The Effect of the Evening Meal (Timing and Content) on Sleep Quantity and Quality Measures in the Wellington Phoenix Female U20 Academy Football Team.

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

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Abstract

Intro: Obtaining sufficient sleep quantity and quality is fundamental for physical recovery and mental well-being of high-performance football athletes. Nutritional strategies to improve sleep for athletes are emerging in the literature. Evening dietary factors such as energy, carbohydrate, protein, and fat intake, and the timing of which they are consumed, has been shown to support sleep quantity and quality. However, the evidence in the athletic population remains highly variable and inconclusive and research on this topic in football athletes, particularly female footballers, is limited. Therefore, the aim of this study was to investigate the evening meal timing, energy intake, and macronutrient composition (e.g. carbohydrate, protein, and fat) on the quantity and quality of sleep for players in the Wellington Phoenix Female U20 Academy Football Team.

Methods: Twenty-five members of the Wellington Phoenix Female U20 Academy Football Team (17.6 ± 1.1 years) participated in this study. Participants completed three 24-hour food records and wore a WHOOP® wristband continuously to track their sleep on one light training day (LTD), one heavy training day (HTD), and one pre-game rest day (PGRD) over one week during the Capital Football Talent Development Programme League season. Evening dietary intake was determined by FoodWorks10 Software using the New Zealand and Australian food composition databases. Sleep onset time, total sleep time (TST), and wake periods (WP) were measured by WHOOP®. Comparison of dietary and sleep measures for each data collection day was conducted by a one-way ANOVA or Kruskal-Wallis test. Pearson's correlation coefficient tests were used to determine the correlation between sleep and dietary values. For data that were non-parametric, displayed as median (25^{th}, 75^{th} percentiles), Spearman's rank correlation coefficient was used. Statistical significance was set at $p<0.05$.

Results: The average evening meal intakes were energy 638.9 kcal, 95% CI [569.9, 718.6]; carbohydrate 59.2 g, 95% CI [51.5, 68.1]; protein 32.3 g, 95% CI [28.7, 36.4]; and fat 23.6 g (25^{th}, 75^{th} percentiles: 15.3, 38.9). The average sleep quantity and quality were TST 468.0 ± 65.3 minutes and WP 12.7 ± 5.6, respectively. Of note, 22.2% to 81.8% of players gained suboptimal TST across the three training days according to recommended sleep guidelines. The average time between the evening meal and sleep start was 221.7 minutes (25^{th}, 75^{th}

percentiles: 167.9, 271.6). No significant differences were found in energy, protein, fat, TST, WP, and time between the three training days. The evening carbohydrate intake was higher on the HTD compared to the LTD (p=0.026). On the PGRD, for every 1 kcal increase in evening energy intake, TST increased by 0.14 minutes (β=0.14, 95% CI [0.04, 0.23], p=0.008), while for every 1 g increase in evening fat intake, TST increased by 1.40 minutes (β=1.40, 95% CI [0.03, 0.34], p=0.021). For every 1% increase in evening carbohydrate intake, TST increased by 1.84 minutes (β=1.84, 95% CI [0.01, 3.59], p=0.041).

Conclusion: This study confirms that poor sleep quantity is prevalent in adolescent footballers who are part of the Wellington Phoenix Female U20 Academy Football Team. This research provides valuable insight into the evening meal habits of adolescent female footballers and shows a positive influence of evening energy, carbohydrate, and fat intake on TST on a PGRD. Therefore, future research may need to review energy and carbohydrate strategies to aid sleep for athletes before competitions or events.

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List of Abbreviations

Abbreviation	**Term**
AFL	Australian Football League
CSEP	Canadian Society for Exercise Physiology
GI	Glycaemic Index
g	Gram
HTD	Heavy Training Day
Kcal	Kilocalorie
LNAA	Large neutral amino acid
LTD	Light Training Day
n	Number
N1	NREM Stage 1
N2	NREM Stage 2
N3	NREM Stage 3
N4	NREM Stage 4
NREM	Non-rapid Eye Movement
NSF	National Sleep Foundation
REM	Rapid Eye Movement
PGRD	Pre-game Rest Day
PSG	Polysomnography
SE	Sleep Efficiency
SOL	Sleep Onset Latency
TST	Total Sleep Time
WASO	Wake After Sleep Onset
WP	Wake Periods

Chapter 1: Purpose

1.1 Purpose

Elite athletes in team sports are required to follow set training programmes, albeit with some degree of interindividual flexibility, and game schedules on a weekly basis throughout their competitive season (Nedelec et al., 2018). To maintain their high training demands alongside balancing other physical and mental stressors, having strategies that optimise recovery and support performance is fundamental (Davis et al., 2022; Gratwicke et al., 2021). One key factor that contributes to athlete recovery, and therefore performance, is sleep (Doherty et al., 2019). The sleep cycle is a natural human process and is considered an advantageous period of adaptation to the training athlete (Doherty et al., 2019; Nobari et al., 2023). Sleep has various physiological (e.g. maintaining immunity and promoting skeletal muscle remodelling) and psychological functions (e.g. improving cognitive function and emotional well-being), thus is fundamental for athletes (Doherty et al., 2019; Gratwicke et al., 2021; Venter, 2012). Specifically for athletes at the elite level, any improvements in the aforementioned factors are likely to aid individuals' performance and subsequently provide sporting teams with an advantage over their competitors.

The ideal total sleep time (TST) can vary between individual elite athletes (Sargent et al., 2021) however, 7-9 hours of sleep per night is generally recommended for healthy adults to maintain cognitive, emotional and physical well-being (Hirshkowitz et al., 2015). Elite athletes from 12 different sports reported that to feel 'well rested' they needed 8.3 hours of sleep per night (Sargent et al., 2021). Whilst this meets the US National Sleep Foundation's (NSF) recommended 7-9 hours of sleep per night for the general population, there are currently no athlete-specific sleep guidelines (Hirshkowitz et al., 2015; Sargent et al., 2021). Subsequently, sleep quantity that is less than the recommendations has previously been identified in team sport elite athletes such as Australian rules football, basketball, rugby union and football, who reported an average of 7 hours sleep per night (Lastella et al., 2015; Randell et al., 2021). Furthermore, research in elite male footballers has also demonstrated reduced TST with averages of 6.9 hours and 7.9 hours in studies conducted by Falkenberg et al. (2021) and Lastella et al. (2015), respectively.

Sleep duration is only one measure of sleep adequacy, and although an athlete may gain sufficient sleep quantity, poor-quality sleep is associated with reduced health benefits (Doherty et al., 2019). Qualitative measures of sleep include, but are not limited to, sleep onset latency (SOL), sleep efficiency (SE), and wake after sleep onset (WASO) (Falkenberg et al., 2021; Gratwicke et al., 2021). Sleep onset latency refers to the time taken to transition from being awake to falling asleep, SE is the ratio of an individual's TST to the total amount of time spent in bed during one night, and WASO is used to describe the total amount of time spent awake during the night after falling asleep (Ohayon et al., 2017). In previous research, elite athletes have been reported to score higher on the Pittsburgh Sleep Quality Index compared to non-athletes, and the higher scores on this validated sleep quality measure are indicative of poorer sleep quality (Demirel, 2016; Swinbourne et al., 2016). Specifically, elite athletes are likely to experience reduced SE and a greater SOL due to their high training and performance calibre, with a further reduction in SE during high-level training days in the competitive season (Vlahoyiannis et al., 2021a). Additionally, middle/high school students (12-18 years) who participated in sports and fell short of gaining 8 hours of sleep per night were 1.7 times more likely to injure themselves compared to those who obtained >8 hours (Milewski et al., 2012). Cumulatively, the reduced ability to fall asleep and an increased frequency of sleep disturbances may be problematic to the athlete as sub-optimal sleeping patterns can have negative impacts not only on their recovery but on vital body functions (e.g. growth and repair of tissue, brain activity and neuromuscular performance) that support good health (Swinbourne et al., 2016; Venter, 2012; Vlahoyiannis et al., 2021a).

Elite athletes are exposed to environmental factors that are thought to contribute to disturbed sleep patterns, predisposing them to fatigue-related injuries (Nedelec et al., 2015). For the team sport athlete, sleep is often interrupted due to the interference of travel, training time, late match time schedules, exposure to stadium lights; mental, emotional and social arousal; caffeine; alcohol consumption; and various medications (Miles et al., 2022; Nedelec et al., 2015; Randell et al., 2021). Therefore, more recently, team sports personnel have sought to gather insights into sleep analytics of their athletic population to provide the athletes and teams with a competitive advantage. Providing strategies that optimise sleep quantity and quality allows athletes to train and compete at their best (Gratwicke et al., 2021).

Analysing sleep is an evolving topic of research, but there is a lack of studies that focus on elite athletes (Cowley et al., 2021). Sex differences are a prominent limitation to existing research as only 6% of sport and exercise science research is on females, and the work on females and sleep is even less (Condo et al., 2022; Cowley et al., 2021). However, insights from previous research suggest sleep quantity and quality vary throughout the phases of the menstrual cycle, a hormonal profile unique to females that is not experienced by males (Hrozanova et al., 2021). This finding is limited to its acute study duration of 61 days and requires validation through further long-term observational research (Hrozanova et al., 2021). Compromised sleep has been reported in elite female football players in comparison to the general population (Miles et al., 2022). Subjected to the specific wake and sleep times of this sporting discipline, these athletes experienced a reduced habitual sleep of 0.3 hours compared to their non-athletic population (Miles et al., 2022). Therefore, research that investigates sleep in athletic females and examines strategies that support sleep in order to aid training and performance benefits is required.

The poor sleep quantity and quality identified in athletes has led to research that explores sleep behaviour interventions in order to improve sleep outcomes (Gratwicke et al., 2021; Lastella et al., 2015). Subsequently, nutrition manipulation has been identified as a plausible strategy to protect and enhance the sleep-wake cycle, therefore aiding recovery and performance whilst also maintaining a good health status (Gratwicke et al., 2021). An existing body of literature has investigated the effect of diet strategies on quantitative (TST) and qualitative (SOL, SE, and WASO) sleep measures however, the research is in its early stages. Areas that have been explored include energy intake over 24-hour periods as well as the energy intake of pre-sleep meals which may vary between training and rest days (Erdman et al., 2013). Optimal nutrition that focuses on adequate daily energy intake is necessary for critical metabolic functions in recovery, but there is limited understanding of whether a relatively low, moderate, or high energy-dense meal in the evening affects sleep outcomes (Doherty et al., 2019). Currently, there are contrasting findings on this topic within sport science. One study on elite male Australian Football League (AFL) athletes reported an increased WASO with an increased daily energy intake and an increased SOL with an increased evening energy intake (Falkenberg et al., 2021). However, no such associations between these variables were found in other elite athletes including female footballers (Greenwalt et al.,

2023) and female AFL players (Condo et al., 2022). When comparing these findings to the general population, definitive conclusions cannot be drawn despite a greater deal of studies investigating the effect of diet on sleep parameters (St-Onge et al., 2016a). Evening meals, particularly those with high energy, have shown negative impacts on sleep quality measures such as SE and SOL when consumed close to sleep time (Crispim et al., 2011). Similarly, research has suggested that a higher daily caloric intake may also negatively influence sleep quantity (Dashti et al., 2016). These findings contradict initial research that indicated the energy content of meals did not influence sleep outcomes (Driver et al., 1999). Regardless, a current review on this topic has concluded that the energy content of the diet can influence sleep however, it is noted that its impact is determined by the magnitude or lack of calorie intake and by other dietary factors such as the macronutrient composition (Binks et al., 2020).

An interest in the macronutrient composition of dietary intake has further steered research into investigating the effect of carbohydrate, protein, and fat in isolation on sleep analytics. Carbohydrates are a well-known fuel source for the working muscles and aiding recovery however, less is known about their relationship with sleep (Vlahoyiannis et al., 2021b). Carbohydrates are involved in sleep-related hormone regulation as consumption causes a secretion of insulin which increases the amount of tryptophan that can cross the blood-brain barrier (Doherty et al., 2019; Vlahoyiannis et al., 2021b). Tryptophan is an essential amino acid that acts as a precursor in serotonin and melatonin synthesis; hormones involved in the sleep-wake cycle (Doherty et al., 2019). For the athletic population, research on this topic is scarce. In female footballers, carbohydrate intake had no influence on sleep duration or disturbances (Greenwalt et al., 2023), whereas in female AFL players, an increased WASO and decreased SE was observed for every 1 g increase in daily carbohydrate intake (Condo et al., 2022). Similar contradictions are noted in research in male cyclists reporting reduced sleep quantity with high carbohydrate intake pre, during, and post-training session (Killer et al., 2017) whilst another study found no significant differences in male basketball players' sleep on nights with a high glycaemic index (GI) evening meal and snack (Daniel et al., 2019). The literature on non-athletes, however, presents findings different to those of the athletic population (Daniel et al., 2019). A systematic review noted that a high GI meal in non-athletic individuals improves sleep quantity and quality parameters (e.g. greater TST, increase in SE, and reduction in SOL), although the magnitude of these effects varied (Vlahoyiannis et al., 2021b). As such, a positive

relationship between the quantity of carbohydrate intake and REM sleep would appear to be evident in non-athletic populations (Vlahoyiannis et al., 2021b). The literature shows that there are contrasting findings across athletes but consistent findings amongst non-athletes. This may be attributed to the differing physiological demands, lifestyle factors, nutritional requirements, and sleeping behaviours between these populations (Barnard et al., 2022). These differences reveal the need for focused research on carbohydrate intake and its effects on sleep for athletes to optimise carbohydrate intake for not only fuelling performance but also to improve sleep.

The majority of athletes have increased protein requirements due to increased physical activity levels and lean muscle mass (Pasquale, 2007). The use of protein as a pre-sleep intervention has recently emerged in the scientific field. This is based on the essential amino acid tryptophan and its role in melatonin production (Gratwicke et al., 2023). In elite female footballers (Greenwalt et al., 2023) and AFL players (Condo et al., 2022), protein intake has been shown to have no influence on sleep measures although once again, evidence is limited. Alternatively, in a similar study on elite male AFL players, a 1 g increase in daily protein was associated with an increase in WASO whereas, evening protein intake was associated with a decrease in SOL (Falkenberg et al., 2021). Subsequently, reviews of this topic on the implications of protein on sleep for athletes suggest that the type of protein consumed would determine the extent of such effects (Vlahoyiannis et al., 2021b). The α-lactalbumin protein is one of the highest sources of natural tryptophan and has been shown to improve sleep quantity and quality in stressed-vulnerable and general populations (Doherty et al., 2019; Gratwicke et al., 2021). Interestingly, in support of this, research in female rugby players showed that supplementation with α-lactalbumin two hours before bed improved SOL (Gratwicke et al., 2023). However, similar results in sleep variables were not improved in elite male cyclists (Gratwicke et al., 2023; MacInnis et al., 2020). Inclusion of α-lactalbumin-rich sources in the evening meal may be a realistic approach to improve sleep in team sport athletes however, its efficacy and effectiveness remains under investigation.

Fat and its constituents' effect on sleep similarly have limited literature but to an even lesser extent than the other macronutrients. Fats are essential in a healthy balanced diet, although saturated fats may hinder sleep. No associations have been found between fluctuations in

total daily fat intake and sleep quantity and quality in elite female athletes (Condo et al., 2022; Greenwalt et al., 2023). When analysing the saturated fat intake in these athletes, a reduced SOL was observed yet WASO and TST were both negatively affected by higher saturated fat intakes in females from the general population (Condo et al., 2022; St-Onge et al., 2016b). Conversely, in male AFL players, sleep was not influenced by saturated fat intake (Falkenberg et al., 2021). Reducing saturated fat content prior to a match day is beneficial for both health and fuelling performance, although its effect on sleep remains to be confirmed (Crispim et al., 2011; St-Onge et al., 2016b). The relationship between nutrition and sleep is rather complex and in reality, whether an athlete or not, macronutrients: carbohydrate, protein, and fat are co-ingested when eating a meal (Gratwicke et al., 2021).

Another dietary strategy that could influence sleep is meal timing. The timing of nutrition, particularly the evening meal, has been shown to positively influence sleep measures. To our knowledge, studies that examined the influence of diet on sleep in elite female athletes did not focus on the specific time nutrients were consumed (Condo et al., 2022; Greenwalt et al., 2023). However, additional papers on male rugby (Lehmann et al., 2022) and male AFL players (Falkenberg et al., 2021) have found significant associations with an increase in TST when the evening meal was consumed closer to sleep time. Furthermore, an improvement in SE was also identified when the period between meal and sleep time was shorter for male rugby players (Lehmann et al., 2022). In healthy adults, no effects on sleep were reported between an evening meal 5 hours and 1.5 hours pre-sleep (Duan et al., 2021) despite other studies showing poorer sleep outcomes when meals were consumed 30-60 minutes before sleep (Crispim et al., 2011; Yamaguchi et al., 2013). The question of meal timing and its efficacy in modulating sleep remains under investigation. Further research is warranted to understand the relationship between meal timing and its probable effect on improving the critical recovery period that is sleep in both male and female athletes.

