently used in the current body of literature on pLEA in female footballers. The LEAF-Q has been shown to be acceptably sensitive (78%) and specific (90%) for determining the risk of pLEA (Melin et al., 2014), though it does not directly measure EA and instead relies on the self-reporting of symptoms associated with pLEA. It is worth considering that the LEAF-Q was validated in endurance sports. There is a possibility for the LEAF-Q to provide biased statistics because the tool fails to fully account for football-specific characteristics, such as the intermittent nature of the game and the type and location of injuries (Rosenvinge et al., 2022).

Female football research available in the literature has employed methods ranging from self-reported diet and exercise records, GPS, DLW, DXA, blood samples, and questionnaires to collected data on EI, EB, EA and pLEA. The range in methodologies may contribute to the large variability in pLEA results in female footballers that will be discussed in this review.

Table 2.1: Summary of Research on Low Energy Availability in Female Footballers

Year	Author	Age	Sample Size	Athlete Level	Study Design	Mean ± SD EA (kcal·kg^{-1}/FFM/day)	Mean Relative EI (kcal·kg^{-1})	Participants with LEA (%)	Mean CHO intake (g·kg^{-1})	Comments
2020	Dobrowolski & Wlodarek	21.5 ± 4.9	31	Professional	3-day dietary food record, Armband SenseWear Pro3 device, BIA	25 ± 11	n/a	64.1%	n/a	Mean EI of 1548 ± 452 kcal Mean EEE of 2703 ± 392 kcal
2021	Moss et al.,	23.7 ± 3.4	13	Professional	5-day weighed food diary, indirect calorimetry (FitMate metabolic system), GPS, MET values via training logs, DXA, LEAF-Q	35 ± 10	n/a	23%	3.31 ± 0.64	15% with optimal EA 62% with reduced EA
2023	Dasa et al.,	22 ± 4	51	Professional	Doubly labelled water, 3 dietary recalls, GPS	Match day = 36.7 ± 17.7 Training days = 37.9 ± 11.7	45.4	Match day = 36% Training days = 23%	Total = 3.9 ± 1.1 Training days = 4.0 ± 1.3 Match days = 4.5 ± 1.9 Rest days = 3.9 ± 1.6	Mean EE was 2918 ± 322 kcal while mean EI was 2274 ± 450 kcal, resulting in a discrepancy of ~22%
2006	Martin et al.,	25.5 ± 3.9	16	International	7-day self-reported activity and food diary	n/a	30.9 ± 5.5	n/a	4.1 ± 1.0	Non-significant energy deficit of ~250kcal/d
2015	Mara et al.,	23-30	8	International	SenseWear Mini Armbands, GPS, DXA	n/a	n/a	n/a	n/a	Mean daily EE for the game day, training days, and rest days in KJ were 12,242 ± 603, 11,692 ± 274, and 9,516 ± 369, respectively, with significant differences shown between days.
2003	Clarke et al.,	Pre-season = 19.7 ± 0.7 Post-season = 20.0 ± 0.9	13	College (D1)	3-day diet records, anthropometrics, and physical tests	n/a	Pre-season = 37 ± 5.0 Post-season = 30 ± 18.0	n/a	Pre-season = 5.2 ± 1.1 Post-season = 4.3 ±1.2	EI in kcal for pre-season and post-season was 2290 ± 310 and 1865 ± 530, respectively, with significant differences

										seen between pre-and post-season.
2013-2014	Reed et al.,	18-21	19	College (D1)	3-day diet logs, exercise logs, Polar FT4 heart rate monitors, Polar Team^2 software, anthropometry, Eating Disorder Inventory 2 Questionnaire, exercise testing, blood samples	Pre-season = 43 Mid-season = 34 Post-season = 44	n/a	Pre-season = 26% Mid-season = 33% Post-season = 12%	Pre-season = 7 ± 1 Mid-season = 5 ± 1 Post-season = 5 ± 1	The proportion of athletes who did not meet the American College of Sports Medicine (ACSM) recommendations for CHO intake (6–10 g·kg^{-1}) was significantly greater in the low than higher EA group
2020	Magee et al.,	19.2 ± 1.1	18	College (D3)	4-day dietary record, GPS, LEAF-Q	27.5 ± 8.9	30.1 ± 7.3	66.7%	3.7 ± 1.0	Relative CHO intake (g·kg^{-1} per day) for pLEA participants was 3.3 ± 0.7 versus 4.6 ± 0.9 for non-pLEA participants
2011	Gibson et al.,	15.7 ± 0.7	33	Youth	Anthropometric assessment, 4-day food records, haematological analysis	n/a	35 ± 10	n/a	5.0 ± 1.6	51.5% of players consumed less than 5 g·kg^{-1} of CHO Average energy deficit of 462 ± 549 kcal
2018	Braun et al.,	14.8 ± 0.7	56	Youth	7-day food record and activity protocol, BIA, anthropometrics, blood samples	30	40.5 ± 7	53%	5.4 ± 1.1	53% of athletes did not meet the minimum EA requirement (>30 kcal·kg^{-1}/FFM)
2023	Paludo et al.,	14.6 ± 1.42	19	Youth	LEAF-Q, ORTO-R questionnaire, menstrual cycle questionnaire, physical performance testing.	n/a	n/a	26.3%	n/a	n/a
2023	McHaffie et al.,	17.9 ± 0.5	23	Youth & International	Remote food photography method, GPS.	34 ± 12	33.6 ± 8.4	34%	Days before the game = 4.8 ± 1.1 and 4.3 ± 1.1 Game days = 4.8 ± 1.2 and 4.8 ± 1.4	Only 19 (8%) accounts of a player reporting a daily CHO intake >6 g·kg^{-1}

2024	McHaffie et al.,	17 ± 1	45	Youth & International	Doubly labelled water (7-8 days), 3-day self-reported food records using remote food photography methods (RFPM), GPS	DLW = 48 ± 14 RFPM = 37 ± 8	n/a	DLW = 5% RFPM = 15%	MD+1 = 3.5 ± 1 MD−1 = 4.4 ± 1.1 g MD = 4.2 ± 1.1	Absolute and relative TDEE was 2683 ± 324 and 60 ± 7 kcal·kg^{-1}FFM, respectively. Mean daily EI was 2047 ± 383 kcal·day^{-1} when players self-reported versus DLW derived EI was 2545 ± 518 kcal·day^{-1} over 7–8 days.

2.3 Professional Female Footballers

The first study to investigate pLEA in professional female footballers was Dobrowolski and Włodarek (2020). Thirty-one Polish female footballers across three league levels (Extra-league, I league, II league) completed 3-day diet records while total daily energy expenditure (TDEE) and EEE were measured using Armband SenseWear Pro3 technology. The EI of the group was 1548 ± 452 kcal which contributed to an EA of 25 ± 11 kcal·kg^{-1}, classifying 64.1% of the participants into a state of pLEA (Dobrowolski & Włodarek, 2020). Following this study, EA was further assessed in a small group (N=13) of female footballers during a competitive season across two rest days, one light training day, a heavy training day and a match day to gain an understanding of EA across days with differing training loads and EEE across the week (Moss et al., 2021). Low energy availability was noted in 23% of the players (<30 kcal·kg-1 FFM), while 62% of players were living in a reduced state of EA or adaptable LEA (30-45 kcal·kg-1 FFM). The prevalence of pLEA was particularly evident on heavier training days. Energy availability was higher on rest days compared to other days and higher on light training days versus a heavy training day, though EI remained relatively consistent at 2124 ± 444 kcal, indicating that players did not adjust EI to meet the energetic demands of their training and match days, a result that is in concordance with previous research (Dobrowolski & Włodarek, 2020; Gibson et al., 2011; Magee et al., 2020). The most recent study to quantify EA in professional footballers used a methodological combination of DLW, GPS, and dietary recalls over 14 days (Dasa et al., 2023). The 51 footballers had an average deficit of 22% between TDEE (2918 ± 322 kcal) and EI (2274 ± 450 kcal). Low EA was subsequently seen in 36% and 23% of players on match day and training days, respectively.

These studies looked at EA over a 24-hour period, but emerging evidence stresses the significance of within-day EA. Within-day EA refers to the amount of time in a day spent in an energy deficit as a result of fluctuating EI and hence EA across a day (Benardot, 2013) and has been noted to contribute to the presence of pLEA and the associated physiological symptoms such as disruptions to hormonal balance, bone turnover and metabolism (Mountjoy et al., 2014). Only one study to date has explored within-day EB in female endurance athletes (Fahrenholtz et al., 2018). This study found that female athletes who spent time in a negative EB state (> -300 kcal) at a higher frequency (22 hours vs. 18 hours) despite having a similar 24-hour EA and EB were more likely to experience menstrual dysfunction and other clinical markers of metabolic disturbance such as reduced $\mathrm{RMR}_{\mathrm{ratio}}$, oestradiol, and increased cortisol

(Fahrenholtz et al., 2018). While there has been no further data collected in female athletes, these findings are supported by the single within-day EB study completed in male endurance athletes by Torstveit et al. (2018) which found that male athletes who spent more time in an energy deficit greater than 400 kcal (20.9 hours vs. 10.8 hours) had a lower RMR and higher blood cortisol levels indicative of metabolic disturbance (Torstveit et al., 2018).

There is a high prevalence of pLEA in female footballers. This has mainly been investigated at the professional and elite levels and not in development players. The intensive schedule of a footballer may make them prone to within-day energy deficits, which may contribute to the presentation of associated physiological consequences and symptoms of pLEA.

2.4 International Female Footballers

International footballers have the added demand of participating in national team fixtures across the season on top of their professional football workload, including league, cup, and international matches (Carling et al., 2012; Nédélec et al., 2012). To fulfil these commitments, games often fall less than 3-4 days between each other – lacking the recommended 72-hour recovery period (Folgado et al., 2015; Ispirlidis et al., 2008). This is typically a result of the FIFA international window, a period set aside for international players to be released from clubs for international play, which condenses multiple matches into a short timeframe to minimise disruption to club competitions (FIFA, 2021). However, this can exacerbate the challenges of recovery and maintaining EI, EB and EA. This makes achieving adequate EI and EA all the more important to support recovery between matches and when looking to maintain performance levels across all games (Folgado et al., 2015). Additionally, international footballers take on the added challenges of trans-meridian travel. This can mean crossing multiple time zones, causing disruption to circadian rhythms. This disruption can lead to jet lag, which may not only impact physical and mental performance but also may affect nutritional intake and behaviours. The altered sleep-wake cycles and digestive patterns associated with jet lag can make it difficult for players to maintain proper nutrition, further emphasising the need for a specific focus on ensuring players have a strategy in place to ensure nutritional needs are still met despite the challenges presented. At the current time there has been only one study directly examining EA in international female footballers. The study compared the prevalence of pLEA in 45 players using the remote food photography method (RFPM) to self-report dietary intake over a 3-day period versus the doubly labelled water (DLW) method over 7-8 days (McHaffie et al., 2024). Prevalence of pLEA was reported to be 5% in DLW, while it was 10% higher when EI was self-reported using the RFPM, corresponding to EI of 2545 ± 518 kcal·day^{-1} and 2047 ± 383 kcal·day^{-1}, respectively. One study by Martin et al. (2006) has looked at the EB, including EI and EEE, of 16 international female players in England. The players recorded diet and physical activity diaries over a 7-day period alongside the use of BMR predictions to calculate TDEE (Martin et al., 2006). The results showed that the average EI was 1904 ± 366.3 kcal while the mean TDEE was 2154 ± 596 kcal, indicating a non-significant deficit of 250 kcal. The players had a relative EI of 30.9 ± 5.5 kcal·kg^{-1} per day, which failed to meet those previously recommended by Economos et al. (1993) of 47-60 kcal·kg^{-1} per day. However, the reported EI of these international players was similar to that which has been reported in other female footballers across varying playing levels (Clark et al., 2003; Dobrowolski & Włodarek, 2020; Gibson et al., 2011; Magee et al., 2020; Moss et al., 2021). Mara et al. (2015) carried out the only other study in international female footballers to date. This study assessed the TDEE and EEE of eight female football players across a 7-day period during the preseason via the use of SenseWear Mini Armbands and GPS technology. Over the four training days, one game day, and two recovery days, the TDEE, including EEE, ranged from 2274 ± 88 kcal to 2925 ± 144 kcal (Mara et al., 2015). This value for TDEE far exceeds the EI reported in the previous study by Martin et al. (2022), suggesting that international female footballers are likely failing to meet their EEE with an adequate EI, and they are, therefore, at risk of pLEA. Research in international female footballers is sparse in the EA space, future studies should seek to further examine the EB and EA in this population during international tournaments to determine if athletes are supporting both health and performance requirements through nutritional intake.

2.5 College Female Footballers

The college sports system is unique to the United States of America (USA). Over the course of a 4-month season, collegiate football teams typically compete in two matches a week, totalling 90 minutes each, alongside partaking in 3-4 training sessions per week (Gentles et al., 2018). The first study to investigate the dietary intake of Division 1 collegiate female football players was Clark et al. (2003). In this study, 3-day diet records, anthropometrics, and physical tests were repeated at pre- and post-season, with results suggesting that EI was significantly greater during the pre-season (37 ± 5.0 kcal·kg^{-1}) compared to the post-season average (30 ± 18.0 kcal·kg^{-1}) with EI ranging from 1750-2880 kcal per day and 830-2890 kcal per day during pre- and post-season, respectively (Clark et al., 2003). EEE was not directly measured, however, so EA levels were not able to be established (Clark et al., 2003). Though, later research by Reed et al. (2013) added to these results in a study of 19 Division 1 collegiate female footballers during the pre-, mid-, and post-season, where 12-33% of players exhibited pLEA at different points of the football season. Their results demonstrated how, in contrast to an EA of 44.5 ± 3.7 kcal·kg^{-1} LBM at post-season, EA was lowest in the mid-season (35.2 ± 3.7 kcal·kg^{-1} LBM) (Reed et al., 2013). More recently, Magee et al. (2020) looked at pLEA in 18 Division 3 college female footballers who completed a 4-day diet record and energy expenditure monitoring period alongside the LEAF-Q. The LEAF-Q categorised 56.3% of the footballers as at risk of pLEA (<30 kcal·kg^{-1} of FFM), while the direct measurement of EA through EI and EEE identified 67% of footballers as being in a pLEA state (23.0 ± 5.7 kcal·kg^{-1} FFM). The discrepancy in results may be due to different sensitivities of direct and indirect LEA assessment tools. Future research should seek a clearer understanding of the use of direct versus indirect measures of EA in accurately and efficiently identifying the risk of pLEA in female footballers.