With minimal evidence on the relationship between nutrition and sleep, several limitations in this area exist. We are presented with conflicting literature between the female and male sexes, highlighting the need for further studies to determine whether or not improved sleep outcomes are subjective to the athlete's sex (Condo et al., 2022; Falkenberg et al., 2021). Sleep studies on elite female footballers have not explored the confounding effects of training,

nutritional adequacy, or eating and sleeping environments on sleep. Unsurprisingly, there is a lack of interventional studies conducted in this population, likely due to the restrictiveness and time-consuming nature of this method for players throughout their competitive season as well as the training and performance calibre of these athletes. Elite female footballers, particularly from the same team, are a well-defined population. Therefore, interpretation of the sleep results from previous research on male rugby players and individual athletes such as cyclists, may not be generalisable to other sporting disciplines. Furthermore, elite athletes have different lifestyle factors compared to the general population therefore, conclusions on nutrition and sleep in the general population may also not be applicable to the athletic population. Regardless of these differences, dietary strategies have shown to be a plausible approach to improving sleep across populations. Therefore, understanding the influence of nutrition as an intervention to protect and enhance sleep may be beneficial to improve cognitive performance, prevent injury, and aid physical recovery in athletes, and requires further investigation (Doherty et al., 2019; Gratwicke et al., 2021).

1.2 Aims

The aim of this study is to describe the effect of the evening meal timing, energy intake and macronutrient composition (e.g. carbohydrate, protein, and fat) on the quantity and quality of sleep of players in the Wellington Phoenix Female U20 Academy Football Team, at a single point during their competitive season.

1.2.1 Objectives

a. To describe the evening meal and sleep habits of players in the Wellington Phoenix Female U20 Academy Football Team.
b. To describe the relationship between the evening meal timing on sleep duration and disruption of players in the Wellington Phoenix Female U20 Academy Football Team.
c. Determine the influence of evening meal energy intake and macronutrient composition (e.g. carbohydrate, protein, and fat) on sleep duration and disruption of players in the Wellington Phoenix Female U20 Academy Football Team.

1.2.2 Hypotheses

a. A significant proportion of the players will not meet sleep quantity recommendations.
b. An evening meal closer to sleep onset will be associated with an improved TST for the players.
c. A greater energy intake in the evening will be associated with an increase in WP for the players.

1.3 Structure of the Thesis

This thesis begins by introducing the concept of sleep and nutrition interactions in female athletes. It then describes the importance of sleep for the health and performance of athletes, the influence of dietary intake and its timing on sleep, concluding with the study aims, objectives, and hypotheses. Following this, chapter two provides an in-depth review of the current literature on sleep and nutrition interactions in high-performance athletes, specifically females. It discusses the prevalence of poor sleep in elite athletes and the influence of evening meal timing, energy intake, and macronutrient content on sleep quantity and quality variables as well as addressing the risk factors associated with poor sleep that influence sporting performance. Chapter three presents the manuscript that provides details of this study inclusive of the abstract, introduction, methods, results, discussion, and conclusion. Finally, chapter four concludes this thesis with a summary of the study's findings, its strengths and limitations, and recommendations for future researchers looking into sleep and nutrition interactions in female footballers.

1.4 Researcher's Contributions

Table 1.1 Summary of Researcher's Contributions to the Study	
Author	Contribution to Thesis
Courtney Younger Master of Science (Nutrition and Dietetics) Student	Primary author of thesis Designed research Food record collection, data entry, and analysis Statistical analysis of food records and sleep Interpreted and presented the results
Dr Claire Badenhorst Primary Supervisor Senior Lecturer School of Sport, Exercise and Nutrition	Primary Supervisor Ethics Application Assisted in interpretation of results Assisted in statistical analysis Revised and approved thesis
Associate Professor Andrew Foskett Co-Supervisor Head of School – School of Sport, Exercise and Nutrition	Co-Supervisor Ethics Application Assisted in interpretation of results Assisted in statistical analysis Revised and approved thesis
Josie McConnochie Co-Researcher Master of Science (Nutrition and Dietetics) Student	Co-researcher Assisted in data entry Assisted in analysis
Isabella Coombes PHD Candidate Head of Female Academy Sport Scientist	Ethics Application Assisted in data collection

Chapter 2: Literature Review

2.0 Introduction

Elite football athletes are involved in a physically demanding sport covering distances of 8-12 km with sprint bouts and unpredictable changes such as turns and jumps during a match (Mara et al., 2015). As such, they participate in a high training volume to prepare for these conditions (Hulton et al., 2022). As professional female football has grown over the past decade, match volume and intensity have increased (Brinkmans et al., 2024). To meet these demanding endeavours, optimising sleep for recovery, performance, and overall health is fundamental (Gratwicke et al., 2021). The relationship between sleep and nutrition has sparked the interest of researchers due to the importance of sleep for athletes. Based on the available literature, this chapter aims to review the sleep requirements and habits, implications of poor sleep, evening dietary requirements and habits, and the influence of diet on sleep in high-performance athletes.

2.1 Sleep

Sleep is a basic human activity that is vital for daily function and optimal health (Chaput et al., 2018). It is defined as a physically inactive state in which we disengage from our external environment and become less conscious of our surroundings (Doherty et al., 2019; Venter, 2012). This complex behavioural state is not only a state of rest but also a period where many active bodily functions take place, such as energy restoration, repair and growth, cognitive functioning, memory organisation, mood stabilisation, and immunity maintenance (Binks et al., 2020; Venter, 2012). Therefore, it is classified as a critical period of both physical recovery and cognitive restoration (Lastella et al., 2015).

Sleep architecture consists of two physiological states: rapid eye movement (REM) and non-rapid eye movement (NREM), which is further divided into four states (Doherty et al., 2019; Venter, 2012). NREM sleep and its micro-architecture consisting of NREM stage 1 (N1), NREM stage 2 (N2), NREM stage 3 (N3), and NREM stage 4 (N4) is achieved at the onset of sleep and is then followed by REM sleep (Venter, 2012). However, both REM and NREM differ in brain electroactivity and cardiac, respiratory, and muscular functions (Venter, 2012). The initial

NREM stages tend to last 30-40 minutes, resulting in a shift in metabolism due to reduction in blood pressure, blood flow, heart rate, and respiration (Nedelec et al., 2018; Venter, 2012). It is also associated with a continuum of light sleep (N1 and N2) to deep sleep (N3 and N4), which all differ in arousal thresholds (Doherty et al., 2019). When the body has reached a state of deep sleep, REM sleep occurs, and it is here that the brain becomes activated and cognitive processors begin (Doherty et al., 2019; Venter, 2012). Over the sleep period, we cycle between NREM and REM and the duration and frequency of each state is indicative of sleep quality.

The sleep-wake cycle is regulated by the circadian rhythm (CR), a biological clock that uses external cues to induce sleep onset or wakefulness over the day-night cycle (Nobari et al., 2023). Humans have the ability to synchronise with their environment, i.e. biological clock, resulting in daily shifts in physiological processes and behaviour (Nobari et al., 2023; Winget et al., 1985). These various biological processes occur in response to the changing internal (e.g. electrolytes, neurotransmitters, and metabolites) and external (e.g. meal timing, physical activity, social and psychological activities, and daylight) environments however, the circadian rhythm is primarily influenced by light (Nobari et al., 2023). Therefore, implementing strategies that positively influence circadian rhythm and promote sleep onset may be beneficial in improving sleep measures.

The sleep state allows for physiological functions (e.g. maintaining immunity, promoting skeletal muscle remodelling, and restoring the endocrine system) and psychological functions (e.g. improving cognitive function and emotional well-being) to take place, highlighting the importance of sleep for basic human function (Doherty et al., 2019; Gratwicke et al., 2021; Venter, 2012). The athletic population tend to have higher physical demands than those in the general population and thereby may have increased requirements for sleep (Lastella et al., 2015). Sleep is therefore a critical period for athletes to help balance the effects of their physically and mentally demanding endeavours. The biological processes that occur during sleep are not only beneficial for health but also for sport-specific training and recovery (Binks et al., 2020; Doherty et al., 2019). To perform at their optimum, high-performance athletes need to be able to make fast, accurate, and appropriate decisions as well as carry out sport-specific motor skills in their training and matches (Lastella et al., 2015). Furthermore, growth hormone production and secretion predominantly (95%) occur during NREM sleep and thus

links its restorative features to this stage of sleep (O'Donnell et al., 2018). On the contrary, consolidating skills through motor memory is associated with REM and N3 sleep stages (Nedelec et al., 2018). Achieving adequate sleep that allows for such functions to take place should therefore be acknowledged when developing skill sets for athletes.

2.2 What Influences Sleep

The natural sleep cycle may be disrupted by lifestyle behaviours of athletes, potentially leading to disturbed sleep patterns (Doherty et al., 2019; Nedelec et al., 2015). These behaviours experienced by footballers include night matches, high intensity exercise, bright light, travel, social arousal, and caffeine (Nedelec et al., 2015). Vlahoyiannis et al. (2021a) conducted a systematic review and found moderate sleep differences between training seasons, reporting reduced total sleep time (TST) and sleep efficiency (SE), as well as a longer N3 during heavy training phases versus in-season phases. Additionally, only N3 sleep was found to be longer in team sport athletes compared to individual athletes (Vlahoyiannis et al., 2021a). A literature review on elite football athletes however, did not find training load to influence sleep but they did identify home matches, an undesired result (defeat or draw), and travel to negatively affect these players' quantity and quality of sleep (Silva et al., 2020). Recently, six elite male footballers showed a reduced TST on match day (6.54 h) versus one day post-match day (7.65 h), but no differences were seen for the other sleep variables (Sanders et al., 2024). The researchers also noted no change in sleep variables, including TST between home versus away games (Sanders et al., 2024). Another recent study (Gjertsås et al., 2024) of 21 elite female Norwegian footballers found an association between very high training loads and reduced TST and REM, with results being similar to the findings of Vlahoyiannis et al. (2021a). Cumulatively, these findings suggest that athletes' sleep is complex and may be influenced by a multitude of factors that may contribute to sleep outcomes (Nedelec et al., 2015). Contradiction lies within and between studies in the systematic literature review and new studies, thus highlighting the need for additional studies to verify these findings. Therefore, future researchers should consider the potential sport-specific influences on sleep for each athlete within their research (Silva et al., 2022).

2.3 Implications of Poor Sleep

A single night's disturbed sleep pattern can impair the several aforementioned physiological and psychological processes that occur during sleep, reducing the ability of athletes to prepare and adapt to training and performance (Silva et al., 2022). Studies have reported a negative effect on muscular strength, power, and speed due to sleep deprivation however, other studies have shown no effects on strength tests (Fullagar et al., 2015b). Consequently, an athlete's risk of fatigue-related injury may increase due to delayed reaction time, decreased concentration and alertness, reduced skill execution, and response speed as a result of poor sleep quantity (Nedelec et al., 2015). In 112 adolescent student-athletes (12-18 years), those who slept <8 hours at night were 1.7 times more likely to have experienced an injury than those who gained more than 8 hours of sleep per night (Milewski et al., 2012). Similarly, in 23 elite male footballers, SE was negatively correlated with the amount of musculoskeletal injuries, injury severity, and absence from the sport (Silva et al., 2020). Despite these results, a systematic review has concluded that there is not enough evidence supporting sleep loss and its associations with poor athletic performance and injury in professional athletes (Dobrosielski et al., 2021). As such, additional research is required to determine whether sleep is a modifiable risk factor for injury prevalence (Dobrosielski et al., 2021).

2.4 Sleep Quantity Guidelines

Sleep recommendations have been established to guide populations on the adequate hours of sleep per night for optimal health. A healthy night's sleep consists of appropriate duration, timing, regularity, and nil disruptions (Chaput et al., 2018; Watson et al., 2015). In 2015, the American Academy of Sleep Medicine and the Sleep Research Society released a joint consensus statement recommending 7-9 hours of sleep per night as ideal for young adults (18-25 years) (Watson et al., 2015). Following this, the US National Sleep Foundation (NSF) reported the same recommendation for young adults with the addition of 8-10 hours required for adequate sleep in teenagers (14-17 years) (Hirshkowitz et al., 2015). In 2016, the Canadian 24-Hour Movement Guidelines for Children and Youth was published by the Canadian Society for Exercise Physiology (CSEP), which included evidence-based sleep guidelines (Tremblay et al., 2016). The 24-Hour Movement Guidelines for Adults was later published in 2020 (Ross et al., 2020). Similar to the 2015 recommendations, CSEP recommended for adults that a sleep

duration between 7-9 hours on a regular basis is required for daily health (Tremblay et al., 2016) and a longer sleep duration of 8-10 hours was recommended for youth (14-17 years) (Ross et al., 2020). Subsequently, global and national (Australia and New Zealand) guidelines have been adapted based on the Canadian 24-Hour Movement Guidelines and thus also recommend adults gain 7-9 hours of sleep per night (Australian Government Department of Health and Aged Care, 2021; Chaput et al., 2018; Ministry of Health, 2024). These guidelines educate entire populations on sleep for good health however, the optimal sleep duration should be individualised for each person as sleep needs differ amongst individuals due to genetic, behavioural, and environmental factors (Chaput et al., 2018).

Elite athletes experience a unique lifestyle that differs from the general population and tends to include high training demands. In order for athletes to recover and adapt in response to their intense activities, it is believed they may require a greater duration of sleep at night (Lastella et al., 2015). Thus, the recommended TST of 7-9 hours may be underestimating the sleep needed by athletes. The ideal TST appears to vary between high-performance athletes, and with limited research on athlete sleep, no specific guidelines have been released for these highly active populations (Nedelec et al., 2018). However, elite athletes have been shown to have higher levels of deep sleep therefore, research-based recommendations suggest that these individuals should attain a greater sleep duration (8-10 hours) to facilitate recovery from their increased training (Biggins et al., 2021; Knufinke et al., 2018). A recent study into endurance athletes (cyclists and triathletes) showed an increase in performance with a 1.6 hour extension of sleep compared to their habitual TST (6.8 hours) but, whether longer sleep hours are appropriate for all athletes despite their interindividual differences remains uncertain (Walsh et al., 2020). Elite athletes have reported their ideal sleep duration to be greater than the current recommendations. Randell et al. (2021) reported that 37 elite athletes required 9 hours and 23 minutes, whilst Sargent et al. (2021) found that in a cohort of 175 elite athletes, 8.3 hours of sleep was required to feel well rested. Little is known about how much sleep athletes need, and depending on the specific sport and individuals within each discipline, some athletes may require more or less sleep than the general guidelines of 7-9 hours per night (Sargent et al., 2021). However, these propositions require future investigations.

2.5 Sleep Quality Guidelines

There is a great focus towards sleep quantity when providing recommendations for healthy sleep. Various other dimensions of sleep such as SE, sleep onset latency (SOL), wake after sleep onset (WASO) and sleep architecture (NREM and REM), affect overall sleep regardless of whether adequate sleep quantity is achieved (Chaput et al., 2018). The current guidelines highlight the need for sleep between 7-9 hours to be of good quality in order to have a positive effect on overall health (Watson et al., 2015). To encourage a quality night's sleep, the Canadian 24-Hour Movement for Adults suggests that sleep should be regular with established sleep and wake times (Ross et al., 2020). In 2017, the NSF released a report to help identify healthy sleep quality parameters following their sleep quantity recommendations (Ohayon et al., 2017). A sleep quality consensus panel reviewed the current literature and concluded that SE >85%, SOL <30 minutes, and WASO <41 minutes indicated good quality sleep for young adults (18-25 years) (Ohayon et al., 2017). A consensus was not reached for 80% of sleep architecture due to the insufficient amount of data however, it was agreed that REM sleep >41% and N3 <5% indicated poorer quality of sleep but further consideration is warranted (Ohayon et al., 2017). It has been well established that an elite athlete's sleep pattern can be negatively influenced by sport-specific factors however, with no current sport-specific sleep guidelines, the total impact of these factors is yet to be established (Vlahoyiannis et al., 2021a). Although these sleep quantity and quality guidelines may help individuals gain a healthy night's sleep, they remain broad and may not be applicable to those with different sleep needs. Given this, it is recommended that athletes have individualised sleep needs and further investigation into elite athlete sleep patterns amongst various sporting disciplines is needed (Walsh et al., 2020).