2.6 Youth Female Footballers

As highlighted, professional, international, and collegiate female football players may not be meeting the demands of their training/competition and normal physiological functioning with an adequate EI. For youth footballers, there are likely to be additional consequences for failing to meet an adequate EA threshold. The growth and development that young athletes undergo on top of the physical activity and psychological/mental functioning that school adds, mean that energy requirements are higher relative to adults. As such, the EA required may be set at a higher threshold than that of an adult in order to avoid deficits in growth, development and activities of daily living (Heather et al., 2021; Petrie et al., 2004). With 54% of all registered female football players being youth players (Braun et al., 2018), it makes the topic all the more important to ensure our youth are best supported to promote healthy development at a vulnerable stage of life. A study by Gibson et al. (2011) assessed the nutrition status of 33 youth elite female football athletes via anthropometric assessment (skinfold thickness, weight, height), 4-day records, hematological analysis, and predictive equations to estimate energy expenditure. These players had an average daily energy deficit of 462 ± 549 kcal, and the mean relative EI (35 ± 10 kcal·kg^{-1}) was lower than the recommended range of 47-60 kcal·kg^{-1} for adult female football players (Gibson et al., 2011). Braun et al. (2018) reported similar findings using a 7-day food and activity record, anthropometric testing and bioimpedance analysis, alongside blood sampling. In the sample of 56 female elite youth football players, the mean energy deficit was 141 kcal per day, and 53% of the athletes did not meet the minimum EA threshold of 30 kcal·kg^{-1} per day (Braun et al., 2018). More recently, Paludo et al. (2023) found that 26.3% of youth athletes in the participating football team were at risk of pLEA. Although these studies did not directly measure EEE, results are consistent with the most recent study by McHaffie et al. (2023) which assessed EEE using direct measurement via GPS technology alongside a remote food photography method to assess EI. McHaffie et al. (2023) found that 34% of players were in a pLEA state, with the mean EA over the 10-day period being 34 kcal·kg^{-1} FFM, though when under-reporting was adjusted for the discrepancies between EI and EEE were less significant. The outcomes of these studies align with those of professional, international, and collegiate players and suggest that female youth footballers are similarly failing to meet their needs for high EEE alongside their additional requirements for growth and development. This outcome is likely to result in increased injury risk, illness, and a reduction in performance and recovery during football season. Such consequences may increase the likelihood of dropouts and, therefore, call for a greater understanding of how youth players can be helped to better meet EA and EI levels.

3.0 Nutritional Elements

3.1 Carbohydrate Intake

Beyond energetic requirements, it is important to consider the macronutrient composition of EI and how it impacts EA. Low carbohydrate availability (LCA) is characterised by a diet with low carbohydrate (CHO) intake before, during, or after exercise, resulting in a reduced amount of CHO available for the body to use due to low endogenous (glycogen stores) and/or low exogenous (CHO and glucose intake) levels of CHO (Lodge et al., 2023). Reductions in CHO intake of 25-60% (depending on the magnitude of pLEA) are consistently seen in pLEA intervention studies (Koehler et al., 2016; Kojima et al., 2020; Loucks & Thuma, 2003; Papageorgiou et al., 2017), despite the well recognised performance benefits of adequately replenished glycogen stores (Mountjoy et al., 2023). Research has demonstrated that performance of prolonged sustained or intermittent high-intensity exercise is enhanced by high CHO availability as a result of adequate CHO intake, while depletion of CHO stores and availability is associated with fatigue in the form of reduced work rates, impaired skill and concentration, and increased perception of effort (Thomas et al., 2016). There is currently no standardised equation or methodology to determine an individual's CHO availability (Lodge et al., 2023), so LCA tends to be measured as the level where CHO intake does not meet the requirements for an individual's body composition and physical activity or exercise levels (Lodge et al., 2023). In the most recent Union of European Football Association (UEFA) expert group statement on nutrition in elite football, 6–8 $g{\cdot}kg^{-1}$ of CHO is recommended on match day, while 3–8$g{\cdot}kg^{-1}$ is recommended on training days, depending on duration, intensity and player goals (Collins et al., 2021). Athletes falling below these recommendations may experience an energy-independent or additive effect of LCA to the health and performance consequences associated with pLEA and the development of REDs (Fensham et al., 2022; Hammond et al., 2019; Hayashi et al., 2022; Heikura et al., 2020; McKay et al., 2022; McKay et al., 2019). Low CHO availability may lead to decreased glucose utilisation, hypometabolism, muscular fatigue, impaired fat storage mobilisation, decreased performance, decreased growth hormone production (Hawley & Burke, 2010; Peklaj et al., 2022), and may be detrimental to bone, immunity and iron biomarkers (Mountjoy et al., 2023).

Despite this, female athletes in endurance, aesthetic, power and strength, and team sports have been reported to have inadequate CHO intake to support the glycogen resynthesis required for the demands of their training and sport (Condo et al., 2019; Peklaj et al., 2022). Low CHO dietary practices have been reported in football players at the professional (Dasa et al., 2023; Dobrowolski & Włodarek, 2020; Moss et al., 2021), international (Dasa et al., 2023; Martin et al., 2006; McHaffie et al., 2024), college (Clark et al., 2003; Magee et al., 2020; Reed et al., 2014), and youth levels (Braun et al., 2018; Gibson et al., 2011; McHaffie et al., 2023). A study of elite youth female footballers in Canada found that 51.5% of players consumed less than 5 $g{\cdot}kg^{-1}$ of CHO, falling below the sports nutrition recommendations (Gibson et al., 2011). Similarly, Reed et al. (2014) found that 47% of Division 1 female footballers during pre-season did not meet the recommendations for daily CHO intake of 6-10 $g{\cdot}kg^{-1}$ (Collins et al., 2021; Thomas et al., 2016), and 73% did not reach the recommended intake during mid-season. This is supported by other studies in professional and Division 3 female footballers, including Moss et al. (2021) and Magee et al. (2020) where CHO intakes were as low as $3.31 g \cdot kg^{-1}$ and $3.7 g \cdot kg^{-1}$ per day, respectively. Additionally, the research conducted by Magee et al. (2020) reported that the relative CHO intake ($g \cdot kg^{-1}$) for pLEA participants was 3.3 ± 0.7 versus 4.6 ± 0.9 for non-pLEA participants. Thus, the studies by Reed et al. (2014) and Magee et al. (2020) suggest that the proportion of athletes who do not meet the American College of Sports Medicine (ACSM) recommendations for CHO intake (6–10 $g \cdot kg^{-1}$) is significantly greater in the pLEA groups compared to the higher EA groups.

The initial research in this area suggests that LCA and a low CHO intake are likely to be contributing to the development of LEA or are occurring alongside it. Though the sample sizes of these studies are relatively small, future studies should continue to assess the dietary practices of larger groups of female footballers with adequate EA and pLEA. Carbohydrate timing pre and post-exercise is of importance to athlete performance and recovery; therefore, future studies should look at the timing of CHO intake around training to better assess CHO availability and its influence on within day EB and EA.

3.2 Changes in dietary intake across a season

A number of studies indicate that even while the energy requirements of training and competition vary over the week, season, and year, female athletes maintain a constant EI (Costill et al., 1988; Nattiv et al., 2007). Currently, only one study has looked at changes in EA across a football season. Reed et al. (2013) assessed EI and EEE in 19 Division 1 female footballers over pre-season (three training days), mid-season (two training and one game day), and post-season (three non-training days). During the pre-, mid-, and post-season, the prevalence of pLEA within the group was 26%, 33%, and 12% respectively. Low EI was the greatest contributor to pLEA in this study. Energy intake decreased over time and was significantly lower at pre- (1776.2 ± 86.4 vs. 3002.9 ± 242.8 kcal per day); mid- (1490.6 ± 98.7 vs. 2566.6 ± 108.8 kcal per day); and post-season (1333.3 ± 299.9 vs. 2219.7 ± 120.3 kcal per day) in participants with low compared with higher EA. While most of the athletes experienced pLEA at some point during the season, only one participant experienced it at all three phases of the season. This may suggest that female footballers could be presenting with adaptable LEA rather than pLEA. However, this study is still the only one of its kind, looking at EA across various periods of the football season. Therefore, it is important for future research to look further at the association between low EI and pLEA in different groups of female footballers to build a better picture of the changes that occur at different time points across the football season.