2.6 Sleep of Elite Athletes

A discrepancy exists between sleep recommendations and the sleep required by elite athletes, with a high prevalence of athletes having poor sleep quantity (Walsh et al., 2020). Whilst it is theorised that athletes require greater sleep quantity than the general population, it has been noted that until recently, evidence in athletes' sleep has been poorly investigated. Regardless, a 2021 systematic review analysed 81 studies that examined the sleep patterns of 1830 elite and semi-elite athletes (Vlahoyiannis et al., 2021a). Vlahoyiannis et al. (2021a) concluded that

the average duration these athletes slept at night was 7.2 hours. In addition, a study of 37 elite athletes reported a TST of 7.8 hours (Randell et al., 2021), while more recent studies reported 36 male Australian Football League players (AFL) had a mean TST of 7.9 hours (Falkenberg et al., 2021), and 32 female AFL players gained on average 7.1 hours of sleep per night over their competitive season (Condo et al., 2022). Thus, when accounting for sex, age, sport type, training season and competition level, athletes appear to have reduced sleep hours (<8 hours). Within the available research, <8 hours of sleep has on average been documented for elite athletes in the literature, which falls short of the proposed amount of sleep needed to prevent neurological deficits (Lastella et al., 2015). For athletes, sleep quantity that falls short of sleep recommendations has been associated with reduced health effects such as cognitive impairment, mood disturbance, impaired memory consolidation, growth and repair of cells, disrupted glucose metabolism, and lowered immune system response (Lastella et al., 2015; Walsh et al., 2020). Therefore, interventions that promote optimal sleep duration are a developing area of research that is being considered for elite athletes (Lastella et al., 2015).

Poor sleep quantity in elite athletes is evident in the literature however, less is known about their quality of sleep. In previous research, the athletic population tends to have reduced SE compared to the general population (Vlahoyiannis et al., 2021a). Elite athletes from a dozen sports rated their sleep quality as 3.9 on a 6-point Likert scale, with 1 being very poor and 6 being excellent (Sargent et al., 2021). Cumulatively, sleep quality-related data from a systematic review showed a sufficient SE (86.3%) and SOL (14.8 minutes), whilst WASO was elevated (52.7 minutes) for athletes compared to the recommendations set by the NSF (Ohayon et al., 2017; Vlahoyiannis et al., 2021a). Specifically, athletes are likely to experience reduced sleep quality due to their training and performance calibre, with a 1.5% reduction in SE observed in elite athletes compared to semi-elite athletes. This reduction became more pronounced (3%) for elite athletes during heavy training phases compared to competitive phases (Vlahoyiannis et al., 2021a). Researchers who studied the sleep of elite male football players found a negative correlation between SE and multiple injury parameters thus, a poor SE in elite athletes may pose a higher risk of injury (Randell et al., 2021). Interestingly, male AFL players were reported to have sufficient SE (91.3%) and SOL (5 minutes) but inadequate WASO (45 minutes) (Falkenberg et al., 2021), whereas female AFL players had sufficient SOL (17 minutes) but insufficient SE (84%) and WASO (48 minutes) (Condo et al., 2022). Differences

have also been observed between sport types. Individual elite athletes reportedly had poorer sleep parameters than team sport athletes, with significantly less TST and SE, and longer SOL and WASO (Lastella et al., 2015). Cumulatively, these findings suggest that sleep variable statistics are likely to differ between sports and genders and should be considered within research projects.

The overall sleep architecture distribution for the athletes included in the systematic review was 23.1% REM, 9.7% N1, 48.7% N2, and 18.5% N3 (Vlahoyiannis et al., 2021a). These results are in line with adequate sleep quality for the sleep stages REM and N3 according to the NSF consensus (Ohayon et al., 2017). Sleep architecture has been shown to vary significantly across training and competitive seasons, although there is minimal evidence (Vlahoyiannis et al., 2021a). For example, time spent in N3 sleep was greater in the pre-season period compared to in-season and heavy training periods (Vlahoyiannis et al., 2021a). It has also been shown to be less in anaerobic athletes compared to aerobic athletes (Vlahoyiannis et al., 2021a). It is well known that elite athletes are susceptible to poor sleep behaviours however, with such limited and poorly systematised data, it is difficult to determine and review the sleep quality and architecture of elite athletes (Vlahoyiannis et al., 2021a).

2.7 Sleep of Elite Football Athletes

Elite football players have different schedules and styles of training compared to other sports, and as a result, their sleep behaviours may also differ (Lastella et al., 2015; Miles et al., 2022). Sleep habits of elite football players are scarcely reported in the literature but have been addressed in other studies of recreational, youth, and college athletes (Silva et al., 2022). Amongst 81 studies included in a systematic review by Vlahoyiannis et al. (2021a), only one out of the 14 (17.3%) studies conducted on footballers, showed a TST of >8 hours per night (Whitworth-Turner et al., 2017). Furthermore, research has indicated that a significant proportion (91%) of match-day studies in elite football players have reported low sleep hours (<7) in addition to a sleep duration of <7 hours observed in 58% of all conditions (match-day and non-match day) (Silva et al., 2022). More recent studies have found similar data, with seven elite male AFL players reporting a TST of 6.2 hours (Miller, 2017), whilst another 10 elite female footballers had a TST of 7 hours (Miles et al., 2022). The latest sleep study of six elite

male footballers showed varying TST on one day before match day, on match day, and one day post-match of 7.57 hours, 6.54 hours, and 7.65 hours, respectively (Sanders et al., 2024). Additionally, match day TST was less than the sleep duration guidelines. In female athlete cohorts, Greenwalt et al. (2023) found the mean sleep duration in 14 elite female footballers ranged from 6.9 ± 2.1 to 8.1 ± 1.1 hours. Whereas in a study of 21 Norwegian elite female footballers, results showed a TST of 8.1 hours, SE of 84.55%, SOL of 41 minutes, WASO of 33 minutes, light sleep (N1 and N2) of 59.3%, deep sleep (N3) of 16.3%, and REM of 24.2% (Gjertsås et al., 2024). Interestingly, these female athletes gained sufficient sleep for all of these measures according to the NSF guidelines (Gjertsås et al., 2024; Ohayon et al., 2017). From the available evidence, it would seem that poor sleep quantity is prevalent in elite football players globally but, its extent within female footballers is still an active area of investigation. Additionally, evidence of adolescent football athletes' sleep patterns including those who are part of development teams is also slight and thus, understanding the sleep of emerging players may support their longevity in football.

Sleep behaviour studies of elite footballers have also investigated sleep quality. In previous research of six elite male footballers, objective sleep measures were sufficient for SE (86.7%), SOL (8.9 minutes) and WASO (16.6%) (Lastella et al., 2015). However, subjective sleep quality determined by a 5-point Likert scale of 1 (very good) to 5 (very poor), was only 2.0 (Lastella et al., 2015). Similarly, Miles et al. (2022) found 10 elite female footballers to have a SE, SOL and WASO of 87.5%, 6.5 minutes, and 53.6 minutes, respectively, yet a score of 3.0 on the self-rating sleep quality scale (1 = very good, 5 = very poor). Conversely, Silva et al. (2022) identified elite footballers to have an insufficient SE (<85%) in 72% of the conditions (match days and non-match days) and a SOL >30 minutes in 46% of the conditions. Therefore, the current studies provide further evidence of the uncertainty of adequate sleep quality amongst elite level athletes, including football players. Further research is warranted on the sleep of athletes due to the limited number of high-quality studies (Vlahoyiannis et al., 2021a).

2.8 Sleep of Female Athletes

Female athletes are poorly represented in sport science research, with a lesser extent of female-only sleep studies on footballers. Sleep studies on team sport athletes are male-

dominant, and as the number of high-performance female players rises, research on these athletes is needed to develop specific strategies that enhance health and performance (Cowley et al., 2021). Females are physiologically different to males and have a unique hormone profile. Emerging evidence suggests that female's sleep, both quantity and quality, is influenced by their menstrual cycle however, this finding is limited due to the short 61 day study duration (~2-3 menstrual cycles) of the study (Hrozanova et al., 2021). Despite this, a variation in light sleep, deep sleep, REM, and SE was seen between menstrual bleeding and non-bleeding days (Hrozanova et al., 2021). The effect menstruation has on sleep parameters remains unclear as contrasting findings exist, some studies report a worsening perceived sleep quality whilst other studies show no difference in subjective sleep quality throughout the menstrual cycle (Hrozanova et al., 2021). Due to these physiological differences, the subsequent recommendations from male-centric studies are not likely to translate to female athletes (Greenwalt et al., 2023). For example, sleep architecture studies have been completed in male-only cohorts, therefore conclusions on the sleep stages for females are still unknown (Vlahoyiannis et al., 2021a). Subsequently, a systematic review has highlighted how the insufficient amount of research conducted on female athletes limits the ability to produce sex-specific sleep guidelines and recommendations (Vlahoyiannis et al., 2021a). Currently, the sex data gap in sport and exercise science research means that only 6% of available research has been completed on females (Cowley et al., 2021). Thus, the lack of female-specific sleep, particularly adolescent female-specific sleep research reflects the noticeable trend of insufficient female-specific research in the sport science field. Further understanding of sleep for female athletes at a period of sporting and physiological development is therefore required and may be key for their continuity in sport.

2.9 Methods of Analysing Sleep

Sleep monitoring tools are a useful way to analyse sleep patterns for individuals. Subjective and objective sleep measures have been used in scientific research, including polysomnography (PSG), actigraphy, written sleep logs, and sleep questionnaires (O'Donnell et al., 2018). Polysomnography objectively measures sleep and is deemed to be the gold standard due to its ability to track eye movement, brain activity, cardiac activity, muscle activity and movement, and breathing characteristics through electrodes (O'Donnell et al.,

2018; Walsh et al., 2020). Polysomnography detects NREM and REM sleep measures however, it is more invasive and expensive, and its operations are more technical compared to other sleep measuring methods (Walsh et al., 2020). For applied science, measuring the sleep of athletes, particularly in competition season, must be practical, realistic, and representative of their natural sleep environment to obtain valid results. Thus, a comprehensive measurement of sleep through PSG may be considered unsuitable for high-performance athletes (O'Donnell et al., 2018). Subsequently, in the sport science literature, sleep studies have utilised other validated sleep measures such as actigraphy. Actigraphy methods involve a wearable activity monitoring device that tracks body movement and computes this data into sleep metrics (e.g. TST, SE, WASO, SOL) (O'Donnell et al., 2018). Although its practicality is useful for sleep studies in athletes, the accuracy of actigraphy can vary depending on the device and its sensitivity (Kolla et al., 2016). Research into the validity of this method has shown a 91% to 93% agreement between differentiating sleep and wake time compared to PSG (Ancoli-Israel, 2003). Recent findings have shown actigraphy to be a suitable method for tracking sleep while also acknowledging the discrepancies that exist when comparing the data to lab-based methods (Walsh et al., 2020). A recent review found that actigraphy tends to overestimate TST and underestimate WASO and SOL in comparison to PSG, but underestimates TST and SOL, and overestimates WASO relative to sleep records/diaries (Walsh et al., 2020). Thus, whilst actigraphy can be classified as 'research-grade', caution must be taken when interpreting these metrics as their ability to accurately detect time awake is less compared to gold standard methods (Kolla et al., 2016; O'Donnell et al., 2018).

The wrist-worn wearable device named WHOOP® was created to monitor athletes' activity. The WHOOP® strap sends information to the smartphone application where athletes can track their heart rate, heart rate variability and sleep (Miller et al., 2020). A validation study found no significant difference in the TST between the WHOOP® strap and PSG (Miller et al., 2020). WHOOP® testing showed similar outcomes to other research-grade wearables. WHOOP®-AUTO (automatically detected sleep) and WHOOP®-MANUAL (manually added sleep) have similar sensitivity and specificity to ACTICAL® actigraphy for sleep and wake, therefore when PSG is not feasible, WHOOP® is a reasonable means of measuring the sleep of athletes (Miller et al., 2021). WHOOP® wristbands have been utilised in the latest sleep studies of female elite football players (Greenwalt et al., 2023; Sanders et al., 2024). However, their use in studies on

athletes of various sports and training and performance calibre is limited to female collegiate Division I basketballers (Taber et al., 2021), male and female professional road cyclists (Sargent et al., 2024), and male and female collegiate athletes of various sports (e.g. basketball, softball, baseball, tennis, football, swimming, and water polo) (Goldman et al., 2024). The use of WHOOP® in development elite athletes has not yet been completed. However, with these athletes being in the recruitment pool for elite and professional sporting teams, research using this wristband would allow for applied research on sleep in this athletic cohort. Thus, its use may be needed to understand the sleep habits of athletes before they enter high-performing environments.

3.0 Nutrition

3.1 Energy Intake

The identified poor sleep quantity and quality and predicted higher needs of sleep for athletes, have led researchers to explore sleep behaviour interventions that promote these sleep measures (Gratwicke et al., 2021). It is evident that optimal nutrition plays a vital role in an individual's overall health as well as supporting performance, training adaptations, and recovery. Subsequently, dietary manipulation has also been shown to positively influence sleep outcomes for athletes and thus nutrition has been identified as a plausible factor to aid improved measures of sleep. The current literature on dietary strategies and their ability to protect and enhance sleep, however, is in its early stages (Gratwicke et al., 2021). Previous studies, although scarce, have focussed their investigations on the effect of nutrition on sleep quantitative (TST) and qualitative (SE, SOL, WASO) parameters. One element of nutrition that has been explored in relation to athlete's sleep is daily energy (kcal) intake and meal-specific energy intake. Saidi et al. (2024) focused on the effect of energy availability (kcal/kg) on sleep in 42 national young male rugby players and found a low SE, reduced N3, and higher WASO was associated with low energy availability (<30 kcal/kg). Secondly, they identified that sleep deteriorated significantly when energy availability was <23 kcal/kg therefore, their results suggested that optimising energy intake may improve sleep quality (Saidi et al., 2024). Interestingly, sleep quality was also influenced by daily energy intake in male AFL players, with a single megajoule increase found to increase WASO by 3 minutes (Falkenberg et al., 2021).

However, these results were not able to be replicated in female AFL players (Condo et al., 2022). The relationship between total energy intake and sleep is not yet clear, particularly in female athletes, and given the role of both sleep and nutrition for athletes, determining the impact of this correlation on overall sleep should be considered.

The evening meal is the last main meal to be consumed before sleep. Discussion on whether a low, moderate, or high-calorie evening meal affects sleep outcomes is present in the literature however, with such little evidence, contrasts within the current recommendations are evident (Doherty et al., 2019). Pre-sleep nutrition of high (>246 kcal) versus low (≤246 kcal) energy based on the 50th percentile of pre-sleep energy intake of participants had no effect on TST or wake periods (WP) in Division I female football players (Greenwalt et al., 2023). Female AFL athletes also showed no significant changes in TST, SE, SOL, and WASO according to their evening energy intake (Condo et al., 2022), however, in the male cohort, every 1 megajoule increase in energy intake from the evening meal was associated with an increase in SOL by 5 minutes (Falkenberg et al., 2021). With such limited findings on athletes, additional research is required to determine different nutritional interventions that support sleep in males and females.

Sleep studies are more prevalent within general healthy populations, but more evidence is required to determine dietary energy manipulation and its effect on sleep (St-Onge et al., 2016a). Studies investigating dietary manipulations have shown various results with regard to the effects on sleep. Previously, an association was identified between each percent increase in SE and an 11.1 kcal reduction in daily energy intake in middle-aged adults (Dashti et al., 2016). Additionally, a sleep duration of <5.5 hours was associated with a higher energy intake of 218.1 kcal per day (Dashti et al., 2016). In 27 healthy females, positive associations were seen between SOL, REM sleep latency, N2 sleep and WASO and an increased caloric intake, whilst a negative association was present between SE and an increased caloric intake (Crispim et al., 2011). Interestingly, in the same study, there were no associations between caloric intake and sleep variables for males (Crispim et al., 2011). On the contrary, short-term energy restriction studies have found no significant influence on sleep parameters (Driver et al., 1999; Lieberman et al., 2008). Within the research, discrepancies are also present when comparing the effect of evening-specific meals on sleep. In contrast to Crispim et al. (2011), Driver et al.

(1999) found no significant effect on sleep from evening meals of varying energy content. Despite the inconsistencies in previous research investigating the association between dietary energy intake and sleep, recent studies have noted that the impact of caloric energy on sleep may be determined not only by its magnitude, but by other dietary factors such as meal timing and macronutrient content (Binks et al., 2020).