4.0 Conclusion

The current body of literature highlights the significance of maintaining adequate EI and CHO availability for optimal performance and health in female footballers. Despite the recognised importance of nutrition in meeting the energetically expensive demands of football, there remains a significant gap in research specifically focused on female footballers. Although several strategies have been identified for assessing the EI and EEE of athletes, achieving accurate values is challenging due to the high risk of measurement errors (Burke et al., 2018; Heikura et al., 2022) and the lack of definitive 'gold standard' assessment tools. As a result of the vast number of methodologies employed across the research in female footballers at the professional, international, college and youth levels, there is a large range in risk of pLEA, spanning from 12% to 66.7%. Despite the variation in pLEA across playing levels, time of season, and between studies, it is clear that a substantial number of female football players do not meet the EI required to sustain the demands of football training and match play on top of regular physiological requirements. There is an emerging consensus that inadequate CHO intake is common among female footballers, contributing to suboptimal EA and EB and associated health and performance consequences. Although advancements have been made in the area of pLEA and low EB in female footballers in recent years, there are still gaps in the research where further understanding is required. This includes further investigation of pLEA across the levels of competition (professional, international, college, and youth athletes) - particularly at the elite development level and across different time points in a football season, within-day EB and CHO availability and the relative risk of pLEA and associated symptoms. By addressing these gaps in future research, it will assist in optimising the health and performance of female footballers, promoting longevity in their athletic endeavours.

Chapter 3: Manuscript

3.0 Abstract

Background: Research in female footballers is limited; however, due to the negative consequences of being in a state of problematic low energy availability (pLEA), further investigation is needed to assess the adequacy of female footballers' energy intake (EI) in supporting physiological function and demands of training.

Methods: Twenty-four female footballers who were part of the Wellington Phoenix U20 Football Academy team in New Zealand participated in this study. Participants were asked to complete a three-day dietary record on one light training day, one heavy training day, and one pre-game rest day. Energy intake was analysed via Foodworks V.1.0 software. For training, exercise energy expenditure (EEE) was estimated using a human motion tracking device (Playermaker, Israel). Paired sample t-tests or Wilcoxon Signed Rank test (non-parametric data) were utilised for comparisons between EI, EEE and EB on different training days. Significance was determined by a p-value of < 0.05.

Results: The average EI for participants on light training, heavy training, and pre-game rest days was 1758.7 ± 549.5 kcal, 1910.1 ± 611.2 kcal and 1805.8 ± 533.2 kcal respectively, with no significant differences in EI between training days. The average relative carbohydrate (CHO) intake ranged between 1.4 – 6.7 $g \cdot kg^{-1}$ across all training days, failing to collectively meet sports nutrition recommendations. The average EB across all training days was 297.1 ± 491.6 with no significant differences between days of data collection. Across the three training days, 25.0% of female development players were in a negative EB. A very strong, significant positive correlation was found between average EI and average EB ($R=0.980$, $n=24$, $P=<0.01$). There was no significant correlation found between average EI and average EEE ($p=0.909$) or average EEE and average EB ($p=0.538$).

Conclusion: The results of this study suggest that female footballers fail to match their EI to their EEE, and a high proportion of players at the elite development level in New Zealand are in a negative EB, which could increase their risk of pLEA.

3.1 Introduction

Playing football at the elite level is an energetically expensive activity. For optimal player performance, female footballers need to consider the energy expenditure of both training and matches (Thomas et al., 2016). Elite female football players will typically partake in 1-2 matches and 4-6 training sessions across a week (Moss et al., 2021), covering distances of up to 8-12 km incorporated with up to 1.68 km of high intensity running efforts and ~1400 activity changes in match play across a range of heart rate zones and intensities (Andersson et al., 2010; Datson et al., 2014; Krustrup et al., 2005). For female footballers, adequate EI that supports their EEE is needed to enable them to have optimal EB and EA (Mountjoy et al., 2023). Inadequate EA for prolonged periods of time and unsupervised by a nutrition professional may put female footballers at risk of being in a state of pLEA along with its associated health and performance consequences, including potentially persistent disruption of various body systems such as the gastrointestinal, immunological, haematological, and endocrine systems (Mountjoy et al., 2023). Limited research on pLEA in female footballers has been completed at the elite development level, though across the varying levels of play (professional, international, college, and youth), prevalence results range vastly from 12% (Reed et al., 2014) to 66.7% (Magee et al., 2020). Within this research area, the mean EA in female footballers has been reported to be as low as 25 ± 11 kcal·kg^{-1} FFM in-season (Dobrowolski & Włodarek, 2020), but could also be as high as 44 kcal·kg^{-1} FFM, which has been observed post-season in a group of Division 1 college footballers (Reed et al., 2013). Regardless, these EA results fall well below previous EI recommendations for female footballers of 47-60 kcal·kg^{-1}, suggesting that a significant number of female footballers may not have sufficient EI to support their EEE. A prolonged period of negative EB could increase the risk of pLEA.

Additionally, low carbohydrate (CHO) intake may contribute to negative EB and, in turn, the development of pLEA (Mountjoy et al., 2023). Low CHO dietary practices have been reported in football players at the professional (Dasa et al., 2023; Dobrowolski & Włodarek, 2020; Moss et al., 2021), international (Dasa et al., 2023; Martin et al., 2006; McHaffie et al., 2024), college (Clark et al., 2003; Magee et al., 2020; Reed et al., 2014), and youth levels (Braun et al., 2018; Gibson et al., 2011; McHaffie et al., 2023). Carbohydrate intakes across the different playing levels at different points in their training and competition seasons have been reported as 3.31-7 g·kg^{-1} per day (Moss et al., 2021; Reed et al., 2014), generally falling well below the ACSM recommendations for CHO intake (6-10 $g \cdot kg^{-1}$). While CHO intake has been investigated in footballers, the association with low EB within their competition season is an area that requires further investigation.

There is a notable gap in the literature concerning the EI and EB of female football players at the elite development level. However, understanding the EB and CHO intake of elite development players is crucial as it may reveal unique challenges they face in maintaining optimal EB and EA, and their potential risk of pLEA and its associated adverse health and performance outcomes. Development players, such as those in the under 20s category, are at a critical stage in their athletic careers, where adequate nutritional intake is essential not only for current performance but also for long-term health, development, and career longevity.

Therefore, this study aims to determine the EI and EB of elite under 20 female Football Academy players in New Zealand and if low CHO intake is a factor that increases the risk of low EB for players.

3.2 Methodology

This study was a cross-sectional study conducted on the Wellington Phoenix U20 female Academy team in New Zealand. Data collection occurred throughout May 2024.

3.2.1. Participants and Recruitment

Twenty-four females (age ± SD) from the Wellington Phoenix female U20 Academy team participated in this study. Inclusion criteria stated that participants had to be members of the Wellington Phoenix Football Club and selected for the women’s reserves team over the 2023-2024 season. Participants had been provided with and returned written informed consent forms for a project on training load and health characteristics prior to the collection of data. In addition, participants were provided an information session on this research arm of the project and offered the opportunity for voluntary participation in the study. The study received ethics approval from Massey University Human Ethics Committee: Ohu Matatika Southern A (23/51).

3.2.3 Dietary Assessment

Players total EI was assessed using a 3-day self-recorded estimated diet record consisting of a heavy training day, a light training day, and a pre-game rest day over a one-week period during their competitive season. Players were provided with written resources: (1) 24-hour Food Record Protocol for Footballers and (2) Diet Recall Photo Handbook, which included instructions and guidance on the process. Players were instructed to record the estimated quantity, product brand names and nutritional panel, and the timing of food and beverages using household measures and the resources provided. Additionally, to increase the accuracy of estimated food values, players sent a photograph of each food item they consumed over the 3-day period (Burke et al., 2018). Food records were to be sent to researchers via the WhatsApp application on the day of recording. Players were encouraged to send their written and visual food records as close to consumption as possible. A comparison between the written diet records and photographs was conducted by researchers to check for any misestimations. Any proposed discrepancies were verified with the players via a direct message as close to the time of recording as possible. Players were instructed to maintain their typical dietary intake during the period of recording.

3.2.4 Energy Expenditure Analysis

Data from each training session was collected from participants using tracking devices (Playermaker, Israel); this included duration, speed, distance, acceleration and deceleration, and distances covered at different intensity thresholds, categorised as high speed running, very high speed running, and sprinting. This information allowed us to assign MET values based on time spent in each speed zone (Ainsworth et al., 2011). The total EEE for each session was derived by multiplying the time spent in each zone by the corresponding MET value, adjusted for the athletes' body weight (in kilograms) and summing the total expenditure in each category together.

The Harris-Benedict equation (Roza & Shizgal, 1984) was used to calculate BMR as it has been previously validated in an athletic population (Mackay et al., 2019; Schofield et al., 2019). The BMR was then combined with the EEE to derive the estimated energy requirements (EER).

3.2.5 Dietary Analysis

The data obtained by the diet records were uploaded to the software Foodworks V.1.0 (Xyris Pty Ltd, Brisbane, 2021), a nutrition analysis program. Total EI (kcal), CHO (g), protein (g) and fat (g) intake for each participant were quantified using the software. When food products weren't available on the Foodworks database, close substitutes were used, or product nutrition panels were used for manual input. Data input was completed by two researchers with dietetic backgrounds independently, being standardised by the use of the Lilacs NZ Food Portion Sizes – Photographic Atlas adapted from Nelson et al. (1997). This method allowed for cross-checking between researchers and entries vs. the food atlas for a higher level of accuracy.

3.2.6 Statistical Analysis

IBM SPSS statistical software suite was used for statistical analysis of diet record data. The data was tested for normality via – Kolmogorov-Smirnov and Shapiro-Wilk test. Normally distributed data are recorded as means ± standard deviation to descriptively present diet variables, while non-normally distributed data are reported as median (25%, 75% percentiles). Categorical data, including EB (categorised as positive or negative), is displayed as a percentage and number of participants. For statistical analysis, participants EI, EEE, and EB were averaged by individual training days or across the total three days recorded across the training week. This is with the exception that the maximum and minimum values reported are from specific, separate days. The player's CHO intakes are represented by a range from minimum to maximum, measured as $g \cdot kg^{-1}$. Comparisons across training days (Light Day, Heavy Day, Pre-game rest day) were conducted using Repeated Measures ANOVA if data were normally distributed, with Mauchly's test assessing sphericity and Greenhouse-Geisser correction applied when necessary. Comparison between participants was carried out using paired-sample t-tests or independent samples t-tests if the data were parametric. For data that were non-parametric, the Wilcoxon signed ranks test was utilised for comparisons. Bivariate correlations between EI, EEE and EB were analysed using Pearson's correlation coefficient. Significance was determined by a p-value of < 0.05.

3.3 Results

3.3.1 Participant Characteristics

Twenty-four female footballers participated in this study, with a mean age of 17.6 ± 1.1 years. Table 3.1 presents a summary of participant characteristics, including age and anthropometrics, as well as daily training duration, dietary intake and EEE over the three days of data collection. One player's pre-game rest day dietary data was removed due to an incomplete dietary record. Five participants had missing EEE data for one or both training days. Nineteen participants were therefore included in the analysis of overall EB.

Table 3.1: Participant Characteristics (n=24)

Characteristics		
Age (years)	17.6 ± 1.1[a]	
Average daily training duration (minutes)	74.5 ± 16.9[a]	
Anthropometrics		
Height (cm)	166.8 ± 6.5[a]	
Weight (kg)	61.4 ± 6.1[a]	
Body Mass Index (kg/m^2)	22.1 ± 1.7[a]	
Dietary		
Energy intake (kcal·day^{-1})	1824.9 ± 474.8[a]	
Carbohydrate (g·kg^{-1}·day)	3.5 ± 1.2[a]	
Protein (g·kg^{-1}·day)	1.5 (1.1, 1.7)[b]	
Fat (g·kg^{-1}·day)	1.2 (0.9, 1.4)[b]	
EER	1527.7 ± 99.0[a]	
EEE (kcal)	170.7 ± 57.8[a]	
	Min.	**Max.**
	5.8	245.9

[a]Mean ± standard deviation
[b]Median (25th, 75th percentiles)
EEE = exercise energy expenditure; EER = estimated energy requirements; Min = minimum value; Max = maximum value

3.3.2 Energy Intake and Energy Expenditure

Table 3.2 presents the mean and range of EI and EEE on light training, heavy training and pre-game rest days. No significant differences in EI were found between training days. Mean EEE was significantly higher on heavy training days compared to light training days. EER for participants was significantly higher on heavy training days compared to light training and pre-game rest days.

Table 3.2: Average Energy Intake and Estimated Energy Requirements

Kcal	Light Day	Heavy Day	Pre-game rest day	P-value

EI	1758.7 ± 549.5^{a}	1910.1 ± 611.2^{a}	1805.8 ± 533.2^{a}	0.370
EI Range	832.0 – 2596.0	835.0 – 3.97.0	748.0 – 2768.0	
EER	1568.2 ± 110.1^{a}	1684.0 ± 116.0^{a}	1417.8 ± 72.2^{a}	<.001
EER Range	1356.1 – 1815.7	1516 – 1924.4	1250.8 – 1548.3	
EEE	117 ± 82.8^{a}	230.0 ± 91.5^{a}		<.001
EEE Range	17.7 – 279.3	5.8 – 397.1		

^{a}Mean ± standard deviation
^{b}Median (25th, 75th percentiles)
P= P-value is a test for differences conducted between participants as assessed by Repeated Measures ANOVA
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)

3.3.3 Carbohydrate Intake

There was no difference in overall daily CHO intake between training days (p=0.360). Across the three days, the proportion of footballers who failed to meet the minimum recommended CHO intake (6 g·kg^{-1}) was 95.8%. However, the proportion of players that failed to meet the minimum CHO recommendations on each of the training days varied, with 100% failing to meet CHO intake recommendations on light training days, 91.7% on heavy training days, and 95.8% on pre-game rest days.

3.3.4 Energy Balance

Energy balance and the proportion of players in positive or negative EB are presented in Table 3.3. The proportion of participants across all training days with a negative EB was 25.0%. While there was no significant difference between participants average EB on light training, heavy training, and pre-game rest days (p=0.758), the proportion of players in negative EB varied, with 38.9% of players in negative EB on light training days, 26.3% on heavy training days, and 25.0% on pre-game rest days.