3.2 Meal Timing

The complex relationship between sleep and nutrition has led researchers to investigate the timing in which we ingest our nutrients and the impact it has on sleep variables. Meal timing and macronutrient content (e.g. carbohydrate, protein, and fat) are prevalent topics in sports nutrition due to their key roles in performance and aiding skeletal muscle recovery (Gratwicke et al., 2021). However, manipulating the quantity and timing of macronutrients has also been identified as a potential sleep modifier. Pre-sleep feeding studies have emerged in sport science however, to our knowledge, no studies have looked at the specific time of the evening meal and its influence on sleep parameters in high-performance female athletes (Condo et al., 2022; Greenwalt et al., 2023). Instead, researchers have looked at the daily dietary patterns of elite athletes. Greenwalt et al. (2023) assessed the effect of the evening meal, defined by a 2 hour pre-sleep window, on sleep metrics in elite female football players. They found no significant differences in sleep duration or disturbances however, the specific timing of their dietary intake compared to sleep onset during this 2 hour window was unknown. Similarly, a study on elite female AFL players investigated daily nutrient intake on sleep and found no significant association between energy intake and sleep outcomes (Condo et al., 2022). The timing of energy intake was not provided, thus further insight into this topic is warranted. However, there is literature present for male athletes with findings suggesting an association with an increase in TST when consuming a meal of ~1500 kcal 1.5 hours versus 3.5 hours before sleep time (Lehmann et al., 2022). For male AFL players, TST was reduced by 8 minutes for every additional hour between evening feeding and sleeping (Falkenberg et al., 2021), whilst for adolescent rugby players, sleep duration improved by 24 minutes when the evening meals were consumed 1.5 hours versus 3.5 hours pre-sleep (Lehmann et al., 2022). Wake after sleep onset improved for participants in both studies when the time between the evening meal and sleep was reduced (Falkenberg et al., 2021; Lehmann et al., 2022). In the healthy

adult population, the relationship between eating time and sleep is not completely understood, with conflicting results of a pre-sleep meal 30-60 minutes prior to sleep subsequently delaying sleep onset and contributing to a reduction in SE (Crispim et al., 2011; Duan et al., 2021; Yamaguchi et al., 2013). Late food intake was also associated with poor sleep-wake regularity (Crispim et al., 2011; Yamaguchi et al., 2013). Conversely, research investigating the influence of a prescribed evening mealtime found no significant difference between a routine dinner (1800) and a late dinner (2200) on sleep architecture (Duan et al., 2021). Thus, the current literature on meal timing and its efficacy in modulating sleep presents a case for further research not only in the healthy general population but also in athletes. Future research may consider investigating the change in evening meal timing to 1.5 hours before sleep, especially with initial research demonstrating that this may increase TST without delaying SOL and reducing SE, all of which allow for improved sleep quantity and quality. The practical implications of a prescriptive evening meal time to better sleep for athletes could lead to enhanced recovery, muscle growth, and consolidation of memories (Binks et al., 2020; Venter, 2012).

3.3 Carbohydrate Intake

Beyond composite foods, macronutrients in isolation have taken the interest of researchers, particularly in regard to the effect on sleep analytics. Carbohydrates are energy molecules that have particular importance for muscle motility, restoring energy, and sleep-wake cycle hormone production (Binks et al., 2020; König et al., 2019). Despite their well-established energy function, less is known about their effect on sleep-related parameters for the athletic population. When co-ingested with protein, carbohydrate intake is followed by a secretion of insulin which promotes the removal of large neutral amino acids (LNAA) (Binks et al., 2020). This alters the LNAA to tryptophan ratio in the blood and favours protein to cross the blood-brain barrier (Binks et al., 2020). The tryptophan protein is involved in serotonin production, which is a precursor of the sleep-regulating hormone melatonin (Doherty et al., 2019).

In 14 Division I female football players, high (>45 g) and low (≤45 g) carbohydrate intake within 2 hours pre-sleep had no significant effect on sleep duration and disturbances (Greenwalt et al., 2023). It was noted that food consumed within this 2 hour period was mostly snack foods

and desserts rather than a main evening meal (Greenwalt et al., 2023). An additional study in a female-only cohort of 32 elite AFL players reported an association between carbohydrate intake and sleep parameters. Specifically, they found that a 1 g increase in daily carbohydrate intake resulted in a 0.05 minute increase and 0.01% decrease in WASO and SE, respectively (Condo et al., 2022). Similar trends have been found when comparing daily carbohydrate intake per kg to WASO and SE. For every 1 g per kg increase in carbohydrate, WASO increased by 3.6 minutes and SE decreased by 0.6% (Condo et al., 2022). Conversely, Greenwalt et al. (2023) found no association between evening carbohydrate intake and sleep metrics. However, when total daily carbohydrate intake was reviewed by Condo et al. (2022), associations were found between an increase in this macronutrient and increased WASO and decreased SE. Prior to these studies in elite female athletes, a systematic review investigated dietary factors on sleep metrics in athletic populations (Barnard et al., 2022). In this review, five studies were identified that assessed the relationship between carbohydrates and sleep in male athletic populations (student, sub-elite, elite and/or professional) (Barnard et al., 2022). In 13 highly trained male cyclists who underwent two nine-day trial periods of high or moderate daily carbohydrate intakes while following an intensive training programme, TST was higher in those with moderate carbohydrate intake than high carbohydrate intake (Killer et al., 2017). It was noted that the total energy intake differed significantly between the high and moderate daily carbohydrate intake groups thus, the moderate daily carbohydrate intake group performed with lower energy intake. No other sleep parameters were affected by the dietary conditions (Killer et al., 2017). Here, future research should consider the energy contribution carbohydrates provide to the diet, particularly when analysing its effect on sleep. In contrast to the previous study, Falkenberg et al. (2021) showed a significant 0.1 minute decrease in TST, a 0.002% increase in SE, and a 0.01 minute decrease in WASO for every 1 g increase in evening carbohydrate (sugar) intake. In addition, no significant associations were found between daily carbohydrate intake and sleep metrics in these athletes (Falkenberg et al., 2021). Additionally, Louis et al. (2016) investigated the impact of low daily carbohydrate intake and thus, low glycogen availability over a three-week endurance training period in 21 triathletes. The low daily carbohydrate intake group had a slight (1.1%) decrease in SE and an increased frequency of restlessness during sleep (Louis et al., 2016). Such results would suggest that reduced glycogen availability has a minimal effect on sleep metrics. While research highlights varying effects of carbohydrates on sleep, to fully understand their

relationship, consideration of carbohydrate source and timing whilst eliminating the influence of differing energy intakes on sleep quantity and quality should be investigated.

Another approach researchers have taken to study the relationship between carbohydrates and sleep is exploring the influence of carbohydrate quality. The glycaemic index (GI) of carbohydrates determines how quickly they can be broken down into simple sugars and absorbed into the blood system, thus resulting in different physiological responses (Doyle et al., 2007). Low GI foods have a GI of ≤55 and high GI foods have a GI of ≥70 (Atkinson et al., 2021). Two studies in the systematic review by Barnard et al. (2022) investigated the influence of GI on athlete's sleep. In 10 recreationally trained male volunteers, TST and SE were longer and higher, respectively, whereas SOL was decreased by 4-fold in those who received a higher GI meal (170) compared to those who received a lower GI meal (81) post-exercise and pre-sleep (Vlahoyiannis et al., 2018). However, these findings were not significant. Interestingly, in nine male high-performance basketball players, no significant differences were found between isocaloric high (>70) and low (<55) GI evening meals in sleep parameters on pre-game nights (Daniel et al., 2019).

At present, the literature available on this topic for the athletic population remains minimal however, some findings suggest that evening carbohydrate intake influences TST and SE, which are consistent with findings for the non-athletic population (Barnard et al., 2022). To determine the full potential of carbohydrate manipulation as a sleep strategy, there is a need for further research on the impact of the amount, timing, and quality of carbohydrates on sleep quantity and quality variables in the sporting population, particularly female athletes (Barnard et al., 2022).

3.4 Protein Intake

Protein is an essential macronutrient that not only provides energy but also contains vital components for the immune system and the repair, growth, and maintenance of tissue, all important factors in recovery for athletes (Pasquale, 2007). Overall, elite athletes are a highly active population that tend to have increased lean muscle mass and thus, higher protein requirements compared to their sedentary counterparts (Pasquale, 2007). The idea of protein

utilisation in sleep has stemmed from the essential amino acid tryptophan and its involvement in serotonin and melatonin synthesis; hormones that regulate the sleep-wake cycle (Doherty et al., 2019; Gratwicke et al., 2021). Free tryptophan in the brain is converted to serotonin from which melatonin, a sleep-promoting hormone, is subsequently produced (Gratwicke et al., 2021). Evidence suggests that tryptophan consumption has a positive influence on sleep however, the magnitude of this is dependent on the amount of tryptophan that is able to cross the blood-brain barrier (Doherty et al., 2019). Once again, insufficient evidence exists on the relationship between protein and sleep for athletes of all levels (Barnard et al., 2022). In a clinical trial, pre-sleep (30-60 minutes) protein-rich and non-protein-rich foods had no impact on actigraphy results in 10 moderately to vigorously active females, although the trial was limited to one night (Leyh et al., 2018). Objectively measured diet and sleep studies have found no significant association between daily and evening protein intake and sleep variables in elite female football (Greenwalt et al., 2023) and AFL players (Condo et al., 2022). On the other hand, Falkenberg et al. (2021) reported that for every gram of total daily protein per kg, WASO was greater (4 minutes), and SE was reduced (0.7%) in men. In addition, every 1 g per kg increase in evening protein intake was associated with shortened (2 minutes) SOL (Falkenberg et al., 2021). In fifteen elite Australian rules football players who underwent a four day whey protein supplementation (55 g = 1 g tryptophan) trial, there was nil influence on sleep variables, including TST, WASO, SE, and SOL (Ferguson et al., 2022). Of note, the participants involved in Ferguson et al. (2022) reported adequate sleep quantity pre-protein supplementation, highlighting the question of whether tryptophan promotes sleep in both individuals with and without adequate sleep (Ferguson et al., 2022). Similar studies have focussed on the α-lactalbumin (LALBA) content of whey protein (the most abundant natural source of tryptophan) and whether LALBA manipulation yields any changes to sleep parameters (Doherty et al., 2019). In sixteen female athletes (n=10 team sport, n=4 middle-distance runners, and n=2 weightlifters), PSG assessments were conducted in the evening when a LALBA whey protein, placebo whey protein, or water beverage was consumed two hours pre-sleep. Stage N2 of NREM was the only parameter to significantly increase in the LALBA whey protein supplemented group compared to the placebo whey protein and water-only group (Miles et al., 2021). Other recent studies however, found no difference in sleep quantity and quality for six track cycling males (MacInnis et al., 2020) and 11 endurance-trained athletes (five male and six female) (Oikawa et al., 2020) when supplemented with 40g

LALBA containing 2g tryptophan two hours before sleep. Unlike the aforementioned study that used the gold standard PSG assessment, sleep data were collected through actigraphy in MacInnis et al. (2020) and Oikawa et al. (2020), which may have contributed to the lack of significant results. In non-athletic populations, LALBA treatment has shown promising effects on enhancing sleep, especially in those who have sleep complaints and difficulties, with results showing a beneficial impact on sleep from ≥ 1 g of tryptophan (Barnard et al., 2024; Gratwicke et al., 2023; Silber & Schmitt, 2010). In objectively measured studies, SOL tends to improve with a 20-60 g LALBA supplement (Barnard et al., 2024), with only one study finding a significant improvement in TST (12.8%) and SE (7.0%) when consuming a LALBA versus a placebo protein shake one hour before sleep (Ong et al., 2017). From the review of the literature in athletic and non-athletic populations, the efficacy of evening protein intake with either tryptophan-rich food sources or supplements to promote sleep in athletes requires further research. From the available studies, tryptophan-rich food sources or supplements may be particularly useful to athletes who have poor sleep habits or experience sport-related stress that negatively affects their sleep. However, future research is needed to validate these findings.

3.5 Fat Intake

Fat is the most energy abundant macronutrient when broken down to free fatty acids and oxidised to produce fuel for the working muscles (von Duvillard et al., 2007). Although fats are vital in a balanced diet, the type of fat (saturated or non-saturated) and the volume consumed may improve or impair sleep (Lindseth & Murray, 2016). Due to the scant number of studies and their varying results, definitive conclusions are unable to be made (Lindseth & Murray, 2016), however, a review of the available research will be provided. In elite female footballers, sleep duration and disturbances were not influenced by high (>10 g) or low (≤10 g) evening dietary fat intake (Greenwalt et al., 2023). Likewise, there was no significant association between total fat and evening dietary fat intake in actigraphy sleep measurements for elite female AFL players however, for every 1 g increase in daily saturated fat and 1 g increase per kg in daily saturated fat, SOL decreased by 0.27 minutes and 17 minutes, respectively (Condo et al., 2022). The proposed influence that fat has on sleep may be the result of inducing cholecystokinin secretion (Condo et al., 2022). This hormone is positively correlated with

increased sleepiness and ratings of fatigue independent of its ability to stimulate insulin secretion in healthy males and females (Wells et al., 1997). Interestingly, in a study conducted on male AFL players, dietary saturated fat intake was not associated with sleep over a 10 day period (Falkenberg et al., 2021). Similarly, a systematic review failed to find any further investigations on this topic for athletes highlighting the niche extent of this research area (Barnard et al., 2022).

Research conducted on fat intake and its impact on sleep in general non-athletic populations is less extensive and inconsistent when compared to other macronutrients. For example, Crispim et al. (2011) found that over a three-day period, there was a positive association between nocturnal fat intake and SOL, REM latency, N2, and WASO in females, yet a negative association was found between nocturnal fat intake and SE and REM sleep in males. However, this study suggested an overall negative influence of fat on sleep (Crispim et al., 2011). On the contrary, other studies have noted an improvement or no indicated effect of fat intake on sleep, however, the population groups differ significantly between these studies and thus, their comparability may be implausible (Lindseth & Murray, 2016). Discrepancies may also be related to the difference in experimental and observational study designs and the use of PSG and actigraphy sleep measurement methods (Lindseth & Murray, 2016). Thus, from the available evidence, whether or not athletes should consider changing their dietary fat intake, specifically saturated fat intake at night, to improve sleep, warrants additional investigation.

3.6 Methods of Analysing Dietary Intake

Estimating energy intake provides insight into the dietary habits of individuals. Various nutrition assessment methods have been followed in dietary studies on athletes however, their susceptibility to being unreliable and invalid is present (Capling et al., 2017). Gaining accurate nutritional information can be challenging due to participants altering their usual dietary intake during self-reported interventions, resulting in a typical under-reporting error to occur (Hill & Davies, 2001). To date, there is no gold-standard method of measuring energy intake however, dietary assessment methods such as food records, 24-hour recalls, food frequency questionnaires, direct observations, and biomarkers used in general populations have also been implemented in sport nutrition research (Capling et al., 2017). Weighted or

estimated food records are widely utilised in nutrition research, but there is a balance between the practicality and plausibility for the athletic population due to the burden of having to self-record food intake amongst their other sporting endeavours (Capling et al., 2017). Although efforts to reduce recording inaccuracy and unreliability have been taken, such as cross-referencing, photographs, and multiple time point assessment, residual errors are still present when estimating the intake of athletes (Burke et al., 2018).

However, using two dietary assessment methods (weighted food record and 24-hour recall) has been shown to provide greater accuracy when quantifying athletes' energy intake (Briggs et al., 2015; Rumbold et al., 2011). A feasible supplementary method for athletes to record their intake is through photographs which has been shown to improve self-reporting and allow for nutritional professionals to correct reporting errors (Gemming et al., 2015). Research recommends obtaining food records from a number of days (consecutive or not) to establish eating habits as opposed to a single day record to eliminate day-to-day variation (Capling et al., 2017). Currently, nutrition professionals are reliant on food records to conduct nutritional assessments however, a combination of methods should be considered to enhance the reliability of reporting, especially within a research setting.

4.0 Conclusion

The sleep and nutrition interaction is an evolving topic in sport and exercise science research in high-performance athletic populations. Understanding this relationship may provide useful strategies to improve the health and performance of female football athletes. Sleep is fundamental for recovery and thus, poor sleep habits are associated with detrimental effects on concentration, reaction time, muscular strength, speed and power. All of these are key skills in football, and any discrepancies in these skills could potentially increase the risk of sport-related injuries and lead to a decrease in performance (Fullagar et al., 2015b; Nedelec et al., 2015). Research has identified various ways in which nutrition can modify sleep, such as meal timing, energy intake, and macronutrient distribution. However, obtaining this information accurately has proven challenging due to the risk of reporting error. Although there is no 'gold-standard' method of analysing diet, a two-assessment method approach is sufficient and could be used in sleep-nutrition research.

This review has summarised the available research that has investigated sleep and the influence of nutrition on sleep amongst football athletes, particularly female players. It is evident that poor sleep quantity and quality are prevalent in elite athletes and may differ by sex, and the training and performance calibre of the athlete. Regardless, females are disproportionately under-represented in current research, and male-dominant data are untranslatable to females due to physiological differences. Thus, gaps remain in the literature that need to be addressed. These include the prevalence of poor sleep quantity and quality, dietary intake, and nutrition timing of female football athletes. Furthermore, adolescent female football players are part of the development pool for elite teams and hence, strategies to support health and performance are key for sport longevity. Addressing these gaps in future research will assist in optimising the health and performance of elite level football athletes and thus, support their endeavours throughout their athletic careers.