Table 3.3: Energy Balance and Carbohydrate Intake

	Average across all training days			
EB (Kcal)	297.1 ± 491.6^{a}			
- CHO (g·kg^{-1})	3.5 ± 1.2^{a} 1.4 – 6.7			
EB Positive (%)	75.0			
- CHO (g·kg^{-1})	3.9 ± 1.1^{a} 2.4 – 6.7			
EB Negative (%)	25.0			
- CHO (g·kg^{-1})	2.2 ± 0.6^{a} 1.4 – 2.9			
	Light Day	**Heavy Day**	**Pre-game rest day**	**P-value**

EB (Kcal)	227.3 ± 571.3[a]	245.2 ± 697.2[a]	388.0 ± 550.7[a]	0.758
- CHO (g·kg^{-1})	3.1 ± 1.2[a] 0.8 – 5.8	3.7 ± 1.4[a] 1.5 – 6.1	3.7 ± 2.6[a] 1.1 – 15.0	0.360
EB Positive (%)	61.1	73.7	75.0	
- CHO (g·kg^{-1})	3.4 ± 1.1[a] 1.0 – 5.8	4.1 ± 1.3[a] 1.9 – 6.1	4.3 ± 2.8[a] 2.5 – 15.0	
EB Negative (%)	38.9	26.3	25.0	
- CHO (g·kg^{-1})	2.1 ± 1.1[a] 0.8 – 3.8	2.6 ± 1.0[a] 1.5 – 4.3	1.9 ± 0.6[a] 1.1 – 3.0	

[a]Mean ± standard deviation
Percentages which are expressed as %
CHO presented as a range (min-max)
P= P-value indicates the test for differences across training days as assessed by Repeated Measures ANOVA
CHO: carbohydrate; EB: energy balance

A strong, significant positive correlation was found between average EI and average EB (R=0.980, n=24, P=<0.01), average CHO intake (g·kg^{-1}) and average EB (R=0.676, P=<0.01), and between average CHO intake (g·kg^{-1}) and average EI (R=0.665, P=<0.01). In this cohort of participants, as EI and CHO intake increased, the more likely a participant was to be in a positive EB. There was no significant correlation found between average EI and average EEE or average EEE and average EB.

3.4 Discussion

This study determined the EI, CHO intake and EB of elite under 20's female Football Academy players in New Zealand. To the best of our knowledge, this is the first study to assess the EI, EB and CHO intake in elite female Football Academy players and compare it to current sports nutrition guidelines, with results suggesting that 25.0% of participants were identified as having negative EB across all training days. This suggests that EI is insufficient for players' EEE and EER and, therefore, would not meet current sport nutrition guidelines for performance.

3.4.1 Energy Intake and Exercise Energy Expenditure

This study found that the EI of female footballers did not differ between heavy training, light training, and pre-game rest days despite there being a significant difference between EEE on the different training days. This study identified a significant difference in EEE between light training days and heavy training days. Notably, the range of the data showed considerable variation, indicating substantial interindividual variability in EEE. The interindividual variation could likely be due to EEE coming from training days and may reflect different demands of the specific sessions for individuals and/or playing positions (Mara et al., 2015). The high inter variability in EEE may suggest that players with higher EEE may be at an increased risk of being in a negative EB, particularly given that EI remained consistent across all training days. The difference in EEE between training days was not matched with the difference in EI in participants, with no significant correlation being found between average EI and average EEE, suggesting that female footballers do not adjust their EI to meet an increasing EEE which likely contributed to 25.0% of players being in a negative EB in this period of data collection. This aligns with previous research, which consistently shows that female footballers fail to match their EI with high or changing EEE that can occur throughout periods of the training and competitive seasons (Dobrowolski & Włodarek, 2020; Gibson et al., 2011; Magee et al., 2020; Moss et al., 2021). Specifically, when comparing the results of our research to other cohorts of female footballers in a similar age group, parallels in the inadequacies of EI can be seen. McHaffie et al. (2023) noted that the mean daily EI of female footballers (17.9 ± 0.5 years) was 2053 ± 486 kcal, which was significantly lower than their energy expenditure, leading to a pLEA prevalence in 34% of players. Similarly, in this current study, a comparable proportion of players (25.0%) may be considered to be at risk of pLEA based on being in a negative EB over the 3-day period; however, without direct measures of pLEA, this is a speculative conclusion. The previous and current study both used similar methods to collect dietary data and minimise the risk of underreporting. However, McHaffie et al. (2023) went a step further by incorporating adjustments to EI to further account for underreporting, which increased EI by 22% and reduced the prevalence of pLEA to just 5%. The differences in daily dietary data collection methods highlight the challenges of accurately measuring EI and underscore the importance of selecting appropriate methods to mitigate underreporting in future research (Burke et al., 2018).

The results of the current study and previous research may indicate a potential knowledge gap in terms of nutritional literacy and awareness in the elite and adolescent female football population, which may be contributing to inadequate EI (Torres-McGehee et al., 2021). Previous research has suggested that athletes appear to lack an understanding of the energy demands of their training and competition; in particular, athletes were unaware of how to adjust their nutritional intake to meet high or increasing EEE (Torres-McGehee et al., 2021). Our research adds to the literature on female footballers, demonstrating that their dietary EI may not be sufficient to support their energy requirements. This may increase their risk of pLEA, especially if a negative EB is maintained for a prolonged period of time and without the support of a nutrition professional. Our results did suggest a positive correlation between average EI and average EB, indicating that those with a higher EI may have a higher EB. Thus, providing nutrition education to help female footballers adjust their EI to support increasing EEE and training demands is likely to support the achievement of an adequate EB and the prevention of pLEA in players. However, these are proposals that require investigation in this group of athletes.

Self-reporting intake has been shown to underestimate EI by 22% and lead to an over estimation of pLEA (McHaffie et al. (2024). McHaffie et al. (2024) used the remote food photography method alongside a brief written description of the quantities, brands, and food types. The lead researcher was present during the training camp where data collection occurred to provide reminders in person as well as physical prompts being placed in the dining area to improve compliance (McHaffie et al., 2024). Considering the similarities in methodologies between this study and the study carried out by McHaffie et al. (2024), this suggests that the consistency in EI across training days in our study could be influenced by underreporting rather than a true failure to adjust intake in response to changes in EEE. Accurate measurement methods like DLW provide a clearer picture of athletes' energy needs and highlight the importance of precise EI assessments in understanding EB and preventing pLEA. Future studies should explore the relationship between direct and indirect methods of measuring EI, energy availability (EA), and EB to better understand how to identify the prevalence of pLEA most effectively among female footballers.

3.4.2 Carbohydrate Intake

Adequate carbohydrate (CHO) intake has consistently been associated with improved athletic performance (Thomas et al., 2016). This study reported a range of CHO intake between 1.4 – 6.7 $g \cdot kg^{-1}$ and an average of 3.5 ± 1.2 $g \cdot kg^{-1}$across all training days. These numbers fall into the low end of the most recent Union of European Football Association (UEFA) expert group statement on nutrition in elite football, which recommends 6–8 $g \cdot kg^{-1}$of CHO on match day and 3–8 $g \cdot kg^{-1}$ on training days (Collins et al., 2021) and fall well below the American College of Sports Medicine (ACSM) recommendations for CHO intake for athletes involved in high intensity training such as footballers (6–10 $g \cdot kg^{-1}$). The failure of elite female footballers in our study to consistently meet current nutritional recommendations for CHO intake is similar to those previously carried out in female footballers at the professional (Dasa et al., 2023; Dobrowolski & Włodarek, 2020; Moss et al., 2021), international (Dasa et al., 2023; Martin et al., 2006; McHaffie et al., 2024), college (Clark et al., 2003; Magee et al., 2020; Reed et al., 2014) and youth levels (Braun et al., 2018; Gibson et al., 2011; McHaffie et al., 2023). Most recently, a study in a cohort of female footballers of a similar age (17 ± 1 years) to that of participants in this current study found the footballers had an average CHO intake of 4.4 ± 1.1 g·kg^{-1}on pre-game rest days, 4.2 ± 1.1 g·kg^{-1}on match days, and 3.5 ± 1 g·kg^{-1}on post-game day (McHaffie et al., 2024). Similar results were found by McHaffie et al. (2023) with another group of female footballers aged 17.9 ± 0.5 years consuming 4.8 ± 1.1 g·kg^{-1}and 4.3 ± 1.1 g·kg^{-1} on pre-game rest days, and 4.8 ± 1.2 g·kg^{-1} and 4.8 ± 1.4 g·kg^{-1} on game day, resulting in only 19 (8%) accounts of a player reporting a daily CHO intake >6 g·kg^{-1}. Several factors may contribute to low CHO intake in athletes, including intentional dietary restriction for body composition goals, lack of nutrition knowledge, inadequate recovery fuelling, or practical barriers such as busy schedules and access to food (Burke et al., 2001). Additionally, dietary assessment methods, such as self-reported food diaries, may influence the accuracy of CHO intake data, with potential underreporting due to recall bias, portion size misestimation, or omission of snacks and sports nutrition products (McHaffie et al., 2024). This study did not investigate factors that influence female footballers' dietary behaviours and CHO intake. Therefore, future research may consider investigating the sport and gender-specific factors that influence and contribute to low CHO intake that are reported in this study and previous research.