Chapter 3: Manuscript

3.0 Abstract

Introduction: Research on nutrition as a means to support sleep and recovery is emerging in the literature with promising sleep outcomes however, the available evidence on female footballers is limited. Therefore, the aim of this study was to describe the effect of evening meal timing, energy intake, and macronutrient composition (e.g. carbohydrate, protein, and fat) on the quantity and quality of sleep for players in the Wellington Phoenix Female U20 Academy Football Team.

Methods: Twenty-five members of the Wellington Phoenix Female U20 Academy Football Team (17.6 ± 1.1 years) participated in this study. Participants completed three 24-hour food records and wore a WHOOP® wristband to measure total sleep time (TST) and wake periods (WP) on one light training day (LTD), heavy training day (HTD) and pre-game rest day (PGRD) over one week during their competitive season.

Results: The evening carbohydrate intake was higher on the HTD compared to LTD (p=0.026) however, no significant differences were found between other dietary and sleep variables across the three training days. The number of players with a TST less than the current recommendations for sleep quantity ranged from 22.2% to 81.8% across the three training days. On the PGRD, for every 1 kcal increase in evening energy intake, TST increased by 0.14 minutes (β=0.14, 95% CI [0.04, 0.23], p=0.008), while for every 1 g increase in evening fat intake, TST increased by 1.40 minutes (β=1.40, 95% CI [0.03, 0.34], p=0.021). For every 1% increase in evening carbohydrate intake, TST increased by 1.84 minutes (β=1.84, 95% CI [0.01, 3.59], p=0.041).

Conclusion: This study confirms that poor sleep quantity is prevalent, and evening energy, carbohydrate and fat intake positively influenced TST on a PGRD in adolescent female footballers. Future research may need to review energy, carbohydrate and fat strategies to aid sleep for athletes before a match.

3.1 Introduction

New Zealand Football has seen a 25% increase in female player numbers between the 2022 and 2023 seasons (New Zealand Football, 2024). Simultaneously, there has been an increase in the professionalism of the sport for females aided by New Zealand recently hosting 32 teams for the FIFA Women's World Cup 2023 (New Zealand Football, 2024). The professional-based New Zealand club; Wellington Phoenix has A-league and U20 academy (youth development system) teams for males and females (Wellington Phoenix, 2024). These elite football players compete at the sport's highest level of competition and have increased physical demands compared to recreational and club-level players due to their greater training volumes and competitive demands (Datson et al., 2014). For these athletes, adequate recovery to balance these stressors between training and competition is key to maintaining health and performance (Fullagar et al., 2015a).

The single best strategy for recovery for elite athletes is gaining adequate sleep, yet sleep has been shown to be compromised for this highly competitive population (Gupta et al., 2017; Halson, 2008). Sleep is fundamental for both physical recovery and cognitive restoration, both of which are beneficial for performance and sport-specific training adaptations (Doherty et al., 2019; Lastella et al., 2015). The current literature on sleep in female athletes is limited. However, insight into female athlete's sleep may be reviewed from various elite sporting disciplines (Walsh et al., 2020). The previous research on female athletes shows TST ranges from 6.9 to 8.1 hours (Condo et al., 2022; Gjertsås et al., 2024; Greenwalt et al., 2023). Amongst these studies, insufficient sleep quality has been identified however, these results have been based on sleep guidelines for the general population. Regardless, the research on sleep in adolescent female athletes is limited. Adolescents are at a critical stage of maturation making sleep more important as it is fundamental for their health and performance (Mason et al., 2023).

Poor sleep identified in elite athletes has resulted in the exploration of dietary strategies to positively influence sleep behaviour (Gratwicke et al., 2021). Research in dietary strategies to improve sleep is evolving however, only a few studies exist for elite female athletes. Regardless, previous research suggests that manipulating daily and evening energy, carbohydrate, protein and fat intake may improve sleep measures (Condo et al., 2022;

Falkenberg et al., 2021). These dietary components have all been shown to independently influence sleep measures due to their involvement in hormone production and arousal in the sleep-wake cycle (Barnard et al., 2022).

The consensus of inadequate sleep quantity and quality variables for female athletes and the subsequent promising evidence on how nutrition impacts sleep highlights the need for further investigation into the association between dietary habits and sleep for female adolescent athletes. Therefore, this study aims to describe the evening meal habits and the relationship between the evening meal timing on sleep quantity and quality, and to determine the influence of the macronutrient composition (e.g. carbohydrate, protein, and fat) of evening meals on sleep duration and efficiency of players who are part of the Wellington Phoenix Female U20 Football Academy Team.

3.2 Methodology

This study was a cross-sectional study conducted on the Wellington Phoenix Female U20 Academy Football Team. Data collection began and concluded in May 2024 during the Capital Football Talent Development Programme League season.

3.2.1 Participants and Recruitment

Twenty-five females (17.6 ± 1.1 years) from the Wellington Phoenix Female U20 Academy Football Team participated in the present study. For this study, participants had to be members of the Wellington Phoenix Football Club and selected for the female U20 academy/reserves team over the 2023-2024 season. Participants were a part of a larger research project investigating training load and health characteristics and their involvement in all parts of the project including this study on sleep and dietary intake was voluntary. The study received ethics approval from Massey University Human Ethics Committee: Ohu Matatika (Southern A) 23/51.

3.2.2 Study Design

This cross-sectional study comprised of three data collection points over one week beginning on the 20th of May 2024. On each data collection day, participants completed a written and

visual 24-hour food record to assess energy and macronutrient intake and wore WHOOP® wristbands continuously throughout the week to track their sleep. The data collection days consisted of a light training day (LTD), a heavy training day (HTD), and a pre-game rest day (PGRD).

3.2.3 Nutritional Assessment

Players were provided with (1) 24-hour food record presentation and (2) 24-hour Food Record Guidelines for Footballers, which included instructions on how to complete a 24-hour food record (see Appendix A). Players were instructed to record the estimated quantity, product brand names, nutritional panel, and timing of food and beverage intake 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 three day period (Burke et al., 2018). Food records were sent to researchers via a private WhatsApp message on the day of recording. Players were encouraged to send their written and visual food records as close to eating time as possible. A review between the written diet records and photographs was conducted by researchers to check for any mis-reporting. Any proposed discrepancies were verified with the players via a WhatsApp direct message within 24 hours after each day of data collection. Players were asked to maintain habitual dietary patterns during all data collection days.

3.2.4 Dietary Analysis

Each verified diet record data was uploaded to the software Foodworks V.1.0, a nutrition analysis program (Xyris, 2024). Data input was completed by two researchers and cross-checked for consistency of the foods being entered, increasing the accuracy of this process. The estimated quantities of food items were kept consistent by the use of a photographic portion-size handbook, standardising this process. Total evening energy (kcal), carbohydrate (g), protein (g) and fat (g) intake for each participant were quantified by Foodworks software. When food products weren't available on the Foodworks database, close substitutes or, where possible, product nutrition panels were used for manual input. The evening meal was considered to be any food or beverage consumed as the last main meal of the day and any additional intake of food and beverages after this meal before sleep. Defined evening hours

for when this meal could be consumed were not specified in this study due to the high variability in the available literature. However, the time when this meal was consumed before sleep was recorded.

3.2.5 Sleep Assessment

Sleep data by WHOOP® was automatically collected from participants. Sleep measures included total sleep time (TST) and number of wake periods (WP). The time of sleep onset was also collected by WHOOP®. Participants were required to wear the WHOOP® wristband continuously (both day and night) except during training. On evenings when the WHOOP® wristband failed to record sleep, participants were required to manually enter their TST. WHOOP® data obtained for each participant throughout the week of data collection was provided by the principal researcher (PhD candidate, Isabella Coombes). TST was recorded by minutes and WP were recorded by frequency. To determine the timing between evening meal intake and sleep, the total time difference between the evening meal and sleep onset (time) was calculated. To assess sleep adequacy, participants were classified into youth (15-17 years) or young adults (18-25 years) as per the Ministry of Health of New Zealand guidelines (Ministry of Health, 2024).

3.2.6 Statistical Analysis

IBM SPSS Statistics 29 software suite was used for statistical analysis of food records and sleep data. Data were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. Parametric normally distributed data were recorded as mean ± standard deviation. The non-parametric data that was normally distributed after log transformation were displayed as mean [95% CI], and the remaining non-parametric non-normally distributed data were reported as median (25^{th}, 75^{th} percentiles). Parametric normally distributed data are displayed in Table 3.2 as mean [95% CI] to aid comparison with transformed non-parametric data. For parametric data, a comparison of dietary and sleep values between players for each data collection day was conducted by a one-way ANOVA test. A Tukey-B and Scheffe post hoc test was conducted if there was a significant main effect observed from the ANOVA test. A comparison of non-parametric data was conducted by a Kruskal-Wallis test. A Pearson correlation coefficient test was used to analyse the bivariate correlations between sleep (TST

and WP) and dietary (time, energy, carbohydrates, protein, and fat) values. For non-parametric data, a Spearman's rank correlation coefficient (r_2) test was used. A linear regression analysis was conducted for significant correlations presented as (β, [95% CI], p) with the beta (β) value indicating a change in the dependent variable for every 1 unit increase in the independent variable. In the case where data was transformed to meet normality, β indicates a 1% increase in the independent variable. A p-value of <0.05 was considered significant.

3.3 Results

3.3.1 Evening Dietary Intake and Sleep Characteristics of Participants

Demographic characteristics, evening dietary intake and sleep results of the participants are presented in Table 3.1. Of the original 25 participants, one participant was removed from the data set due to incomplete dietary and sleep data across all three training days. The number of participants across the three training days is displayed in Figure 3.1. Each participant who had incomplete dietary or sleep data was removed from a single day only and was still included in the datasets for the other two training days. One player manually entered their TST on the 'HTD' as the WHOOP® wristband incorrectly recorded their sleep. Therefore, 23 female football players have been included in this data while 22, 23, and 22 players were included in the dietary dataset on the LTD, HTD and PGRD, respectively. In the sleep dataset for the LTD and HTD, 23 players were included, whilst 21 players were included on the PGRD.

Table 3.1 Descriptive Characteristics, Evening Dietary Intake and Sleep of Participants		
Characteristics	**Average across all training days**	
Age (years)	17.6 ± 1.1[a]	
Weight (kg)	61.4 ± 6.1[a]	
Dietary		
Evening energy intake (kcal)	638.9 [569.9, 718.6][b]	
Evening carbohydrate intake (g)	59.2 [51.5, 68.1][b]	
Evening protein intake (g)	32.3 [28.7, 36.4][b]	
Evening fat intake (g)	23.6 (15.3, 38.9)[c]	
Sleep		
TST (minutes)	468.0 ± 65.3[a]	
	Min	**Max**
	308.9	637.8
WP (n)	12.7 ± 5.6[a]	
Time (minutes)	221.7 (167.9, 271.6)[c]	

[a]Mean ± SD

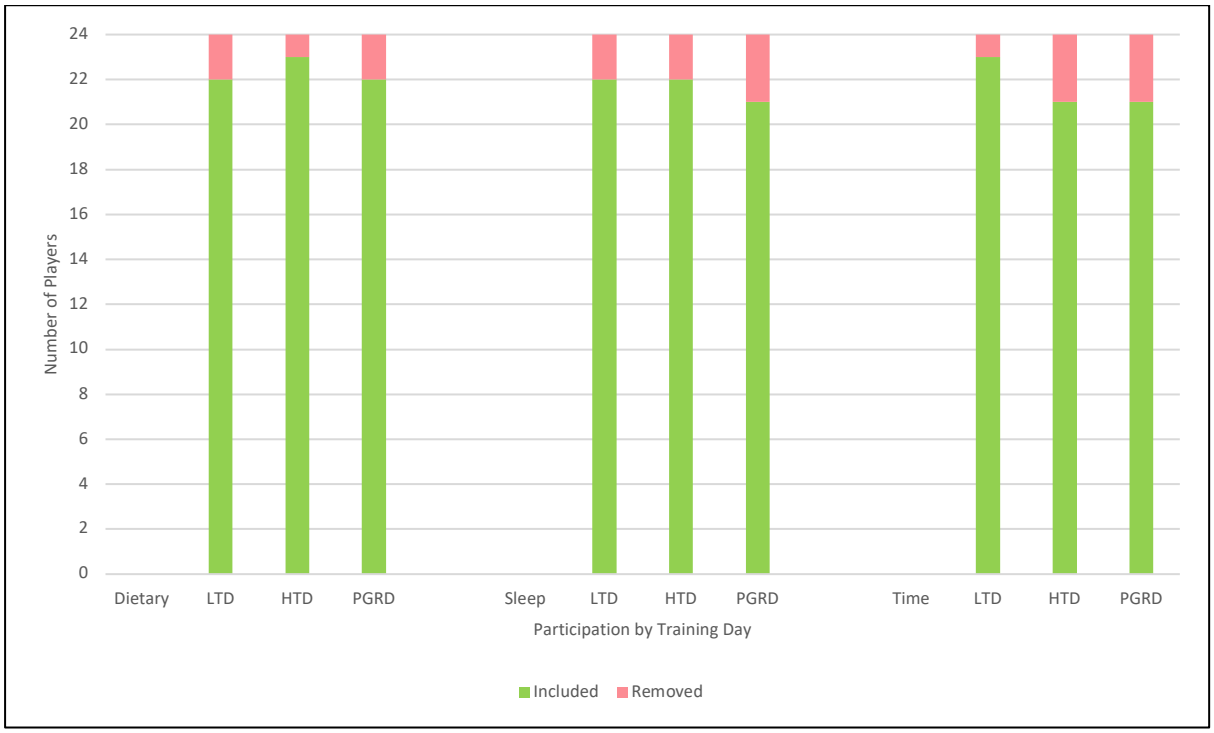
[b]Mean [95% CI]

[c]Median (25^{th}, 75^{th} percentiles)

TST: total sleep time; WP: wake periods; kcal: kilocalorie; kg: kilogram; g: gram; n: number

Time: calculated as sleep start time – evening meal time

Figure 3.1 Participation of Players per Dataset by Training Day



Note: **LTD: light training day, HTD: heavy training day, PGRD: pre-game rest day, Time: refers to the time between the evening meal and onset of sleep, calculated as sleep start time – evening meal time**

3.3.2 Evening Dietary Intake

Average evening energy, carbohydrate, protein, and fat intakes on three data collection days for the participants are presented in Table 3.2. The different proportions of evening macronutrient intake for each training day are presented in Figure 3.2. No significant differences were found in evening energy (p=0.181), protein (p=0.843), and fat intake (p=0.370) over the three training days. A significant difference was found in carbohydrate intake between LTD, HTD, and PGRD (p=0.020), with post-hoc analysis indicating that the significant difference in evening carbohydrate intake was between LTD and HTD (p=0.026). Evening carbohydrate intake was greater on the HTD compared to LTD, with no difference in evening carbohydrate intake between HTD and PGRD or LTD and PGRD (p=0.777 and p=0.130).