Previous research has demonstrated that inadequate CHO intake may lead to an energy-independent or additive effect on the health and performance consequences associated with pLEA and the development of REDs (Fensham et al., 2022; Hammond et al., 2019; Hayashi et al., 2022; Heikura et al., 2020; McKay et al., 2022; McKay et al., 2019). Previously, Reed et al. (2014) noted that the proportion of athletes who did not meet the ACSM recommendations for CHO intake was significantly greater in the low EA group (100%) than in the higher EA group, where only 29% of athletes failed to meet the recommendation in the preseason, and 60% in the midseason. Similarly, Magee et al. (2020) reported that relative CHO intake (g·kg^{-1} per day) for LEA participants was 3.3 ± 0.7 versus 4.6 ± 0.9 for non-LEA participants. Whilst our study didn't measure EA, we did find a strong correlation between CHO intake and EB, as well as between CHO intake and EI, suggesting that adequate CHO intake is likely to support an increase in EI and reduce the risk of a negative EB. Given that the average CHO intake in this study falls below the recommendations, it could be suggested that low CHO intake may have contributed to the low EB of the participants.

This further highlights the importance of aligning CHO intake with current sports nutrition guidelines to ensure adequate fuel for performance and the maintenance of EB. Improving CHO intake in line with these recommendations may help female footballers better meet their energy needs and optimise health and performance outcomes to promote career longevity, particularly in young development players.

3.4.3 Energy Balance

Over the course of three days of data collection during a week of participants' competitive season, on average, 25.0% of the participants were in a negative EB. While the current study has reported on negative EB, similar proportions of players with insufficient energy status, specifically pLEA, have been reported in previous research, with results ranging between 23% and 36% (Dasa et al., 2023; McHaffie et al., 2023; Moss et al., 2021; Paludo et al., 2023; Reed et al., 2013). However, a few studies have reported much higher prevalences of pLEA in female footballers, ranging from 53% up to 66.7% (Braun et al., 2018; Dobrowolski & Włodarek, 2020; Magee et al., 2020). The large ranges in prevalence rates within female footballers may be a result of differences in methods used to calculate EEE and EI due to a lack of a gold-standard methodology in the measurement of EB and EA.

The study found a strong positive correlation between EI and EB. Therefore, on days where players had a lower EI, the risk of being in a negative EB was higher. Previous research results, such as McHaffie et al. (2023), align with these findings and have demonstrated that days with greater EEE are typically associated with an increased risk of a negative EB. Despite the correlation between EI and EB, the study found that the proportion of players in a negative EB was highest on the light training day, with a similar proportion of players in a negative EB on heavy and pre-game rest day. In some instances, athletes do not adjust their dietary intake to account for recovery, leading to inadequate EI on these days as well, despite energy needs remaining high for recovery and preparation (McHaffie et al., 2024). While reasons for low EI and subsequently negative EB were not investigated as part of this project, research in NZ female athletes has found elite female athletes often face external pressures to conform to specific body ideals, which can lead to disordered eating behaviours or conscious restriction of food intake (Heather et al., 2021). These pressures could contribute to why athletes in this study may not be consuming enough, even on lighter training days, which in turn impacts their overall EB (Heather et al., 2021). When assessing the energy status of female footballers, future research should consider the eating attitudes and disordered eating behaviours of participants using validated tools such as the Eating Disorder Examination Questionnaire (Fairburn & Beglin, 1994) and the Profile of Mood States Questionnaire (McNair, 1971). The addition of these tools may provide insights into potential contributing factors to low EI that result in a negative EB, which, if not addressed, may result in prolonged pLEA and associated negative health risks/outcomes.

3.4.4 Strengths and Limitations

To the best of our knowledge, this is the first study in New Zealand to assess the EB and the associated risk factor, low CHO intake, in elite under 20's female Football Academy players. This study involved a comprehensive dietary assessment utilising a mixed method approach incorporating written food diary entries alongside food photography, and timely researcher follow-up contributed to increased accuracy of the collected data. Only two researchers were involved in data input, which allowed for crosschecking and consistency in the process. This improved the reliability of the analysed food data.

Energy availability was not directly measured in this study due to the difficulties of in-field measurements of fat-free mass (FFM), making this unfeasible for this study. Due to the lack of direct EA measurements, we are not able to determine the prevalence of players in a pLEA state. The calculation of participants' EER is likely an underestimation of the true EER of the female footballers due to physical activity outside of training not being accounted for (e.g. school or work activity). Additionally, underreporting of EI was not accounted for, which is a known limitation in dietary assessments and may have influenced the accuracy of EI data. Finally, EI and EEE data were only collected across three days. This provides a snapshot of their eating patterns across three distinct training days but may not be representative of EI across players' entire competitive season; however, participants were asked to maintain their normal dietary intake on all days of data collection.

3.5 Conclusion

In conclusion, 25.0% of players within the elite under 20's female Football Academy team in New Zealand were identified as having a negative EB. This may be a result of consistent EI across all training days despite differing EEE. These results indicate that elite female footballers at the development level may not be matching their EI to higher or increasing EEE across the training or competitive season. Interestingly, EB was lowest on light training days, with 38.9% of players falling into a state of low EB on this day in comparison to 26.3% and 25.0% on heavy training days and pre-game rest days, respectively. Players failed to consistently meet current nutritional recommendations for CHO intake. Our results further demonstrate the direct impact that failure to meet the minimum threshold for adequate CHO availability may have on EB. This is of concern, especially with previous research demonstrating that inadequate CHO intake may lead to an energy-independent or additive effect on the health and performance consequences associated with pLEA and the development of REDs.

Chapter 4: Conclusion

4.1 Achievement of Aims and Hypotheses

The overall aim of this research was to determine the energy intake (EI) and energy balance (EB) of elite under 20 female Football Academy players in New Zealand and if low carbohydrate (CHO) intake is a factor that increases the risk of low EB. Our study reported that 25.0% of female footballers were identified with a negative EB. This suggests that female footballers in New Zealand are consistently not matching their EI to their exercise energy expenditure (EEE), particularly on days where there are lighter training loads during the football competition season. This finding aligns with previous research in female footballers, which has identified similar trends (Dobrowolski & Włodarek, 2020; Gibson et al., 2011; Magee et al., 2020; Moss et al., 2021). When athletes have a dietary EI that fails to account for their current total daily energy expenditure (TDEE), the risk of pLEA may be increased, especially if negative EB is maintained for a prolonged period of time and if a player has a low EI in an unsupervised manner without support from a nutrition professional (Mountjoy et al., 2023). Results may provide insight into the potential risk of pLEA in this group of athletes, which is important as pLEA is associated with disruption to various body systems such as the gastrointestinal, immunological, haematological, and endocrine systems – all of which contribute to unfavourable health and performance consequences (Mountjoy et al., 2023).

It was hypothesised that EI would not vary significantly between heavy and light training days. Our results supported this hypothesis, with no significant differences in EI between training days. Furthermore, we expected that EB would be more negative on heavy training days compared to pre-game rest days. Interestingly, our results showed the highest prevalence of negative EB on light training days, with 38.9% of participants being in a state of negative EB on this day. A possible reason for the high prevalence of low EB is the inadequate CHO intake observed across training days. Our study found that players consumed an average of 1.4-6.7 $g \cdot kg^{-1}$ per day of CHO, falling below the American College of Sports Medicine (ACSM) recommendations for CHO intake for athletes involved in high intensity training such as footballers (6–10 $g \cdot kg^{-1}$). Low CHO intake was strongly associated with a negative EB, suggesting that the failure to meet the minimum threshold for adequate CHO availability likely had a direct impact on EB. The results of this research provide some valuable insights into the dietary habits of development elite athletes. Especially with previous research suggesting that low CHO independently and in combination with low EI may adversely impact performance and recovery associated with pLEA in female athletes.

Previous research has suggested the low CHO and low EI may be the result of poor nutrition literacy or because of socio-cultural pressures to look a certain way. As a result, female athletes may not be consuming enough energy or CHO due to poor food preparation and planning or because of disorder eating behaviours or eating disorders. Whilst this research is cross-sectional and only provides details on the dietary habits for a single week, it has highlighted areas that future research may need to investigate to identify the causes of inadequate CHO and EI in order for appropriate nutritional support strategies to be implemented.

4.2 Strengths

To the best of our knowledge, this is the first study in New Zealand to assess the EB and the associated risk factor, low CHO intake, in elite under 20's female Football Academy players. It was unique in that it looked at EI and EEE across differing training intensities, including light and heavy training days, alongside a pre-game rest day, and in that it aimed to understand whether low CHO intake was predictive of a player being at risk of low EB and subsequently pLEA.

A strength of this study was the utilisation of a hybrid method using written measurements and descriptions alongside photographs before and after consumption on a messaging app. This method of assessment is particularly reliable by allowing researchers to send reminders and verify any issues with food data reporting immediately (Lieffers & Hanning, 2012). The use of photographs reduced participant burden and accounted for participants who may have low food literacy and struggle to accurately report food portions (Stumbo, 2013). Cumulatively, these methods increase the accuracy of participant diet records and, in turn, the overall reliability and validity of the results in the study.

Moreover, EEE was measured and prescribed rather than relying on subjective methods like the Rating of Perceived Exertion (RPE). By prescribing and directly measuring EEE based on actual training loads and activity types, we were able to obtain a more accurate representation of the participants' EEE across different training intensities (Hills et al., 2014). This approach reduced the potential variability and bias that can come from self-reported or perceived effort measures, ensuring that the EEE data reflected the true demands of each training day. Additionally, the study used the Harris-Benedict equation (Roza & Shizgal, 1984) to estimate BMR. This is a strength of this study, as this validated equation is considered a reliable method of calculating BMR in athletic populations (Mackay et al., 2019; Schofield et al., 2019). The use of this validated equation for BMR in athletes, along with directly measuring EEE, meant that the EB equations' accuracy was enhanced, allowing us to gain a clearer understanding of the energy demands of female footballers during our data collection.

Finally, to ensure consistency of data input, two researchers worked alongside each other to input the dietary information into FoodWorks software. This enabled immediate review and cross-checking of the data, reducing reporting bias and researcher errors. Lilacs NZ Food Portion Sizes – Photographic Atlas adapted from Nelson et al. (1997) was used to standardise portions and make the portions more accurate. Similarly, only one researcher assigned the METs to each participant 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 concerns regarding the impact measuring FFM could have on players, with the possibility of it leading to comparisons between players and having the potential to trigger body image issues or disordered eating behaviours, participants' EA was unable to be measured. This means that EB has been calculated for participants. Energy balance doesn't consider a female footballer's FFM and, as a result, may not be as useful as an indicator of energy status because it may not allow for an understanding of energy use for EEE versus energy for normal physiological processing. Therefore, the results of this study may be better considered as estimates of the energy status of a female footballer rather than a direct measurement.

The EERs that have been calculated for female footballers participating in this study are likely to be an underestimate of these players' true EER due to physical activity outside of training not being accounted for. This is particularly relevant in school-age females who may have been participating in school activities and other incidental activities. Thus, reinforcing the idea that the EEE and EERs in this current study should be considered estimates and not direct measures of these variables.

Negative EB was only found in a single week and not over a prolonged period of time which is required for some of the associated symptoms of pLEA. While the associated symptoms, such as irregular or absent menstrual cycles and low bone mineral density, have been well recognised (Mountjoy et al., 2023) as indicators of pLEA, these measures were not investigated in this study due to practical limitations. These measures require specialised equipment and longitudinal monitoring, both of which can be logistically challenging and costly to implement in field-based research, making it unfeasible to include in our study. Additionally, some symptoms, such as menstrual dysfunction, may be underreported by participants or masked by hormonal contraceptive use, making accuracy in data collection complex. The absence of these measures means that conclusions on the impact of low or negative EB are not able to be determined from this study.

Lastly, EI and EEE data was only collected across three days. One week of data collection may not represent long term dietary habits and, as such, may not be reflective of dietary intake at different times of the competitive season. Though this was done across days of varying training intensities to represent the span of players' regular habits as closely as possible, and players were asked to maintain their usual eating habits, this is difficult to guarantee. Additionally, underreporting of EI was not accounted for in this study. Underreporting is a well-documented issue in dietary assessment, particularly among athletes, and may have influenced the accuracy of the reported EI data. While methods exist to adjust for or estimate underreporting, such as predictive equations or correction factors (Poslusna et al., 2009), these were not applied. The nature of food diary collection and dietary analysis is also susceptible to human error; throughout the data processing and analysis, an effort was made to mitigate this as much as possible, but not all errors can be eliminated. Therefore, caution may be necessary when applying the interpretation of EI to other populations.

4.4 Recommendations and Future Directions for Research

Given that the prevalence of a negative EB was high among this cohort of elite under 20’s female Football Academy players in New Zealand and that the EI and CHO intake of this population was inadequate for their sporting requirements for performance and health, future research on the potential contributing factors to these results, such as nutritional literacy or disordered eating, may be required. Future research should focus on validating these findings within other groups of female footballers at the development level, as well as employing additional data collection methods in order to gain a better understanding of the potential outcomes of these current dietary behaviours.

- Future research should explore changes in EB, EI, and EEE across a training and competitive season since this study was conducted at a single point in time. Assessing fluctuations in EB over multiple weeks will help to build a better understanding of how female footballers are periodising their EI to match EEE at varying training intensities and volumes. This could also help to identify critical periods where athletes are at a higher risk of negative EB. Understanding whether these athletes adequately adjust their EI to match their EEE during a training and competitive season is essential, as failure to do so could put them at risk of pLEA and adversely impact their physiological health, sporting performance, and career longevity.
- Research has indicated that poor nutritional knowledge or disordered eating could reduce CHO intake and EI. Therefore, future research investigating these factors may be needed to help identify what support should be provided to these athletes in order to enable optimal health and performance.
- Considering the high prevalence of negative EB in female footballers, research on the health and performance outcomes related to their dietary behaviours is required to develop an understanding of how these factors impact athletes.
- Future studies should seek to gain an understanding of the differences in EEE between differing playing positions, as these differences may result in unique nutritional requirements. Understanding these differences may help to tailor dietary interventions and reduce the risk of negative EB and pLEA across varying playing positions within football teams.

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