Table 3.2 Average Dietary Intake				
	LTD (n=22)	**HTD (n=23)**	**PGRD (n=22)**	**P**
Energy (kcal)	550.4 [443.7, 683.0]	670.5 [545.5, 824.1]	776.3 [625.9, 926.7]†	0.181
Carbohydrate (g)	45.3 [34.0, 60.5]	71.4 [56.4, 90.4]	63.6 [52.8, 76.7]	0.020
Protein (g)	36.0 [28.2, 43.7]†	34.4 [27.6, 41.2]†	33.9 [27.0, 42.7]	0.843
Fat (g)	21.9 [16.7, 28.7]	28.5 [19.4, 37.6]†	36.3 [25.7, 47.0]†	0.370

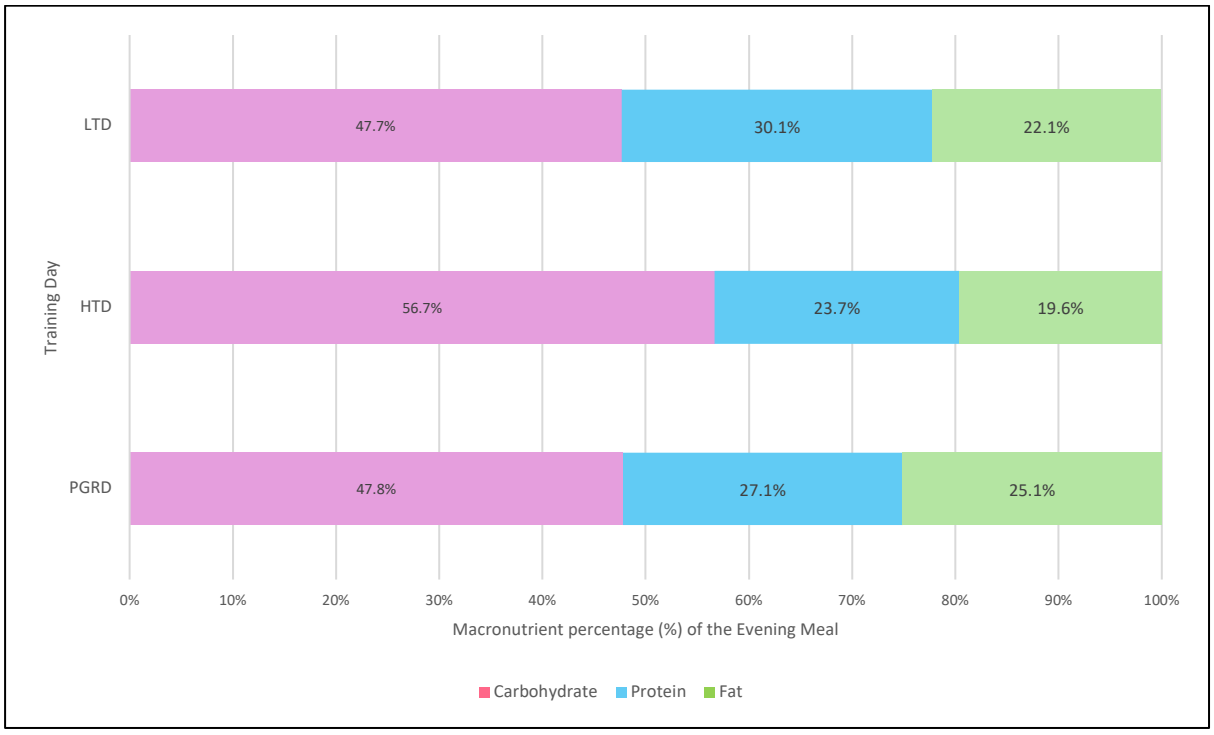
Values are presented as mean [95% CI]

†Normally distributed data are displayed as mean [95% CI] for comparison with transformed non-parametric data

P = P-value is a test for differences conducted between each training day as assessed by one-way ANOVA

LTD: light training day; HTD: heavy training day; PGRD: pre-game rest day; kcal: kilocalorie g: gram; n: number

Figure 3.2 Macronutrient Distributions in the Evening Meal by Training Day



Note: **LTD: light training day, HTD: heavy training day, PGRD: pre-game rest day**

3.3.3 Sleep

Sleep was analysed for 23 players on LTD and HTD however, on PGRD, the sleep of 21 players was analysed. Overall, 57.5% (n=34) and 26.5% (n=33) of the total nights of sleep assessed were less than both youth (15-17 years) and young adults (18-25) New Zealand TST guidelines,

respectively. Across the three training days, the number of youth players (n=11) who slept <8 hours was 36.4% on the LTD, 81.8% on the HTD, and 54.5% on the PGRD. The number of young adult players (n=12) who slept <7 hours was 33.3% on both the LTD and HTD, whilst 22.2% slept <7 hours on the PGRD. No significant differences were found in TST and WP between LTD, HTD, and PGRD (TST p=0.237 and WP p=0.079), as shown in Table 3.3. No significant difference was found between the time of the evening meal and sleep start on the LTD, HTD, and PGRD (p=0.779).

Table 3.3 Average Sleep and Time between the Evening Meal and Sleep

	LTD (n=23)	**HTD (n=23)**	**PGRD (n=21)**	**P**
TST (minutes)	482.7 ± 67.1[a]	449.6 ± 64.9[a]	465.2 ± 64.5[a]	0.237
WP (minutes)	13.1 ± 5.7[a]	10.6 ± 5.1[a]	14.3 ± 5.6[a]	0.079
	LTD (n=22)	**HTD (n=23)**	**PGRD (n=20)**	**P‡**
Time (minutes)	216.7 (157.0, 253.2)[b]	225.8 ± 14.9[a]	248.0 ± 22.3[a]	0.779

[a]Mean ± SD

[b]Median (25th, 75th percentile)

P = P-value is a test for differences conducted between each training day as assessed by one-way ANOVA

P‡ = P-value is a test for differences conducted between each training day as assessed by Kruskal-Wallis Test

Time: refers to the time between the evening meal and onset of sleep, calculated as sleep start time-evening meal time

TST: total sleep time; WP: wake periods, LTD: light training day; HTD: heavy training day; PGRD: pre-game rest day

3.3.4 The Association between the Evening Meal and Sleep

Table 3.4 presents the results of the correlation analysis between dietary intake amounts (kcal and gram) and sleep variables (TST and WP) over the three training days. One player on the LTD and three players on the PGRD were removed to ensure all included players provided both dietary intake and sleep data for the correlation analysis. Evening energy (kcal), evening carbohydrate (g), evening protein (g), and evening fat (g) intake did not significantly correlate with TST or WP on LTD and HTD. On the PGRD, a strong positive and significant correlation was found between TST and evening energy intake (r=.575, n=20, p=0.008). A significant and moderate positive correlation was found between TST and evening carbohydrate (r=.461, n=20, p=0.041) and between TST and evening fat (r=.512, n=20, p=0.021) on PGRD, despite no significant differences in TST, evening energy, evening carbohydrate, and evening fat

observed across the three training days. There were no significant correlations found between the timing of the evening meal and TST on LTD (p=0.246), HTD (p=0.056), and PGRD (p=0.115), and between the timing of the evening meal and WP on LTD (p=0.481), HTD (p=0.560), and PGRD (p=0.609).

Table 3.4 Correlation (r-value) between the Evening Meal Content and Timing on Sleep

	LTD (n=22)		**HTD (n=23)**		**PGRD (n=20)**	
	TST	**WP**	**TST**	**WP**	**TST**	**WP**
Energy	.000	.418	-.399	.124	.575**	.215
Carbohydrate	-.280	.315	-.265	.281	.461*	.127
Protein	.295	.078	-.158	-.181	.068	-.031
Fat	.125	.419	-.297	.102	.512*	.298
Time	-.258	-.159	-.404	-.128	-.354	.122

**p(two-tailed)<0.05, **p(two-tailed)<0.01*

r = r-value is a test for correlation between dietary and sleep as assessed by Pearson's correlation coefficient and Spearman's rank test.

Time: calculated as difference between evening meal time and sleep start time

LTD: light training day; HTD: heavy training day; PRGD: pre-game rest day

On the PGRD, for every 1 kcal increase in evening energy intake, TST increased by 0.14 minutes (β=0.14, 95% CI [0.04, 0.23], p=0.008), while for every 1 g increase in evening fat intake, TST increased by 1.40 minutes (β=1.40, 95% CI [0.03, 0.34], p=0.021). For every 1% increase in evening carbohydrate intake, TST increased by 1.84 minutes (β=1.84, 95% CI [0.01, 3.59], p=0.041).

3.4 Discussion

This study described the characteristics of the evening meal (timing and content) and sleep, as well as the relationship between the evening meal and sleep quantity and quality of players from the Wellington Phoenix Female U20 Football Academy Team in New Zealand. To the best of our knowledge, this is the first study to assess the relationship between the evening meal and sleep in female football players in New Zealand. Our results found that poor sleep quantity

was prevalent in this cohort, with the total night's sleep duration in 57.5% and 26.5% of youth (15-17 years) and young adults (18-25 years), respectively being less than the New Zealand TST guidelines (Ministry of Health, 2024). Whilst sleep did not significantly differ between the training days, our results suggest that evening energy, carbohydrates, and fat intake on a PGRD positively influences sleep quantity but did not affect sleep quality. Finally, our results demonstrated that the evening meal timing did not differ between data collection days, and the timing of the meal had no influence on the following night's sleep.

3.4.1 Evening Meal Habits

Both sleep and nutrition are essential for athlete recovery, training adaptation, performance and general health (Binks et al., 2020; Doherty et al., 2019). Understanding the evening dietary and sleep patterns of female footballers can be useful to support the aforementioned components. This study reported the average evening energy intake across the three training days to be 639.8 kcal, 95% CI [569.9, 718.6] and consisted of, on average, 59.2 g, 95% CI [51.5, 68.1] carbohydrates, 32.3 g, 95% CI [28.7, 36.4] protein, and 23.6 g (25^{th}, 75^{th} percentiles: 15.3, 38.9) fat. In a similarly aged cohort of Division I female footballers, the average pre-sleep dietary intake was 330 ± 284 kcal and had 46.2 ± 40.5 g of carbohydrates, 7.6 ± 7.3 g of protein, and 12.0 ± 10.5 g of fat (Greenwalt et al., 2023). Conversely, in national and international competing female Canadian athletes (football being one of the four most prevalent sporting types), prospective daily food records reported the average evening meal without snacks consisted of 700 ± 238 kcal; 85.8 ± 36.6 g of carbohydrate; 40.5 ± 40.4 g of protein; 22.3 ± 11.1 g of fat (Erdman et al., 2013). The difference in evening nutritional intake may be due to the additional days of training (2.4 ± 0.7 days) during the study period in the Canadian cohort compared to the two training days in our study. In our study, the average pre-sleep feeding window was 3 hours compared to the pre-defined 2 hours in Greenwalt et al. (2023). Whereas, in Erdman et al. (2013) the evening meal was defined to be exclusive of evening snacks. Different definitions of the pre-sleep feeding window amongst these studies are likely to have contributed to the differences in the evening meal habits. Furthermore, in female athletes, the evening meal habits and characteristics have not been intensely researched. Currently, the high variability in results and methods between studies makes meaningful

recommendations and comparisons difficult. Therefore, further research on female athletes' evening nutritional intake is needed.

At present, recommended athlete nutritional intakes are not specific to a single meal such as the evening meal. The current guidelines suggest a higher carbohydrate intake on training days versus rest days, reflecting carbohydrate periodisation to support training loads (Thomas et al., 2016). The present study found that the evening carbohydrate intake was ~10% higher on the HTD compared to the LTD and PGRD. While not exclusive to an evening meal, increased total daily carbohydrate intake on match days and training days compared to rest days has been similarly reported in footballers in the Dutch Female Eredivisie (Brinkmans et al., 2024). This study and Brinkmans et al. (2024) both demonstrate periodisation of carbohydrate intake within a training week. These results support nutrition guidelines that recommend athletes increase their carbohydrate consumption for higher exercise intensities and expenditures (Thomas et al., 2016). Of note, previous research consistently demonstrates that the evening meal tends to be the most caloric meal consumed in a day for elite female athletes (Anderson et al., 2017; Erdman et al., 2013). Therefore, results from this study suggest that players are likely to achieve carbohydrate periodisation to refuel and recover from different training loads by their evening meal. Despite this result, the current dietary behaviours of the participants do not indicate evening carbohydrate loading on the PGRD for the following match day. A nutritional recommendation such as this would provide energy and help restore glycogen stores to support quality performance and effective recovery (Thomas et al., 2016). Evening and total daily carbohydrate intake patterns across different training days have only been largely examined in male players, making it hard to draw comparisons to female athletes (Martinho et al., 2024). Given the fuelling practices identified in this study, future research may also consider investigating the influence of afternoon or evening training timing on the evening intake of carbohydrates.

Energy and macronutrient periodisation may also be expected along with carbohydrate intake for athletes however, this was not found in the present study. No significant findings of adjusted energy, protein or fat content of the evening meal across all three training days were observed. Similar results were identified in Norwegian female footballers (Dasa et al., 2023) and male adolescent Portuguese footballers (Granja et al., 2017), where no change in total

energy, protein, and fat intake was found between different training days. Conversely, daily energy intake was shown to increase on training days compared to rest days for players in the Dutch Female Eredivisie (Brinkmans et al., 2024). Training days with two training sessions also showed an increase in daily energy, protein and fat intake compared to days with one training session (Brinkmans et al., 2024). It is likely that the national teams in the aforementioned research have access to nutrition information and health support personnel that provide nutrition education on eating practices for days with different training loads (Inchauspe et al., 2020). Whilst periodisation of nutrition was seen in Brinkmans et al. (2024) on a day where training frequency was higher, the training schedule for players in this study was not assessed. Given this, research should continue to investigate the dietary patterns of female footballers across a training week to gain a deeper insight into nutritional refuelling and recovery practices as well as preparatory evening dietary intakes for different exercise loads the following day.

3.4.2 Sleep Habits

Both optimal sleep quantity and quality are considered essential to support sporting performance and health of athletes (Binks et al., 2020; Doherty et al., 2019). The average TST across all three training days in the study was 468.0 ± 65.3 minutes and did not differ between the LTD (482.7 minutes), HTD (449.6 minutes), or PGRD (465.2 minutes). Subsequently, 57.5% of youth (15-17 years) and 26.5% of young adults (18-25 years) did not meet the minimum hours of sleep recommended for optimal health according to New Zealand sleep guidelines (Ministry of Health, 2024). The percentage of players who did not meet TST guidelines was greatest on the HTD (81.8%) for youth, whereas for the young adult players, 33.3% of players displayed suboptimal sleep on the LTD and HTD compared to the PGRD (22.2%). Similar results demonstrating no influence of training load on TST have been reported in other female football cohorts (Silva et al., 2022). However, in Norwegian elite footballers, a shorter TST was associated with very high training loads (Dasa et al., 2023), similar to the reduced number of youth and adult players achieving TST recommendations on the HTD in our study. Data collection did not include a match day in this study however, with high exercise loads on match days for footballers, a reduced TST may be observed (Gjertsås et al., 2024). Since evidence suggests that suboptimal sleep increases injury risk and poor performance outcomes, the

short TST for both youth and young adults in this study, particularly on a night following high training loads, is of concern and may be an area that warrants future research (Fullagar et al., 2015b; Nedelec et al., 2015). For future research in adolescent athletes, various sport-related influences on sleep outcomes such as training time, travel, high-intensity exercise, or exposure to light, as well as the combination of other lifestyle factors including school/work schedules, diet, naps, and stress may need to be considered (Nedelec et al., 2015; Venter, 2012). Given that a single night of disturbed sleep may impact training adaptation and performance, future research may be needed to determine the performance impacts of inadequate sleep after both LTD and HTD in female footballers.

To consider a night's sleep as optimal, it needs to be not only of sufficient duration but also of good quality (Watson et al., 2015). The average sleep quality indicated by the number of WP per night was 12.7 ± 5.6 and did not change significantly across the training week. When comparing our data to the US National Sleep Foundation's (NSF) sleep quality recommendations (Ohayon et al., 2017), our results did not indicate good sleep quality as youth (14-17 years) and young adult (18-25 years) players had >3 and >4 awakenings, respectively. However, our findings should be interpreted with caution as the NSF states awakenings are WP that are more than 5 minutes, whereas the duration of WP in this study were not measured (Ohayon et al., 2017). Similar to the present results, Greenwalt et al. (2023) also used WHOOP® technology to assess sleep quality and found that the average number of WP ranged from 12.7 to 14.7 amongst female footballers. Although not significant, the WP of the current study was highest on the PGRD suggesting that sleep quality could be poorer on the night before a match day. In future research, it may be important to monitor sleep for players to assess whether high numbers of WP are a predominant problem on a PGRD and to determine the need for strategies to support pre-match day sleep and match day performance. This study and Greenwalt et al. (2023) demonstrate that elite-level female footballers experience to some extent insufficient sleep quality. Because poor sleep quality has been linked to overall suboptimal recovery, future research may be needed to determine whether the sleep quality of female footballers is in line with sleep quality guidelines.

3.4.3 The Effect of the Evening Meal on Sleep

The timing of food intake to support optimal sleep is becoming an increasingly investigated strategy for athletes. The average time between the evening meal and the start of sleep for all three training days was 221.7 minutes (3.7 hours) and did not vary between training days or influence sleep variables across the week. Similarly to our study, Greenwalt et al. (2023) found no effect of a 2 hour pre-sleep food intake on TST and WP in 14 Division I female footballers. In other sporting disciplines such as Australian Football League (AFL), TST was reduced by 8 minutes for every additional hour between the evening meal and sleep for males (Falkenberg et al., 2021). Additionally, TST increased by 24 minutes when the evening meal was consumed at 1.5 hours compared to 3.5 hours before sleep for adolescent male rugby players (Falkenberg et al., 2021; Lehmann et al., 2022). In both Falkenberg et al. (2021) and Lehmann et al. (2022), wake after sleep onset (WASO) improved when the evening meal was consumed closer to sleep time, whereas the measure of sleep quality (WP) in this study did not. It is challenging to compare the results between females and males, especially with research suggesting sex-specific differences in nutrition metabolism and sleep may exist. For example, sex hormones fluctuate throughout the menstrual cycle affecting substrate metabolism and can contribute to varied needs for physiological recovery during sleep in each menstrual phase (Boisseau & Isacco, 2022; Hrozanova et al., 2021). Furthermore, comparisons between studies are difficult due to the high variability in the pre-sleep food intake window and whether the menstrual cycle phase has been accurately reported. Future research may need to standardise this period and consider the menstrual cycle phases to determine if there is an association between the evening meal timing and sleep in female athletes.

As the evening meal is the last main meal before sleep, it needs to provide sufficient energy for the overnight fasting period thus, sleep studies have focused on this specific meal (Lehmann et al., 2022). In this study, evening energy intake improved TST but not WP on the PGRD however, no link was observed between these variables on the other two training days. Our results suggest that a 1 kcal increase in evening energy intake was associated with a 0.1 minute increase in TST on the PGRD. In contrast to our study, Greenwalt et al. (2023) found that pre-sleep energy intake of female elite footballers did not correlate with TST over the competitive season although, the average evening energy intake was ~50% less than players

in our study. This is likely due to the short 2 hour feeding window however, similarly to our results, evening energy did not correlate with WP. In comparison to a cohort of male AFL players, the same discrepancy between our study was found where TST was not influenced by evening energy intake however, sleep quality variables such as WASO and sleep onset latency (SOL) were negatively affected (Falkenberg et al., 2021). While not significant, the increased evening energy intake on the PGRD compared to the LTD and HTD may be a possible explanation for these differences in the literature as research suggests higher energy intakes promote sleep onset by reducing feelings of hunger and increasing satiety during the sleep period (Falkenberg et al., 2021; Lehmann et al., 2022). Future research may investigate whether the TST benefits of a higher evening energy intake outweigh the possible negative impacts on sleep quality in athletes. Additionally, future research trials may consider investigating the impact of increased evening energy intake on sleep for rest and high energy expenditure days as a strategy to facilitate sleep.

Research suggests that macronutrients may influence the sleep cycle (Binks et al., 2020; Doherty et al., 2019). Specifically, carbohydrates are involved in the synthesis of sleep promoting hormones such as melatonin and serotonin (precursor of melatonin) (Binks et al., 2020; Doherty et al., 2019). In this study, despite a higher evening carbohydrate intake on the HTD, it was only on the PGRD that carbohydrates influenced TST but not WP. It was found that a 1% increase in evening carbohydrate intake was associated with a 1.8 minute increase in TST. In comparison to the single other pre-sleep nutrition and sleep study conducted on elite female footballers (Greenwalt et al., 2023), no influence of high (>45g) versus low (≤45g) pre-sleep carbohydrate intake on sleep was found. Of particular note, in Greenwalt et al. (2023) players mostly consumed snack foods and desserts during the 2 hour pre-sleep eating window, which would likely have differed in carbohydrate quality compared to that of the main evening meal in our study (Greenwalt et al., 2023). This is of consequence as a high sugar intake induces a rapid release of insulin and therefore may increase arousal, reducing sleep (Gangwisch et al., 2020). Interestingly, high sugar intake has also been shown to increase insomnia risk in females (Gangwisch et al., 2020). In regard to sleep, evening carbohydrate intake requires further investigation as primary research suggests an impact on sleep variables in female footballers. For female athletes, more research on the quality of carbohydrates (e.g.

high or low GI) is required to assess whether evening intake of high sugar foods negatively impacts sleep.

Protein intake, particularly the amino acid tryptophan, is involved in the synthesis of sleep-wake hormones (Binks et al., 2020). The degree to which tryptophan influences sleep is dependent on the amount that is able to cross the blood-brain barrier (Doherty et al., 2019). Similarly to the research across elite female athletes, evening protein intake did not influence TST or WP for all three training days in this study (Condo et al., 2022; Greenwalt et al., 2023). Due to the paucity of research on protein's effect on sleep in athletes, drawing comparisons between our study and the existing literature is challenging. Nonetheless, evening protein intake could be of use for athletes who experience poor sleep. An α-lactalbumin (protein rich in tryptophan) supplement has repetitively been shown to support individuals experiencing poor sleep in healthy populations (Barnard et al., 2024; Gratwicke et al., 2023; Silber & Schmitt, 2010). Given the prevalence of poor TST amongst athletes in this study, players may find increased evening tryptophan intakes beneficial for their sleep. To verify these propositions, researchers should consider the amino acid profile of the evening protein intake with a focus on athletes who report disturbed sleep.

Fat is a vital component of the diet yet the link to sleep is unclear. Similar to energy and carbohydrate intake, fat intake enhanced TST but not WP suggesting an improvement in sleep quantity but not sleep quality on a PGRD. This study showed that for every 1 g increase in fat, TST increased by 1.4 minutes. It has been proposed that the link between high levels of fat and sleep is attributed to the release of cholecystokinin, which induces sleepiness and fatigue (Wells et al., 1997). Notably, increased daily saturated fat intake was associated with a decreased SOL in female AFL players, suggesting a link between saturated fat and sleep quality. Although our study did not differentiate between types of fat, a beneficial effect of fat intake on TST on the PGRD was found for this female cohort. This interesting result may warrant further research to investigate if the evening intake of different types of fat, particularly saturated fat influences sleep quality in female athletes.

3.4.4 Limitations

This study investigated the association between nutrition and sleep by carrying out an in-depth two-assessment method dietary analysis (written record and photographic diary) with researcher prompts and follow-up. Although efforts to reduce reporting and analysis inaccuracy were taken, under and misreporting may have been present due to players inaccurately estimating food quantities and researcher comparison of meal photographs to the portion manual. To minimise participant burden, sleep was assessed by WHOOP® wristbands (actigraphy) and not polysomnography (PSG). A technological measurement error resulted in one player having to manually enter their sleep duration on the HTD and therefore, it is likely to be an estimation of their TST. This approach also restricted sleep quality assessment to the WP variable, whereby the duration of awakenings was not calculated.

Data was collected on three days of a single week over one competitive season. These three days were further divided into one LTD, HTD, and PGRD to represent three different training loads over the course of the week. This observational study did not account for the other factors that may have affected evening meal and sleep habits such as, but not limited to, the living situation, school/work schedule, naps, sleep environment, training time, menstrual phase, and social arousal of players. Hence, our findings are limited due to the lack of control of these confounders.

Our ability to compare our results is limited due to the scarcity of literature available assessing the effect of the evening meal on sleep, specifically in female athletes. Research proposes that hormonal fluctuations experienced by females throughout the phases of the menstrual cycle may impact nutrition metabolism and the need for sleep (Boisseau & Isacco, 2022; Hrozanova et al., 2021). Given this, the results on males are untranslatable to females, which can be assumed to explain the highly variable data between the two sexes. The underrepresentation of female athletes in sport science research, especially on this topic makes it challenging to generalise the evening meal and sleep habits of female football populations.

3.5 Conclusion

Our research provides insight into the evening dietary and sleep habits of footballers from the Wellington Phoenix Female U20 Academy Football Team in New Zealand. Suboptimal sleep was observed as youth and young adult players were sleeping less than the recommended TST. This is concerning given the associated risk of injury, poor performance, and insufficient recovery with inadequate sleep (Fullagar et al., 2015b; Nedelec et al., 2015). It is evident in this study that nutrition may positively influence sleep quantity but not quality, with evening energy, evening carbohydrates, and evening fat intake being the dietary factors impacting sleep on a PGRD. Given that suboptimal sleep on a PGRD can impair physical and mental performance, strategising evening consumption of these dietary components may be beneficial for an athlete's sleep (Doherty et al., 2019). Our study provides interesting and novel insights into the interplay of evening nutrition and sleep for adolescent females in the New Zealand athletic population. Future research should consider using these findings to further the understanding of whether female athletes are achieving optimal sleep according to sleep guidelines, and if evening dietary intake influences sleep quantity and quality. Improved comprehension of sleep and evening meal habits of developing female footballers may be beneficial to support their overall health and sporting endeavours.

Chapter 4: Conclusion

4.1 Achievement of Aims and Hypothesis

The overall aim of this research was to describe the evening meal timing, energy intake and macronutrient composition (e.g. carbohydrate, protein, and fat) on the quantity and quality of sleep for females who are part of the Wellington Phoenix Female U20 Academy Football Team in New Zealand at a single point during their competitive season. There is limited representation of females in sport science research with minimal studies on the topic of evening nutrition impacts on sleep for athletes. Our results suggest that a concerning number of adolescent female footballers in New Zealand experience suboptimal sleep duration, a result that correlates with previous research on elite football athletes (Silva et al., 2020). The average number of WP was similar to Division I female football athletes (Greenwalt et al., 2023), however comparison between National Sleep Foundation (NSF) guidelines (Hirshkowitz et al., 2015) and other studies (Condo et al., 2022; Gjertsås et al., 2024) is challenging due to the use of different sleep quality measurements. Whilst the characteristics of sleep quality remain unclear, total sleep time (TST) and wake periods (WP) did not change significantly across the light training day (LTD), heavy training day (HTD), and pre-game rest day (PGRD) for the female footballers in the present study. Research indicates that suboptimal sleep has adverse effects on health and athletic performance; therefore, identifying poor sleep habits for athletes is useful for coaching and health support personnel in understanding the sleep quantity and quality needs of their players (Fullagar et al., 2015a; Nedelec et al., 2015).

This study determined evening meal habits did not significantly differ, except for evening carbohydrate intake, across the three training days. Players consumed a higher amount of carbohydrates on the HTD compared to the LTD. This dietary pattern demonstrates, to some degree, carbohydrate periodisation based on training load. Despite this, no significant difference in energy was observed across the training week, suggesting that they may not be sufficiently periodising their daily carbohydrate intake for performance and recovery despite increased evening carbohydrate intake. This study provides insight into evening dietary and sleep habits for adolescent female footballers in New Zealand. This is valuable for health personnel to further educate players on increasing energy and carbohydrate intake on HTD or PGRD.

This study found no relationship between evening meal timing and TST or WP. These findings contrast the TST and WP trends seen in male Australian Football League (AFL) (Falkenberg et al., 2021) and young male rugby players (Lehmann et al., 2022). However, the high variability between studies in the pre-sleep feeding window may be a reason for these differences. Nutrition timing may be part of a broader strategy to feasibly improve the sleep of athletes thus, standardising the evening dietary intake period to a short pre-sleep feeding window of 1.5-2 hours may be required in future research.

It was determined that evening energy and macronutrient intake influenced sleep quantity but not quality in the present study. The evening intake of energy, carbohydrates and fat was positively and significantly associated with TST but not WP on the PGRD. However, there was no relationship between any dietary and sleep variables on the LTD or HTD in this study. Again, these findings reflect the high variability and inconclusiveness of the current literature on the topic of nutrition and sleep interactions for elite athletes (Condo et al., 2022; Falkenberg et al., 2021; Lehmann et al., 2022), with the available research on elite female footballers limited to one singular pre-sleep nutrition study (Greenwalt et al., 2023). Given that research suggests a higher energy and fat intake promotes sleep onset, the associations seen between nutrition and sleep on the PGRD may be due to the increased energy and fat intake on the PGRD compared to the LTD and HTD (although not significant) (Falkenberg et al., 2021; Lehmann et al., 2022; Wells et al., 1997). Further investigations to quantify the evening energy, carbohydrate, and fat intake needed to influence sleep quantity may be warranted. This may help determine whether an increase in these dietary variables will enhance sleep on physically and mentally demanding training or match days. This information would enable coaching and health support personnel to inform players on how to optimise sleep during the competitive season.

It was hypothesised that a significant proportion of players would not meet sleep quantity recommendations, and this was found to be true. Our study revealed a concerning number of youth players (15-17 years) failed to meet the recommended 8-10 hours of sleep by the Ministry of Health of New Zealand guidelines. Across the three training days, at least one-third of youth players (n=11) had suboptimal TST each day, with a concerning 81.8% sleeping less

than 8 hours on the HTD. For young adult players (n=12), 33.3% slept less than the recommended 7-9 hours on the HTD and LTD, followed by 22% on the PGRD. It is important for athletes, particularly adolescent athletes to gain optimal sleep quantity as it helps prepare athletes to make fast, accurate, and appropriate decisions whilst maintaining their physical demands during training and matches (Lastella et al., 2015). Since our results suggest suboptimal sleep is prevalent, future research may look into the impact poor sleep quantity has on training and performance in female athletes.

We hypothesised that an evening meal closer to sleep onset would be associated with an improved TST however, our results found this to be untrue. Nutrition timing is particularly useful around training and matches however, its relationship with sleep is less known, especially in young athletes (Lehmann et al., 2022). Our findings suggest that the time between the evening meal and sleep start may not influence sleep quantity although, research of other elite athletic cohorts found otherwise. For example, an evening meal 1.5 hours pre-sleep increased TST compared to an evening meal 3.5 hours pre-sleep in young male rugby players (Lehmann et al., 2022). These differences, however, may be due to the use of a cross-over, within-participant study design, unlike our observational study. The study design of Lehmann et al. (2022) allowed for training load, training intensity, and evening meal time to be constant, whilst also removing co-founding factors of sleep such as electronic screen time and caffeine, thus increasing the validity of the results. Interventional studies that prescribe evening meal times may be used in future to further understand the influence of meal timing on sleep in female athletes. However, such studies should examine this in a free-living environment to allow athletes to continue their sporting endeavours.

Our findings oppose our hypothesis implying that evening energy intake did not influence sleep quality for adolescent female footballers in this study. Sleep quality recommendations suggest the higher the frequency of sleep disturbances the poorer the sleep quality (Ohayon et al., 2017). In previous research, WP was not influenced by high (>246 kcal) versus low (≤246 kcal) energy intake for female footballers (Greenwalt et al., 2023) however, in male AFL players (Falkenberg et al., 2021) and females of the general population (Crispim et al., 2011), sleep quality improvements have been associated with increased evening and daily caloric intakes, respectively. Given the variability in the literature, it may be important for future research to

further explore the evening meal and sleep quality habits to establish the relationship between these two behaviours for athletic populations.

4.2 Strengths

To the best of our knowledge, this is the first study in New Zealand to assess the relationship between the evening meal and sleep for youth and elite development female football players. Adolescents are underrepresented in sport science research and even more so in sleep-nutrition literature. This study provides insight into the evening meal characteristics and sleep habits of a unique group of adolescent female footballers across three different training days (LTD, HTD, and PGRD) within a competitive season.

One of the study's strengths was the high compliance of participants over the data collection period. Across the three data collection days, compliance for both evening dietary intake recording and sleep monitoring was 95-100%, increasing the reliability and validity of the results from this study.

The present study used a two-assessment method of both written and photographic records to collect dietary information on the evening meal to ensure all evening food and beverages were recorded each day. The photographic diary was particularly valuable as it recorded the exact time at which meals were eaten and therefore, participants could refer to these details rather than memory, thus increasing the validity of meal timing. Additionally, researchers prompted the players and asked appropriate follow-up questions to ensure accuracy when recording dietary data, particularly the meal time and ingredient quantities. This allowed researchers to correct any recording errors. Previous literature has shown that supplementary photographic food records reduced under-reporting by providing valid estimates of food (Gemming et al., 2015). When analysing the dietary records, researchers were further able to standardise the process of data input by using a photographic portion-size handbook to estimate food quantities when the written recording was missing. Moreover, dietary assessment was conducted for two week days and one weekend day over a single week. This accounted for day-to-day variation of evening meals and therefore improved the accuracy of evening meal habits across the training week.

A final strength of this study was the use of actigraphy to assess the sleep habits of adolescent female footballers. WHOOP® technology has been shown to record similar TST values to polysomnography (PSG) and therefore, in the absence of using the 'gold standard' method, we provided an assessment of sleep that was reliable and valid (Miller et al., 2020). Furthermore, the WHOOP® wristband is less invasive than PSG and only required players to wear the WHOOP® wristband, thus increasing compliance and reducing participant burden in this study. Utilising this technology allowed for consistent results across data collection days and therefore reduced measurement bias.

4.3 Limitations

A limitation of this study was the dietary assessment methodology relying on self-reporting. Although efforts to reduce reporting inaccuracy were taken, dietary assessments are subject to under or misreporting. Dietary records place a considerable burden on participants particularly for athletes to report truthfully and accurately (Capling et al., 2017). Despite the hybrid assessment method increasing estimation accuracy, misreporting of intake is frequently observed in the sport science literature (Capling et al., 2017). Moreover, it must be noted that this assessment method is subject to human error. Researchers estimated food quantities by comparing meals to the photographic portion-size handbook to the best of their abilities however, minor errors are unavoidable.

The WHOOP® wristband was subject to technological measurement error. A noticeably short sleep duration of 95 minutes was reported for a player on the HTD however, post-data follow-up revealed this to be untrue. Therefore, this player manually entered their sleep duration of 8 hours. The WHOOP® measures TST to the exact second however, it is likely this player recorded an approximate sleep duration, reducing the validity of this datapoint. This approach also restricted sleep quality assessment from the WP variable, whereby the duration of WP was not examined. The current guidelines classify the number of awakenings (>5 minutes) >3 for youth (14-17) and >4 for young adults (18-25) as poor quality sleep however, WHOOP® states that WP are brief periods that last a few minutes (WHOOP, 2019). Therefore, a discrepancy between these two variables exists, making it challenging to compare our results

to the current guidelines. Another similar measurement used in the sleep quality guidelines is wake after sleep onset (WASO), where poor sleep quality is indicated by <41 minutes but again, we cannot directly compare this variable to WP in this study (Ohayon et al., 2017). With no other sleep quality measurements taken in this study, determining the duration of WP would provide more insight into the sleep disturbances for these players and whether they contribute significantly to their overall sleep quality.

The data collection period consisted of three days which were classified by training load. It included an LTD, HTD and PGRD from a single week over one competitive season. This collection period aimed to represent the overall dietary and sleep patterns on days with different training loads. Thus, the interpretation of evening meal and sleep habits for female footballers in this study requires a cautious approach. Furthermore, given the available literature on evening nutrition and sleep for athletes is limited, specifically for females, it is challenging to compare our results with male cohorts. Research has proposed that the menstrual cycle affects substrate metabolism and the need for recovery by sleep, which males do not experience (Boisseau & Isacco, 2022; Hrozanova et al., 2021). This may explain the contrast between our results and other studies. Due to this, male studies are thought to be untranslatable to female athletes, highlighting the need for further research on this group of elite level and developing female athletes.

A final limitation of this observational study is that it did not account for the sport-specific and lifestyle factors proposed to influence sleep habits. Factors such as, but not limited to, the living situation, school/work schedule, naps, sleep environment, training time, physiological changes, and social arousal of players may have influenced the TST or WP (Nedelec et al., 2015; Venter, 2012). Literature suggests that an athlete's sleep may be influenced by a multitude of factors and is not restricted to pre-sleep nutrition hence, the findings of this study are limited due to the inability to account for confounding factors of sleep (Nedelec et al., 2015).

4.4 Recommendations and Future Directions for Research

Given that suboptimal sleep quantity is prevalent amongst adolescent females who are part of the Wellington Phoenix Female U20 Academy Football Team in New Zealand, adverse effects on their recovery, performance, and overall health may be present. Furthermore, this study reported a significant association between evening nutrition and improved sleep quantity on a PGRD for this group of athletes. As the professionalism of female football is increasing in New Zealand and internationally, future research should focus on further investigating the evening meal and sleep habits of adolescent female athletes. Greater understanding of these behaviours may help determine the need for nutritional strategies that optimise sleep for athletes at a stage of both sporting and physiological development. This will ultimately support their continuity in the sport.

<u>Future research recommendations</u>

- Given the identified biological differences between females and males, further sport science research is needed in female athletes, particularly in adolescents. Females have a unique hormonal profile that fluctuates throughout the menstrual cycle, which may lead to variations in nutrition metabolism and sleep requirements. This highlights the need for future research to consider the menstrual cycle phase in nutrition and sleep studies in female athletes.
- Since this study only assessed three days of different training loads in one week during a single competitive season, future research should consider assessing evening meal and sleep habits at various time points such as pre-season, in-season and post-season to represent these behaviours fully.
- Future research should investigate the use of energy and carbohydrate periodisation to support female athletes' training load. It should also assess whether increasing carbohydrate intake in the evening is sufficient, and if increasing energy intake is needed to achieve recommended nutrition periodisation.
- Future research should investigate the next-day performance and recovery impact following HTD or after nights of poor sleep. A poor sporting performance may follow a suboptimal night's sleep which was reported on the HTD in this study. However, for

female footballers and female adolescent athletes, the influence of this poor sleep on next-day performance remains to be investigated.

- This study defined the time between the evening meal and sleep as the pre-sleep feeding window however, this period is highly variable in the available literature. To produce comparable studies, future research may need to standardise this timeframe to help determine the impact of evening nutrition on sleep.

Nevertheless, our study adds to this narrowly focused field of study by providing a unique insight into the evening nutrition and sleep habits of adolescent female footballers, especially on an evening before an important match day.

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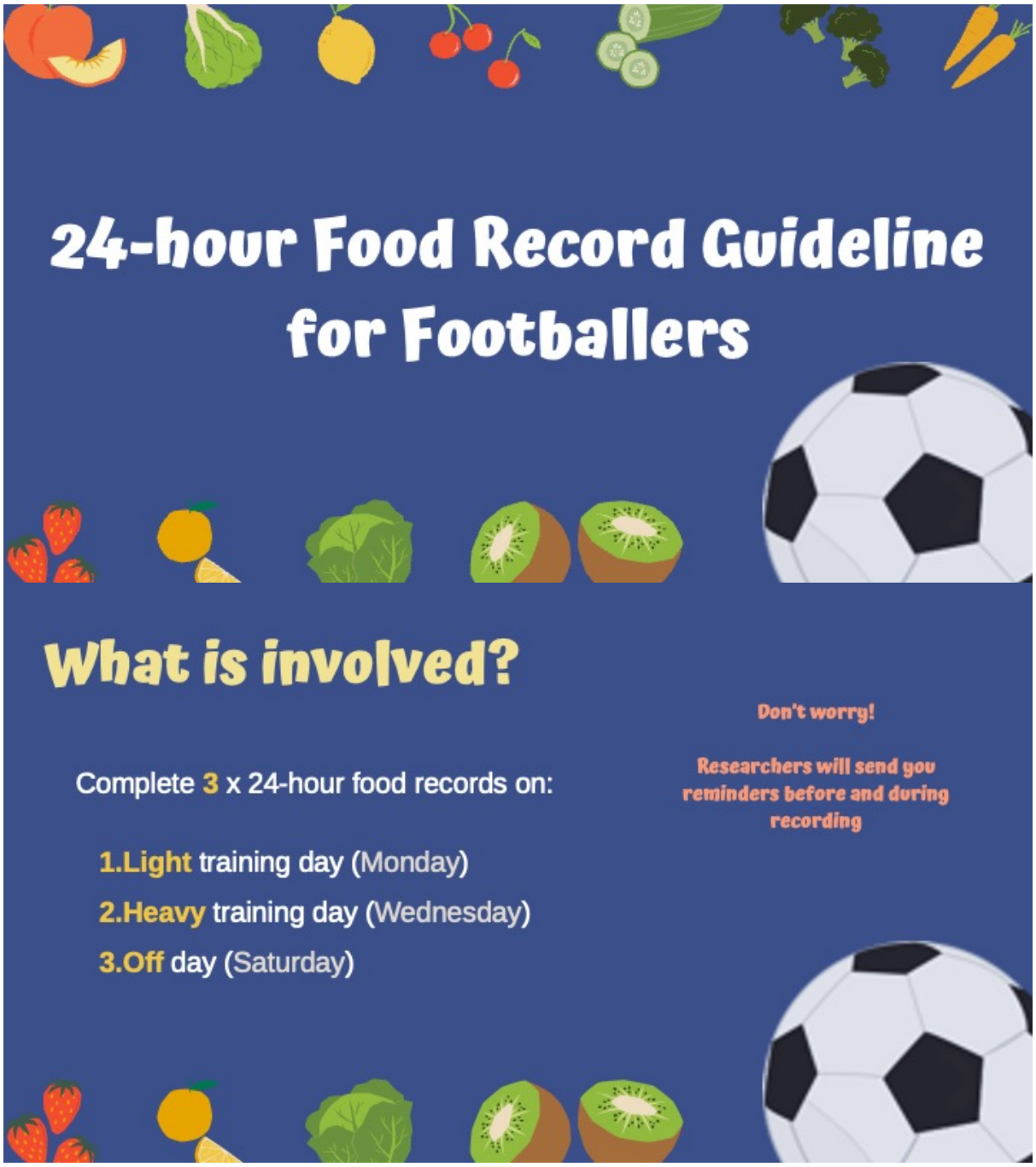
Appendix A: 24-Hour Food Record Guideline



What to do?

- Record food **at the time of eating or just after** – try to avoid doing it from memory at the end of the day.
- Include all meals, snacks, and drinks, even tap water.
- Include **anything you have added** to foods such as sauces, gravies, spreads, dressings, etc.
- Write down any information that might indicate **size or weight** of the food to identify the portion size eaten
- Send **photos** of meals and snacks to the researcher's phone number via **WhatsApp**

Tips

- Please eat as **normally as possible**
- Be **honest** with food intake - no one outside of the study will have access to your food record
- Researchers will message via WhatsApp if required to help you to complete the food record, answer any of your questions and verify any of the descriptions.

Pictures of the food

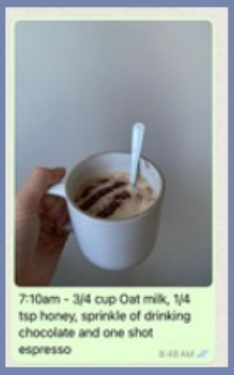
- Take a picture **BEFORE** you eat the food
- If there is any food left on your plate, take a picture of the **remaining food** to help researchers get an idea of how much food was eaten
- If you are eating a **packaged item** (e.g muesli bar), take a photo of the **brand, serving size and packaging** of the product in the image.
- **All drinks** are to be included

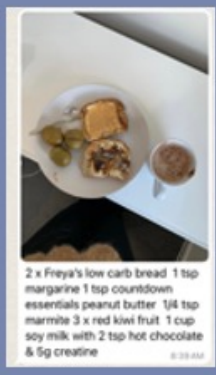
Describing Food & Drinks

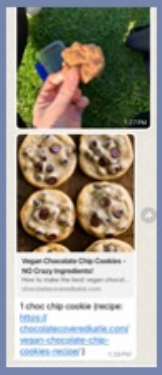
- Include **brand names** and **varieties/types** e.g. 1 Cup Sanitarium Natural Muesli
- Give details of **cooking methods** e.g. fried, grilled, baked, poached, boiled etc
- Please **record cooked portion** of food e.g. cooked rice, pasta, meat, vegetables etc
- **Record recipes** and the amount eaten
- Record as much detail (location, foot item, size, ingredients - including dressings) when **eating out** as well as a photo of the meal and menu
- Specify the **amount of food** eaten and include how much was not eaten using...

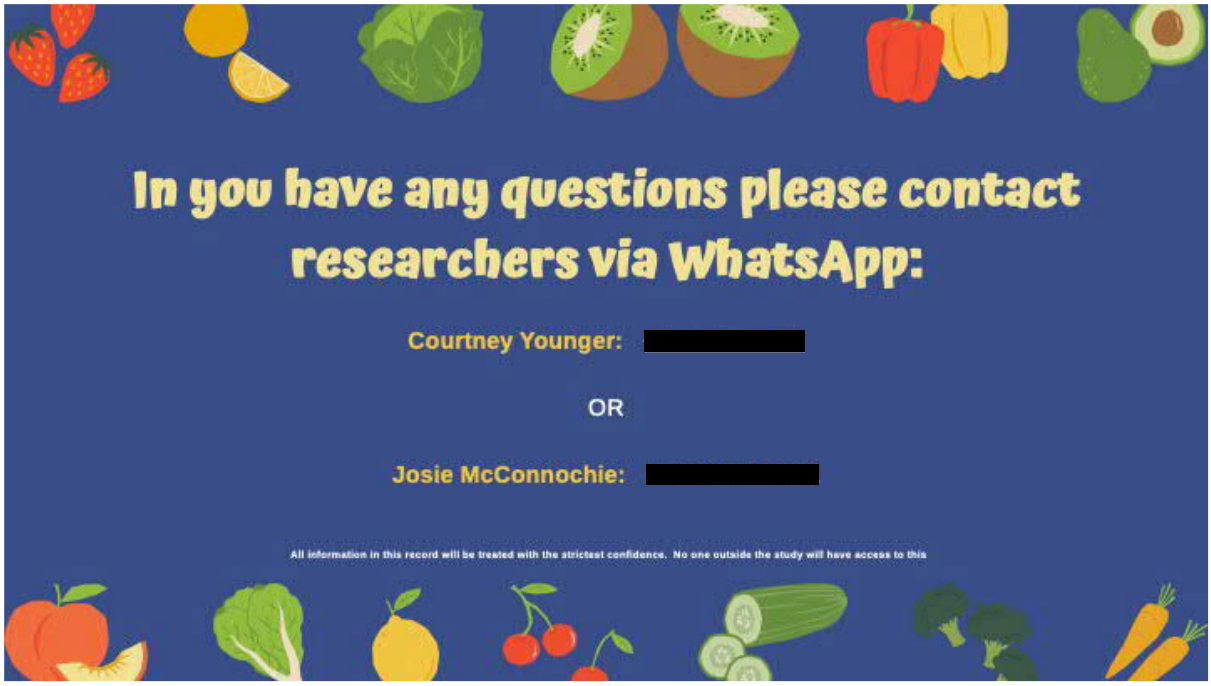
1. Household measurements (cups, tablespoons, teaspoons)
2. Weight marked on packaging (425g tinned baked beans)
3. For bread - toast, sandwich or medium
4. Using comparisons

Examples








In you have any questions please contact researchers via WhatsApp:
Courtney Younger: [redacted]
OR
Josie McConnochie: [redacted]
All information in this record will be treated with the strictest confidence. No one outside the study will have access to this

24-hour Food Record Guideline for Footballers

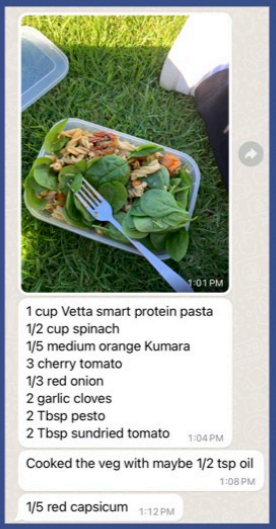
Complete 3 x 24-hour food records on a:

Light training day (Monday) **Heavy** training day (Wednesday) **Off** day (Saturday)

What to do?

- Send a **photo** of meals via **WhatsApp**
- Record food **at the time of eating or just after** – try to avoid doing it from memory at the end of the day.
- Include all meals, snacks, and drinks
- Include **all ingredients added** to foods such as sauces, oils, gravies, spreads, dressings, etc.
- Record information that might indicate **size or weight** of the food
- Include **brand names** and varieties/types
- Give details of **cooking methods** e.g. fried, grilled, baked, poached, boiled etc
- Please record **cooked portion** of food e.g. cooked rice, pasta, meat
- **Record recipes** of home prepared dishes and portion size
- Record as much **detail** (location, foot item, size, ingredients - including dressings) when **eating out** as well as a photo
- Specify the amount of food eaten and left over

Examples



Pictures of food

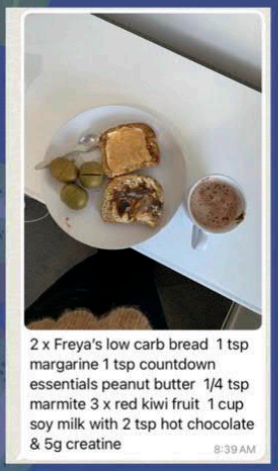
- Take a picture **BEFORE** you eat the food
- If there is any food left on your plate, take a picture of the **remaining food** to help researchers get an idea of how much food was eaten
- **Packaged item?** (e.g muesli bar), take a photo of the **brand, serving size and packaging**
- **All drinks** are to be included

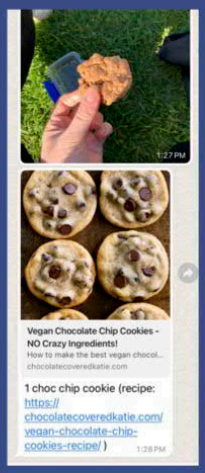
24-hour Food Record Guideline for Footballers

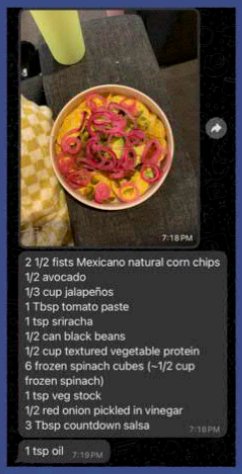
Tips

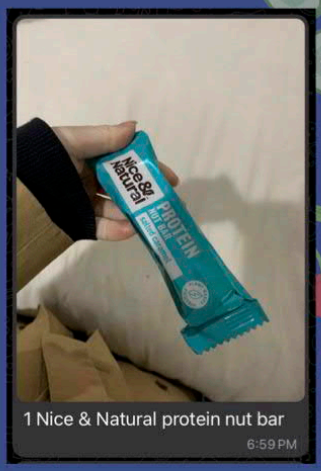
- Please eat as **normally as possible**
- Be **honest** with food intake - no one outside of the study will have access to your food record
- Researchers will message via WhatsApp if required to help you to complete the food record, answer any of your questions and verify any of the descriptions.

Further Examples









Don't worry!
Researchers will send you reminders before and during recording

In you have any questions please contact researchers via WhatsApp:

Courtney Younger: [redacted]

OR

Josie McConnochie: [redacted]

All information in this record will be treated with the strictest confidence. No one outside the study will have access to this